



TwinEU Use Cases, pan-European scenarios and KPIs

Deliverable No: D2.2

Work package: WP2

Official delivery date: 30.06.2025

Actual delivery date: 26.06.2025

Dissemination level: Public



Co-funded by
the European Union

Project: 101136119 | HORIZON-CL5-2023-D3-01 | www.twineu.net

Disclaimer

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Document Authors		
Beyza Cizmeci (Fraunhofer)	Jordi Granés (ANELL)	Nermin Suljanović (EIMV)
Esteban Pastor Calatayud (ETRA)	Nuno Pinho da Silva (R&D Nester)	Jonathan Aviles Cedeño (TU Delft)
Stamatis Diakakis (UBE)	Rui Sousa (INESC TEC)	Maria Papadimitriou (CINT)
Ilias Zafeiropoulos (UBE)	Alberto Escalera (REE)	John Vlachogiannis (3SI)
Vladan Ristic (SCBG)	Ferdinando Bosco (ENG)	Juan Galeano (RWTH)
Pencho Zlatev (SETECHCO)	Ulf Häger (TU Dortmund)	Rui Pestana (REN)
Thomas Brouhard (ART)	Vasiliki Kontargyri (UoA)	Pere Herraiz (ANELL)
Ellen Jaenecke (Envelio)	Bálint Hartmann (F4STER)	Javier Rodrigo (OMIE)
Teti Garmpi (TGT)	Daniele Porcu (ENEL)	Natalia Lapuente (CIRCE)
Felix Dorsemagen (E.ON One)	José Rueda Torres (TU Delft)	May Myat Thwe (TU Delft)
Nikolaos Koltsaklis (UPRC)	Alex Stefanov (TU Delft)	Shafiulla Syed (TU Delft)

Version	Date	Author(s)	Notes
0.1	12.03.2024	UBE	Initialized
0.2	11.01.2025	UBE	ToC
0.3	18.02.2025	UBE, 3SI, TGT, CINT, UoA, SETECHCO, TUDO, SCBG	Consolidation of contributions for section 2
0.4	05.03.2025	ETRA, ENG, ED, UBE	Consolidation of contributions for sections 2,3
0.5	01.04.2025	FhG, ART, UBE, R&D Nester	Consolidation of contributions for sections 1, 3, 4,5
0.6	16.05.2025	UBE	Consolidation of the complete chapters and executive summary
0.7	2.6.2025	UBE, ETRA, ED	UBE consolidate ED and ETRA comments

Responsible Partner	UBITECH Energy (UBE)	
Checked by WP leader	Ilias Zafeiropoulos (UBE)	16.05.2025
Verified by the appointed Reviewers	Apostolos Kapetanios (ED) Esteban Pastor Calatayud (ETRA)	28.05.2025 30.05.2025
Approved by Project Coordinator	Padraic McKeever (Fraunhofer)	25.06.2025

Table of Contents

Executive Summary	12
1 Introduction	14
1.1 Scope and objectives of the Work Reported in this Deliverable	14
1.2 Outline of the Deliverable	14
1.3 How to Read this Document	15
2 The stakeholders' views and feedback from Task 2.2 "Energy stakeholders' requirements for the digital twin of the pan-European grid"	16
2.1 Methodology	16
2.2 The Key Findings	16
2.3 Next Steps and directions proposed to advance TwinEU objective:	17
3 The Digital Twin concept and the TwinEU approach	19
3.1 Introduction	19
3.2 Research and innovation approaches to Digital Twins	26
3.3 The AIOTI approach	30
3.4 The VDE approach for the electricity network modernization	31
3.5 The manufacturers' approach	35
3.6 The federated DT architecture of the TwinEU project	39
3.7 Core concepts	40
3.7.1 Digital twin federation	40
3.7.2 Data Space structure	41
3.7.3 Service Workbench and AI tools	41
3.7.4 TwinEU Reference Architecture	42
4 TwinEU pilot technologies conditions and technical requirements	44
4.1 Methodological approach for the definition of TwinEU's key digital technologies boundary conditions and high-level requirements	44
4.2 Summary of technologies involved and communication flows and their gap analysis result per pilot	44
4.2.1 Iberian Pilot Site	45
4.2.2 Eastern-Mediterranean Pilot Site	54
4.2.3 Hungarian Pilot Site	59
4.2.4 Bulgarian Pilot Site	65
4.2.5 German Pilot Site	69
4.2.6 Italian Pilot Site	74
4.2.7 Slovenian Pilot Site	77
4.2.8 Dutch-French Pilot Site	80
4.3 Technical requirements to enable the seamless coordination and cooperation of DTs in the TwinEU Continuum	84
5 TwinEU Use Cases	92
5.1 Use Case Definition Methodology	92
5.2 The IEC 62559 template	95
5.3 Task 2.4 Workflow	95

5.4	TwinEU UCs overview	96
5.4.1	Bulgarian Pilot Site UCs	97
5.4.2	Dutch/French Pilot Site UCs	107
5.4.3	Eastern-Mediterranean Pilot Site UCs	110
5.4.4	German Pilot Site UCs	115
5.4.5	Hungarian Pilot Site UCs.....	122
5.4.6	Iberian Pilot Site UCs	125
5.4.7	Italian Pilot Site UCs	139
5.4.8	Slovenian Pilot Site UCs.....	144
5.4.9	Required KPIs for project performance and validation from the GA.....	148
5.4.10	Evaluation plan KPIs for the Use Cases demonstration	151
6	The pan-EU impact of the TwinEU federated DT solutions to the electricity grid and market challenges.....	165
6.1	Key challenges for the European power system related to the TwinEU DT technologies	165
6.2	Supporting the key priorities of the European energy strategy with the TwinEU DT technologies	173
6.3	Main avenues for the definition of pan-European scenarios in TwinEU.....	180
6.3.1	Definition of pan-EU scenarios in the context of TwinEU	180
6.3.2	The grid hosting capacity map	180
6.3.3	Co-optimization of the energy and balancing capacity market coupling with dynamic flow-based auction	183
6.3.4	High accuracy forecasting	186
6.3.5	Flexibility management and frequency support	186
6.3.6	System security and stability.....	187
7	Conclusion	189
	References	191
Annex A	Full description of the technologies implemented per Pilot	195
A.1	Digital Twins involved in the Iberian Pilot Site Ecosystem	195
A.1.1	REE's Transmission Grid DT.....	195
A.1.2	REN's Transmission Grid DT	196
A.1.3	OMIE's Electricity Market DT	197
A.1.4	ANELL's Distribution Grid DT.....	199
A.1.5	Cuerva's Distribution Grid DT.....	200
A.1.6	INESC TEC's Iberian Electricity System high-level DT	202
A.2	Digital Twins involved in the Eastern Mediterranean Pilot Site Ecosystem	204
A.2.1	DT of the HVDC interconnection between the mainland Transmission System of Greece and the insular Transmission System of Crete	204
A.2.2	Greek Transmission System DT	204
A.2.3	Greek Distribution System DT	204
A.2.4	Cyprus Power System DT ecosystem	205
A.2.5	Greek Electricity Market DT	205
A.3	Digital Twins involved in the Hungarian Pilot Site Ecosystem.....	206

A.3.1	DT1&2&3 –Digital Twin of MAVIR, EON EED and APG grids, constituting of sensor based physical conductor models (Task 6.8) and flow-based line capacity calculations (Task 7.3).....	206
A.3.2	DT4 – HUPX (HU NEMO) DT – spot market platform for day-ahead and intraday auctions and Platform for data storage and visualization (Task 7.3).....	207
A.4	Digital Twins involved in the Bulgarian Pilot Site Ecosystem	208
A.4.1	DT of the Bulgarian transmission system.....	208
A.4.2	Partial DT of the Bulgarian distribution system	208
A.4.3	DT of the cross-border energy market.....	209
A.4.4	High-level digital twin of the Bulgarian power system	209
A.5	Digital Twins involved in the German Pilot Site Ecosystem	210
A.5.1	Westnetz’ HV distribution grid DT	210
A.5.2	Westnetz MV/LV distribution grid DT (Envelio’s intelligent grid platform)	210
A.5.3	E.ON Energie Deutschland’s market aggregator.....	211
A.6	Digital Twins involved in the Italian Pilot Site Ecosystem	212
A.6.1	ENEL’s Distribution Grid DT for Design Validation	212
A.6.2	ENEL’s Distribution Grid DT for DERs prequalification.....	212
A.6.3	TRI’s Transmission Grid DT for Design validation.....	212
A.6.4	Terna’s Transmission Grid DT for RTS	213
A.7	Digital Twins involved in the Slovenian Pilot Site Ecosystem	214
A.7.1	ELES’s Transmission Grid DT	214
A.7.2	EG’s Distribution Grid DT	214
A.7.3	HSE’s Electricity Market DT	215
A.8	Digital Twins involved in the French/Dutch Pilot Site Ecosystem	216
A.8.1	Integrated Digital Twin for the Dutch Electricity System.....	216
A.8.2	Integrated Digital Twin for the French Electricity System	218
Annex B	The complete TwinEU IEC 62559 templates of the pilot UCs.....	221
B.1	Bulgarian Pilot Site UCs	221
B.2	Dutch-French Pilot Site UCs.....	321
B.3	EAST-MED Pilot Site UCs.....	346
B.4	German Pilot Site UCs.....	409
B.5	Hungarian Pilot Site UCs	462
B.6	Iberian Pilot Site UCs	496
B.7	Italian Pilot Site UCs.....	599
B.8	Slovenian Pilot Site UCs	611

List of Figures

Figure 1: Performance DT as expressed in ENTSOe Technopedia	19
Figure 2: Impact on DSOs of various technologies (Source: E.DSO Technology radar)	20
Figure 3: The cloud-based framework architecture of System of Digital Twin Systems (SDTS), connected to a single DTS [15]	28
Figure 4: Digital Twin System Reference Model (DTS-RM) [17]	29
Figure 5: Interplay between real objects and DZiNE across different lifecycle phases	32
Figure 6: Exemplary interaction of multiple digital twins in the context of establishing a new transformer in a substation	33
Figure 7: The Siemens Electrical Digital Twin ecosystem	38
Figure 8: A digital twin for the electric grid can improve business process efficiency across multiple dimensions [Schneider Electric]	39
Figure 9: TwinEU architecture concept	42
Figure 10: Four-step methodology followed for the development of T2.3	44
Figure 11: Client-server scheme example	53
Figure 12: Proposed communication flows in Bulgarian demo	68
Figure 13: Interactions between WP2 tasks	93
Figure 14: TwinEU top-down UC approach implemented	94
Figure 15: T2.4 workflow towards final version of TwinEU UCs	95
Figure 16: T2.4 time-plan depicting development steps of UCs	96
Figure 17: Westnetz Self-service connection check platform	181
Figure 18: Benefits of advanced hosting capacity maps provided during TwinEU project	182
Figure 19: Calculation modes for different use cases	183
Figure 20: Implementation graph for the pan-EU scenario for the co-optimization of energy and balancing capacity market coupling with dynamic flow-based auction (option 1)	184
Figure 21. Implementation graph for the pan-EU scenario for the co-optimization of energy and balancing capacity market coupling with dynamic flow-based auction (option 2)	185
Figure A-1 - DT module: Renewable resources profiles tool	195
Figure A-2 - OMIE's Market Operator Information System (SIOM) architecture	198
Figure A-3 - ETER product architecture with the new Simulation profiling module.	200
Figure A-4 - Measurement map of the Cuerva's living lab	202
Figure A-5 - DT of the Iberian system interconnected with central Europe	203
Figure A-6 - Dynamic model of the DT including the AGC control loops and load response	203
Figure A-7 - Overview of Dutch Integrated DT	217
Figure A-8 - Architecture of Dutch Integrated DT	217
Figure A-9 - The French Digital Twin Framework	218
Figure A-10 - General Architecture- Power System Simulator tool	220

List of Tables

Table 1: Data exchanges between RSCs and TSOs for Operational Planning	50
Table 2: Data exchanges categories between TSOs and DSOs	51
Table 3: Data exchanges between TSOs and MO	51
Table 4: TSO-MO communications	52
Table 5: Data exchanges between DSOs and MO	54
Table 6: Data exchanges between MO, TSO, and DSO in Greek DT	57
Table 7: Data exchanges between MO, TSO, and DSO in Cypriot DT	58
Table 8: Data exchanges between TSOs and RSC in Greece-Cyprus HVDC interconnection use case	58
Table 9: Gap analysis for the communication flow in Cypriot DT	59
Table 10: Data exchanges between RSCs and TSOs	63
Table 11: Data exchange between TSO and DSO – Hungarian Demonstrator’s DTs	63
Table 12: Data exchange between TSO and Market Operators – Hungarian Demonstrator’s DTs	63
Table 13: Data exchange between TSO and Market players – Hungarian Demonstrator’s DTs	64
Table 14: TSO-RSC gap in comm. flows	64
Table 15: TSO-DSO gap in comm. flows	65
Table 16: Relevant data exchange between TSO and DSO – Bulgarian demo	67
Table 17: Relevant data exchange between TSO and FSP/Aggregator – Bulgarian demo	67
Table 18: Relevant data exchange between DSO and FSP/Aggregator – Bulgarian demo	67
Table 19: German Pilot gap analysis summary	70
Table 20: Data exchanges between TSO and DSO	71
Table 21: Data exchange between DT Software IGP and DSO	71
Table 22: Communication flows via APIs	72
Table 23: Communication flows gap assessment summary for the German Pilot	73
Table 24: Data exchanges between TSO and DSO	76
Table 25: Data exchanges between DSO and design supplier	76
Table 26: Data exchanges between TSO and DSO	78
Table 27: Data exchanges between TSO and MO	79
Table 28: Data exchanges between MO and Market Player	79
Table 29: Data exchange between physical model and digital twin	82
Table 30: French Pilot Data exchange between physical model and digital twin	82
Table 31: Set of technical requirements to enable the seamless coordination and cooperation of DTs in the TwinEU Continuum	84

Table 32: Bulgarian Pilot's – BG01 UC overview	97
Table 33: Bulgarian Pilot's – BG02 UC overview	98
Table 34: Bulgarian Pilot's – BG03 UC overview	99
Table 35: Bulgarian Pilot's – BG04 UC overview	100
Table 36: Bulgarian Pilot's – BG05 UC overview	101
Table 37: Bulgarian Pilot's – BG06 UC overview	102
Table 38: Bulgarian Pilot's – BG07 UC overview	103
Table 39: Bulgarian Pilot's – BG08 UC overview	104
Table 40: Bulgarian Pilot's – BG09 UC overview	105
Table 41: Bulgarian Pilot's – BG10 UC overview	106
Table 42: Dutch Pilot's – NL01 UC overview	107
Table 43: Dutch Pilot's – NL02 UC overview	107
Table 44: French Pilot's – FR01 UC overview	109
Table 45: Greek Pilot's – EM-GR-01 UC overview	110
Table 46: Greek Pilot's – EM-GR-02 UC overview	111
Table 47: Cypriot Pilot's – EM-CY-01 UC overview	113
Table 48: Cypriot Pilot's – EM-CY-02 UC overview	114
Table 49: German Pilot's – Ge01 UC overview	115
Table 50: German Pilot's – Ge02 BUC overview	115
Table 51: German Pilot's – Ge03 BUC overview	116
Table 52: German Pilot's – Ge04 UC overview	116
Table 53: German Pilot's – Ge05 UC overview	117
Table 54: German Pilot's – Ge06 UC overview	118
Table 55: German Pilot's – Ge07 UC overview	119
Table 56: German Pilot's – Ge08 UC overview	121
Table 57: Hungarian Pilot's – Hu01 UC overview	122
Table 58: Hungarian Pilot's – Hu03 UC overview	123
Table 59: Hungarian Pilot's – Hu03 UC overview	124
Table 60: Iberian Pilot's – Ib01 UC overview	125
Table 61: Iberian Pilot's – Ib02 UC overview	126
Table 62: Iberian Pilot's – Ib03 UC overview	127
Table 63: Iberian Pilot's – Ib04 UC overview	128
Table 64: Iberian Pilot's – Ib05 UC overview	129
Table 65: Iberian Pilot's – Ib06 UC overview	130

Table 66: Iberian Pilot's – Ib07 UC overview	131
Table 67: Iberian Pilot's – Ib08 UC overview	132
Table 68: Iberian Pilot's – Ib09 UC overview	132
Table 69: Iberian Pilot's – Ib10 UC overview	134
Table 70: Iberian Pilot's – Ib11 UC overview	134
Table 71: Iberian Pilot's – Ib12 UC overview	135
Table 72: Iberian Pilot's – Ib13 UC overview	137
Table 73: Iberian Pilot's – Ib14 UC overview	138
Table 74: Italian Pilot's – IT01 UC overview	139
Table 75: Italian Pilot's – IT02 UC overview	140
Table 76: Italian Pilot's – EACL-IT-01 UC overview	141
Table 77: Italian Pilot's – EACL-IT-02 UC overview	142
Table 78: Italian Pilot's – EACL-IT-03 UC overview	143
Table 79: Slovenian Pilot's – SLO-BUC-01 UC overview	144
Table 80: Slovenian Pilot's – SLO-BUC-02 UC overview	146
Table 81: Slovenian Pilot's – SLO-SUC-1 UC overview	147
Table 82: Mapping of KPIs linked with TwinEU Objectives (from GA)	149
Table 83: The Bulgarian pilot UC KPIs	151
Table 84: The Dutch/French pilot UC KPIs	153
Table 85: The EAST-MED pilot UC KPIs	154
Table 86: The German pilot UC KPIs	156
Table 87: The Hungarian pilot UC KPIs	158
Table 88: The Iberian pilot UC KPIs	159
Table 89: The Italian pilot UC KPIs	162
Table 90: The Slovenian pilot UC KPIs	164
Table 91: List of RCC tasks (source JRC analysis 2023)	171
Table 92: Summary of topics identified as “priority” or “significant” to each of the TwinEU pilots, using a “coloured map” approach with different colours	179

List of Abbreviations and Acronyms

Acronym	Meaning
ADMS	Advanced Distribution Management System
aFRR	Automatic Frequency Restoration Reserve
AI	Artificial Intelligence
AMQP	Advanced Message Queuing Protocol
ANN	Artificial Neural Network
API	Application Programming Interface
BIM	Building Information Modelling
BMO	Balancing Market Operator
CAS	Central Authentication Service
CBME	Cross-border Market
CCR	Capacity Calculation Regions
CGMES	Common Grid Model Exchange Standard
CIM	Common Information Model
CPS	Cyber-Physical System
DAM	Day Ahead Market
DER	Distributed Energy Resources
DLR	Dynamic Line Rating
DMS	Distribution Management System
DPP	Digital Product Passports
DR	Demand Response
DSO	Distribution System Operators
DT(s)	Digital Twin(s)
DZiNE	Digital Twin in the network and electricity industry
ECSO	European Cybersecurity Organisation
EEG	German: Erneuerbare-Energien-Gesetz
EMS	Energy Management System
FCR	Frequency Containment Reserve
FSP	Flexibility Service Provider
GA	Grant Agreement
GIS	Geographic Information System
HVDC	High Voltage Direct Current
ICCP	Inter-Control Centre Communications protocol
IDSA	International Data Spaces Association
IEA	International Energy Agency
IGP	Intelligent Grid Platform
JSON	JavaScript Object Notation
KPI	Key Performance Indicators
LFM	Local Flexibility Market
LOIN	Level of Information Need
MDM	Meter Data Management
mFRR	Manual Frequency Restoration Reserve
ML	Machine Learning
MO	Market Operator
MQTT	Message Queuing Telemetry Transport
MTU	Market Time Unit
NCCS	Network Code on Cybersecurity

NCER	Network Code for Emergency and Restoration
NEMO	Nominated Energy Market Operator
NGSI-LD	Next Generation Service Interfaces - Linked Data
NIST	National Institute of Science and Technology
OT	Operational Technology
PDBF	Base Daily Operating Programme
PDVP	Day-Ahead Viable Schedule
PHF	Power Handling Facility
PMU	Phasor Measurement Unit
RA	Reference Architecture
RCC	Regional Coordination Centre
RES	Renewable Energy Source
RSC	Regional Security Coordinator
SCADA	Supervisory Control and Data Acquisition
SDTS	System of Digital Twin Systems
SGI	Smart Grid Indicators
SIQM	OMIE's Information System in Spanish (Sistema de Información de OMIE)
SO	System Operator
SOGNO	Service Oriented Grid for the Network of the Future
SotA	State of the Art Analysis
SPP	Solar Power Plant
SSOT	Single Source of Truth
STATCOM	Static Synchronous Compensators
SVC	static VAR compensators
SWE	South West Europe
TSO	Transmission System Operators
UML	Unified Modeling Language
WAMS	Wide Area Monitoring
WPP	Wind Power Plant
WWSS	WebSocket Secure Service

Executive Summary

This deliverable defines and consolidates the technical foundation, implementation strategy, and the systemic validation of the TwinEU project's federated Digital Twin (DT) architecture. It presents the outcomes of Tasks 2.3, 2.4, and 2.5 under WP2, which collectively address the technological landscape, business Use Case (UC) design, performance evaluation via KPIs, and the design of pan-European validation scenarios.

TwinEU builds on a layered architecture that integrates local DTs into a federated, interoperable system, aligned with key principles of decentralization, trust, and data sovereignty. The reference architecture includes three core pillars:

- **DT Layer:** Integrating IoT, edge computing, and Digital Twins.
- **Federation Layer:** DT Connector embedded in each Digital Twin and the TwinEU Data Space Middleware which enables secure, standards-based data and model exchange through Data Quality, Data Access policies, IDM and Semantic interoperability.
- **Service Workbench & AI Layer:** Powering data-driven tools for operational insights and decision-making along with horizontal TwinEU DT services and the AR Exploration module.

This architecture supports seamless integration across distributed pilot sites, using common communication interfaces and advanced simulation capabilities. A detailed mapping of communication flows and digital asset layers was performed across all eight TwinEU pilots to identify technology gaps and ensure alignment with project-wide objectives.

Under Task 2.4, a total of 50 UCs has been developed using the IEC 62559-2 standard template. The UCs are classified into four hierarchical categories (High-Level, Generic, Specialized, and Individual) and were developed using a top-down approach derived from the primary objectives of TwinEU. The UCs represent both local grid priorities and cross-regional strategic goals, enabling TSO-DSO cooperation, market optimization, predictive maintenance, and cyber resilience.

In addition, the KPIs linked to TwinEU are addressed. Two categories of KPIs are defined and monitored:

- **The GA-referred KPIs:** Fifteen KPIs have been mapped to ten TwinEU objectives, covering cross-stakeholder collaboration, system replication, standardization, cybersecurity, AI integration, and business model creation. Currently, 4 KPIs have been fulfilled, with several others progressing across pilots.
- **UC-specific KPIs, defined in the IEC 62559 templates:** Each pilot developed and reported UC-specific KPIs to assess local DT functionality, user experience, performance, and scalability. These metrics will be used in the future to assess progress and validate implementation results in upcoming TwinEU activities.

A systematic review of recent EU policies has been performed, leading to the identification of 19 key system priorities, which are grouped under thematic clusters, including Grids, Demand Response, Cybersecurity, Digitalization, Market Design, and mapped against pilot tasks to assess TwinEU's strategic relevance. All pilots are evaluated against these priorities, with relevance levels assigned accordingly. Significant topics such as grid hosting capacity,

smart grid development, cybersecurity aspects, flexibility assessments, and cross-border digital infrastructure are widely addressed by pilot DTs, highlighting TwinEU's contribution to Europe's digital energy transition.

To demonstrate the federated architecture's scalability, a set of Pan-EU scenarios is defined, where models and data from different pilots will be integrated to address shared system-level challenges. These include:

- Pan-EU Hosting Capacity Map (German pilot)
- Market Co-optimization with Dynamic Flow-Based Auctions (Hungarian pilot)
- High-Accuracy Forecasting Models (Bulgarian and Iberian pilots)
- Flexibility Management and Frequency Support (Eastern-Mediterranean and Iberian pilots)
- System Security and Stability Enhancements (Italian, Slovenian, and Dutch/French pilots)

These scenarios are designed to validate the federation capabilities of the TwinEU architecture, promoting cross-pilot collaboration in real-time operational contexts and supporting EU-wide regulatory objectives.

This deliverable consolidates the foundational work that bridges technical capabilities with regulatory mandates and operational needs. The harmonized development of UCs, technologies, and KPIs under a common framework enables effective cross-pilot collaboration, setting the stage for system-wide validation and future exploitation. The federated TwinEU architecture is positioned as a transformative solution to digitalize Europe's power systems while enabling real-world impact aligned with EU energy and climate goals. The next steps of the project involve demonstrating these capabilities under real conditions in WP5–WP8 and launching cross-pilot testing of pan-EU scenarios, thereby realizing the federated DT vision at scale.

1 Introduction

1.1 Scope and objectives of the Work Reported in this Deliverable

The TwinEU project is bringing together a unique set of competences coming from grid and market operators, technology providers and research centres, aiming to develop a framework for a Pan-European digital twin architecture, based on the federation of local twins developed to meet specific challenges of power system operation. This TwinEU architecture aims to facilitate the reliable, resilient, and safe operation and development of the grid infrastructure while enabling new business models that will accelerate the deployment of renewable energy sources in Europe.

The demonstration process of the TwinEU innovations is carried out in eight (8) pilots across Europe, implementing several DT technologies for addressing specific challenges of grid management for transmission and distribution networks.

The current deliverable explores these opportunities, with a focus on mapping stakeholder requirements for DTs and analysing their role in the energy system. The findings aim to guide the integration of DTs across the EU energy landscape in a federated way, fostering innovation and addressing key challenges.

1.2 Outline of the Deliverable

This deliverable presents the work that has been carried out in Tasks 2.3, 2.4, 2.5 of TwinEU project, mainly addressing the DT technologies developed in the pilots, the detailed UCs to be demonstrated, the evaluation plan and KPIs as well as the pan-EU scenarios proposed to validate the impact of TwinEU federated architecture. D2.2 is also presenting the activities of interviewing with the energy stakeholders described in the task 2.2 .

This Chapter 1 presents the introductory material for the report.

Chapter 2 presents the activities of interviewing with the energy stakeholders, described in Task 2.2 and conducted after the submission of [D2.1](#), as well as the results of these interviews.

Chapter 3 presents shortly the various approaches for DTs for various categories of energy stakeholders and finally the TwinEU approach.

Chapter 4 presents concisely the TwinEU pilot DT technologies and the technical requirements for their interactions. It is complemented by Annex A with the full information.

Chapter 5 presents the TwinEU use cases that will be implemented in the pilots. It is complemented by Annex B with the full information

Chapter 6 presents the pan-EU scenarios of the TwinEU federated IT architecture and the challenges they can address.

Chapter 7 presents the conclusions of the report.

Annex A presents the full information for DT technologies in Chapter 4.

Annex B presents full information about the UCs deployed in the pilots.

1.3 How to Read this Document

D2.2 follows a stepwise approach. Building upon the challenges identified and the stakeholders feedback from interviews and questionnaires, as these have been elaborated in tasks 2.1 and 2.2, and reported in [D2.1](#), we proceed with presenting the details of the pilot DTs and the technology requirements. Following this, the pilot use cases have been developed and presented with the respective evaluation KPIs.

Following this structure, the reader can see a correlation of the pilot technologies with key European priorities posed by the European Commission directives, European institutions and policy makers. Then, detailed propositions for pan-EU scenarios that will leverage the capabilities of the federated TwinEU architecture are presented and explained, to provide directions for the validation process of the TwinEU architecture.

2 The stakeholders' views and feedback from Task 2.2 “Energy stakeholders’ requirements for the digital twin of the pan-European grid”

This chapter presents insights derived from ten comprehensive interviews conducted with Advisory Board Members representing diverse sectors such as technology providers, industry associations, transmission and distribution operators, research institutes, and professional services. These interviews aimed to capture practical perspectives and real-world experiences in implementing DTs within the European electricity grid. The focus of these interviews was to identify operational challenges, document best practices, and explore opportunities for integrating emerging technologies to support the development of a federated digital twin framework across Europe's electricity infrastructure.

2.1 Methodology

Interviews were conducted with Advisory Board Members representing:

- Technology Providers and Manufacturers of Digital Twins
- EU initiatives (Destination Earth - DEstinE)
- Associations (EU DSO Entity, T&D Europe)
- TSOs
- DSOs
- Professional Services Providers
- Developers of Real-Time (RT) Simulation Tools
- Researchers from Energy Meteorology and Energy Systems Modelling institutes (German Aerospace Centre)

Each interview lasted approximately one hour and followed a semi-structured format with primary questions addressing specific operational challenges, best practices, data sharing, and future technological integration. Interviews were recorded, transcribed using Microsoft Copilot, and reviewed for accuracy and completeness. The interviews addressed the following six main questions:

- Operational challenges and inefficiencies that DT could address.
- Best practices or success stories in DT implementation.
- Data sharing and collaboration strategies via DT platforms.
- Specific DT implementation visions for immediate deployment.
- Emerging technologies are critical for future-proofing DT solutions.
- Roles of DT in accelerating policy compliance and grid decarbonization.

2.2 The Key Findings

Operational Challenges

- Inconsistent data models and reluctance to adopt new technologies due to cybersecurity concerns and regulatory uncertainties.
- Challenges in integrating environmental data (e.g., biodiversity, vegetation management) with grid operations.

- Limited digitalization and inadequate monitoring capabilities, especially in low-voltage grids.
- Real-time monitoring complexities and data quality issues, particularly concerning decentralized energy resources.
- Difficulties with real-time grid stability, data model interoperability, and predictive maintenance.
- Issues in integrating real-time field measurements into simulation environments.
- Integration challenges between meteorological data and energy system operations, highlighting the necessity for effective uncertainty management.
- Siloed digital representations, interoperability barriers, and regulatory complexities hindering seamless data sharing.

Best Practices and Lessons Learned

- Adoption of incremental deployment strategies with standardized APIs and interoperability protocols.
- Promoting transparent data-sharing practices and clearly defined governance structures for effective stakeholder collaboration.

Data Sharing and Collaboration Strategies

- Establishment of standardized and secure data exchange protocols.
- Creation of open platforms and collaborative ecosystems for stakeholder interaction.

Implementation Vision

- Immediate deployment scenarios focusing on real-time predictive maintenance and monitoring for critical infrastructure.
- Prioritization of low-voltage grid management and decentralized energy resources integration

Emerging Technologies and Trends

- Adoption of AI, augmented reality, cloud computing, and machine learning to support rapid digitization and advanced predictive analytics.
- Real-time simulation and digital replicas to enhance forecasting, grid management, and operational optimization.

Policy, Regulation, and Decarbonization

- Leveraging DT capabilities to meet EU energy and climate targets.
- Enhancing DT-driven transparency and accountability for regulatory compliance.

2.3 Next Steps and directions proposed to advance TwinEU objective:

Based on these comprehensive insights, the following actions are identified and planned to contribute with the TwinEU development:

- Refining interoperability standards and data sharing protocols to facilitate real-time collaboration and information exchange. A guideline on this can be the Harmonized Electricity Role Model, through the last version published in the ENTSOe site

(<https://www.entsoe.eu/data/cim/role-models/>) in January 2025. This document describes the roles that can be played for given objects within the European electricity market, as identified in current development being carried out in information exchange

- Implementing pilot programmes focused on predictive maintenance, real-time balancing, and comprehensive integration of environmental and grid operation data.
- Continuous stakeholder engagement to refine digital twin frameworks and adapt to emerging technologies and regulatory landscapes.
- These strategic steps aim to build a robust, scalable, and sustainable digital twin ecosystem aligned with Europe's energy transition and climate objectives.
- Develop pan-European UCs reflecting diverse stakeholder priorities, focusing particularly on predictive maintenance, grid resilience, interoperability, and low-voltage grid digitization.
- Establish clear KPIs addressing interoperability metrics, real-time monitoring performance, cybersecurity resilience, and decarbonization progress.
- Promote standardized DT frameworks, leveraging AI, edge computing, and real-time data analytics to ensure operational efficiency, predictive accuracy, and rapid responsiveness.
- Align DT development initiatives with EU regulatory frameworks, promoting incentives and clear policy guidelines to stimulate innovation, enhance collaboration, and ensure robust cybersecurity practices.

The integrated insights herein provide a solid foundation for shaping future research, technology deployments, and policy initiatives under TwinEU, supporting Europe's transition towards a digitally optimized, sustainable, and resilient energy system. These next steps will be taken under consideration in WP3-WP9 developments

3 The Digital Twin concept and the TwinEU approach

3.1 Introduction

The DT was first introduced in a 1991 book by David Gelernter's book named "Mirror Worlds", as a broader idea that became the DT concept [1]. The DT concept, has been known by different names (e.g., virtual twin), was first called "*digital twin*" by Hernández and Hernández in 1997 [2],[3]. Since then, the term DT has proliferated in industries and sectors, providing different levels of functionality and maturity as the respective computational capabilities improved during the years. The characteristics of this DT concept consists of three distinct parts: **(i) the physical object or process and its physical environment, (ii) the digital representation of the object or process, and (iii) the communication channel between the physical and virtual representations (the digital thread).**

In the energy sector, there have been several approaches developed and implemented in the last years. The grid operators' organizations ENTSOe and E.DSO have already included the DTs in their grid technologies portfolio under monitoring.

In 2020, ENTSOe introduced **Technopedia** [4], which includes factsheets on different innovative and state-of-the-art technologies in relation to power transmission assets, system operation, digitalization and flexibility solutions. Technopedia factsheets aim to facilitate better understanding of smart grid technologies, their benefits for transmission system operators and their readiness level.

In Technopedia, ENTSOe is approaching the topic of DT as a digital representation of a physical asset aiming to optimize the value chains in various industry sectors, such as in automotive manufacturing and energy products (Figure 1). **DTs are categorized based on the purposes of implementation: (i) Product Digital Twin**, ensuring reliable design in product development and improvements, **(ii) Production Digital Twin**, improving production planning and manufacturing, and **(iii) Performance Digital Twin**, capturing, analysing and acting on data while an asset is in operation.

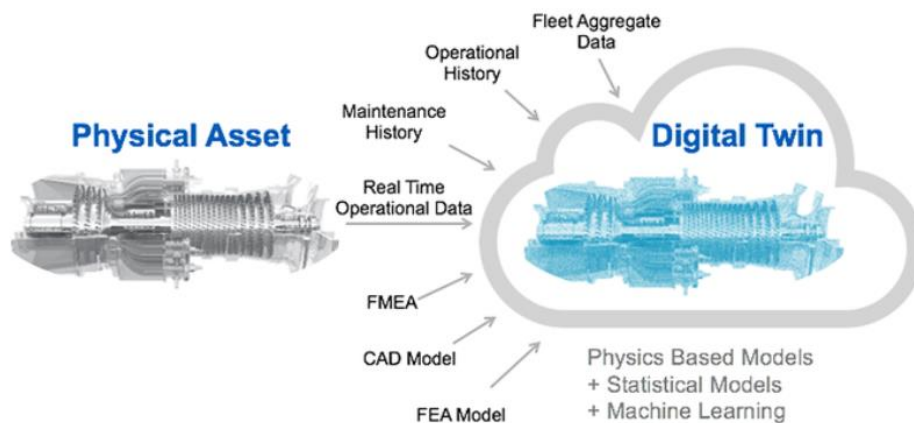


Figure 1: Performance DT as expressed in ENTSOe Technopedia

The latter is most relevant with system operators' business practices, because as asset owners they gather the necessary data and may feed modelling and simulation software

solutions to support their decision making at several operational levels, e.g. planning, system operation or asset management activities.

This digital “picture” of installed power equipment may be used to operate complex grid infrastructure more accurately. It is explicitly mentioned in the ENTSOe Technopedia that “despite that DT products and services are available, further proof is required of the DTs trade-off or implementation in TSOs’ core business”.

This is an area where the TwinEU can certainly contribute, since TwinEU pilots will reach a high TRL 7 demonstrating their functionalities in the System Operators’ environment.

Additionally, the implementation of DTs can serve as one comprehensive method for valorising data from various sources – therefore ensuring cohesion. A general structure of DT can consist of (i) the Engine responsible for the operation of the central multi-user database as well as several data management functions, (ii) Sensors and corresponding interfaces to obtain data and transfer within another, (iii) the User Interface to facilitate the requested functionalities, such as graphical data visualization. In Technopedia, it is also mentioned that the main developments are promoted by industrial companies like Siemens AG and General Electric Corp, which offer different products and software solutions to Asset Owners and other stakeholders.

This is an area where the TwinEU will contribute, since the federated DT architecture of TwinEU will connect and valorise “distributed” DTs (models and data) stemming from System Operators’ environments and their coordination with technology providers and academia. More details on this in Section 3.6 - 3.7 within D2.2.

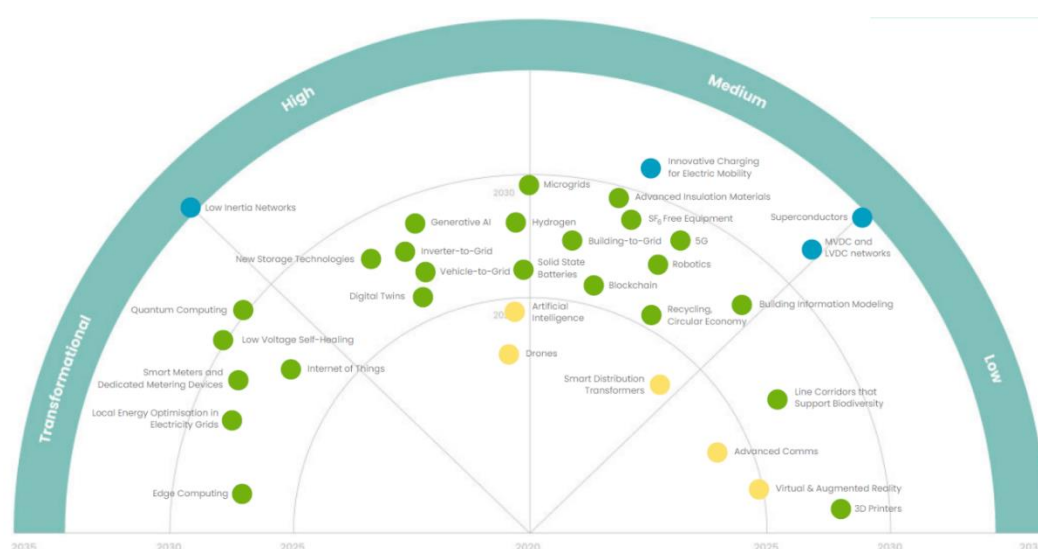


Figure 2: Impact on DSOs of various technologies (Source: E.DSO Technology radar)

E.DSO has developed the Technology Radar [5], with the objective of identifying and analysing trends and stimulating innovation. The Technology Radar document evaluates technological topics that have a potential impact on DSOs and their ecosystem (public authorities, suppliers, customers, and employees). It aims to: (i) identify new technologies, technological trends and potential disruptions early, (ii) increase awareness of the opportunities and threats associated with emerging technological developments, (iii)

stimulate innovation by the combination of technology reports and business potential assessment.

For each innovation trend, a factsheet has been produced that summarizes the key elements relating to the technology considered, the developments in progress as well as the analysis of potential impacts for the DSOs. Digital Twins hold a place in the Technology Radar, defined as a virtual representation that support monitoring, diagnosis, simulation and forecasting activities of installations, processes or entire systems, including electricity and energy systems. **DTs aim to enable a precise, close to reality, representation of systems and operations to improve the management and lifecycle of structures, by making use of digitally mapped descriptive data generated by distributed digital automation.** In particular, the development of a DT for the pan-European electricity grid has been prioritized with the Declaration of Intent between the DSO Entity and ENTSOe [6] **aiming to promote the five areas identified in the “Digitalizing the energy system –EU action plan”** i.e. (i) observability and controllability, (ii) efficient infrastructure and network planning, (iii) operations and simulations for a more resilient grid, (iv) active system management and forecasting to support flexibility and demand response, and (v) data exchange between TSOs and DSOs.

According to the E.DSO Technology Radar, the adoption of DTs in the environment of DSO operations will have a significant impact in the sector. While the collection and management of vast amounts of data will be a challenge, this data can bring valuable insights into system operations. DTs can further enable the optimal management of grid capacity to host renewables but also entail significant complexity and upfront costs as high-performance, scalable digital infrastructure. DSOs are advised to (a) define the functional requirements for the DTs, ensuring that the developments promoted by European regulation align with the need of the industry; (b) reach a consensus on the definition of DT that foresee scalability and replication throughout Europe; and (c) promote interoperability and assess the use of open-source component configurations as enablers of the wide-scale deployment of DTs by several actors.

In this scope, the **TwinEU federated DT architecture and platform will unleash the capabilities of Data Spaces in a highly interoperable and scalable platform.** More details on this in Section 3.6 - 3.7 of D2.2.

The technical use cases identified for DSOs are grid optimization, active system management, asset management, cyber-physical grid resilience and security, network planning, TSO-DSO coordination, training and education, disaster response, energy efficiency.

As explained in Section 5 “TwinEU Use Cases” of the current D2.2, the **TwinEU project will demonstrate use cases connected to all above-mentioned technical use cases** i.e. grid optimization (e.g. UC BG05), active system management (e.g. UC Ib09, GE06), asset management (e.g. UC BG08), cyber-physical grid resilience and security (e.g. UC NL01), network planning (e.g. Ib10), TSO-DSO coordination (e.g. EM-GR-01, GE07), training and education (e.g. UC FR01), disaster response (e.g. Ib07), energy efficiency (e.g. HU02).

Other ongoing projects led by DSOs are also mentioned such as Envelio’s Intelligent grid Platform, E-REDES platforms (DPlan, Analytics4Assets, LiveGrid, GridView, VEGA, PREDIS, ORES), Enedis DT platforms for Asset Management, Operational Planning and Network Control.

The International Energy Agency has published a report [7] that offers a global stock take of the world's electricity grids as they stand today, taking a detailed look at grid infrastructure, connection queues, the cost of outages, grid congestion, generation curtailment, and timelines for grid development. IEA identifies signs that grids are becoming a bottleneck to clean energy transitions and analyses the risks if grid development and reform do not advance fast enough.

Delayed action on modernizing the grid for the clean energy transition means prolonging reliance on fossil fuels, resulting in an increase in emissions and costs to society. An unprecedented level of attention from policy makers and business leaders is needed to ensure grids support clean energy transitions and maintain electricity security. Regarding the digitalization of the energy sector, this is considered as a key factor for the clean energy transition and its impact is elaborated along several areas that impact the operation of the electricity grids.

To summarize the most important points for the energy system clean transformation, the IEA carefully highlights the following arguments:

- The National Energy and Climate Plans have set **ambitious goals**: They dictate the world's electricity use to grow 20% faster in the next decade than it did in the previous one. Electricity demand needs to grow even more rapidly in a global pathway to net zero emissions by 2050, which is consistent with limiting the rise in global temperatures to 1.5 °C. Electricity networks are critical to facilitate such levels of growth as the world deploys more electric vehicles, installs more electric heating and cooling systems, and scales up hydrogen production using electrolysis.
- **Grids need vital upgrade** to live up to the expectations of energy transition and electrification: The slow pace of grid development i.e. expansion and strengthening, digitalization, modernization, capacity utilization, presents risks to electricity security while both decelerating and increasing the cost of achieving the clean energy reforms. This is a current issue that networks are facing, where grid projects suffer long lead times. The delay of the necessary upgrades and grid connection acts as a bottleneck for renewables deployment in many places, while several systems will need increased flexibility from the grid to balance the intermittent renewables. Regarding the position of digitalization and IoT in distributed resources during the grid modernization process, these create also an additional opportunity for smarter and more resilient grids, while requiring them to operate more flexibly and be protected from cybersecurity threats.
- **System planning** for transmission and distribution grids needs to be further aligned and integrated with broad long-term planning processes by governments. Transmission and distribution projects often take 5 to 15 years to plan, permit and complete, compared with 1 to 5 years for new renewables projects and less than 2 years for new EV charging infrastructure. Thus, the network plans need to integrate inputs from long-term energy transition plans across sectors, anticipating and enabling the growth of distributed resources, connecting resource-rich regions including offshore wind, and reflecting links with other sectors including transport, buildings, industry, and fuels such as hydrogen.

As presented in Section 5 “TwinEU Use Cases”, the TwinEU project demonstrates several UCs enabling: **(i) efficient RES penetration in the energy system to support the ambitious goals of decarbonization** (i.e. BG06, Ib06, Ge08) and **(ii) digitally enabled system planning processes for flexible connections** (i.e. Ib10, Ib09, Ge01).

- **Robust stakeholder and public engagement**, secure supply chains and skilled workforce are key elements to inform scenario development and build modernized grids. The public needs to be aware of and informed about the link between grids and successful energy transitions. In this way, public objections to grid infrastructure projects can be mitigated and projects can be finalized at a faster pace. Additionally, the expansion of supply chains by creating firm and transparent project pipelines, the standardization of procurement and technical installations and interoperability among legacy and smart equipment should be priorities in grid investment strategies. These pathways require skilled professionals across the entire supply chain; thus, it will be essential to build out a pipeline of talent, ensure digital skills are integrated into power industry curricula and manage the impacts of the energy transition and increased automation on workers through reskilling and on-the-job training.

The TwinEU will **conduct a power system training simulator use case** (UC FR01) as it is explained in Section 5 “TwinEU Use Cases”, that can improve the skills of system operators’ personnel in handling critical situations and grid contingencies

- **Regulation** needs to be reviewed and updated to support not only deploying new grids but also improving the use of assets. Grid regulation needs to incentivize grids to keep pace with the rapid changes in electricity demand and supply. Regulatory risk assessments also need to improve to enable accelerated buildout and efficient use of infrastructure. Smart grid technology for efficient forecasting and dynamic line rating of transmission corridors would optimally manage the existing capacities, along with the establishment of flow-based markets [8]. Additionally, the EU regulatory propositions for promoting anticipatory investments [9] as means for accelerating clean energy transition are in this direction. With the term “anticipatory investments” is referred the investments that are risky for society because they may turn out be underused, at least for some years, until developments on the generation side.

The TwinEU includes a **dedicated Task 9.2 for regulatory and market recommendations for incentivizing and accelerating digital twin solutions** developed in the project.

Regarding the digitalization of the distribution grids, the direction of DERs’ energy flows within the grid is becoming less predictable, often characterized by a reversal of power flow, even from distribution to transmission grids, requiring the deployment of new digital technologies. This unpredictability and power injections from distributed generation facilities can result in more dynamic system conditions and local line overloads, depending on the equipment involved.

IEA suggest that digitalization and smart grids co-ordinate the needs and capabilities of all the power systems actors (generators, grid operators, end users and other market players) to operate all parts of the system as efficiently as possible, **minimizing costs and environmental impacts while maximizing system reliability, resilience, flexibility and stability**, addressing both short-term as well as long-term grid challenges.

For example, self-healing automation of the medium- and low-voltage grid, already implemented by Enel in Italy and Duke Energy in the United States, ensures the automatic containment of the duration of an outage and the number of customers involved, thereby preventing cascading power outages [10]. DTs can play a key role in building and studying scenario exercises for these use cases affecting the distribution grid operation.

Regarding the transmission grids, digital technologies play a significant role in grid modernization process, where they can increase capacity and enhance efficiency, reliability and flexibility, allowing them to handle higher loads and transmit electricity more effectively. Digitalisation and smart grids can defer the construction of new lines or assist in cases where line extension deployment is decelerating due to several purposes. Several power electronics and sensor-based technologies are at the forefront of grid modernization: (i) Dynamic Line rating, involving real-time monitoring of weather conditions and line temperatures to adjust the current carrying capacity of transmission lines accordingly, (ii) FACTS technology such as static VAR compensators (SVCs) or Static Synchronous Compensators (STATCOMs) that can effectively enable real-time control of power flows, voltage levels and other stability characteristics (iii) HVDC, assisting in the transportation of large amounts of electricity and functionalities for bidirectional load flow and assist in black start processes (iv) Wide Area Monitoring (WAMS) orchestrating PMU sensors and advanced analytics and AI algorithms (v) transformers' sensors, drones and satellite-based technology have revolutionized the condition monitoring and inspection of power lines.

As described in Section 5 “TwinEU Use Cases” and the UCs descriptions, the **TwinEU DT technologies implemented in the pilots will connect with the above-mentioned smart grid technology** i.e. DLR (i.e. UC HU01), WAMS PMU and HVDC connections (i.e. EM-CY02).

These smart grid technologies generate a tremendous amount of data that can enable the development of highly accurate predictive models as well as digital twins to conduct elaborate system studies. On the other hand, cyber incidents have been increasing in the digitalized infrastructures, thus a systematic approach is needed to ensure resilience against cyber risks and attacks.

Regarding cybersecurity and DTs, the European Cybersecurity Organization (ECISO) issued a very interesting paper, elaborating on the impact of Digital twins on Cybersecurity [11]. ECISO explores the role of DTs in cybersecurity, focusing on their potential to predict failures, optimize processes, and enhance security in various sectors. Key insights on DTs and Cybersecurity are the following:

Digital Twin Capabilities in Cybersecurity:

- **Simulation & Virtualization:** DTs create real-time replicas of physical systems, allowing for risk analysis, predictive maintenance, and failure tracking.
- **Security Management:** They serve as testing labs for security strategies, enabling intrusion detection, threat mitigation, and training simulations.
- **Governance & Risk Management:** DTs enhance risk analysis by simulating attacks and predicting their impacts, leading to more resilient cybersecurity frameworks.

Use Cases of Digital Twins in Cybersecurity:

In business applications:

- DTs help organizations simulate business processes, improving decision-making and operational efficiency.
- In the energy sector, DTs optimize grid security by predicting potential system compromises.

In education & skills development:

- Simulation-based learning using DTs provides hands-on cybersecurity training.
- DTs replicate real-world cyber threats, helping professionals develop practical defence skills.

In industrial cybersecurity:

- DTs are used in Industry 4.0 and 5.0 to monitor factories, manufacturing plants, and industrial automation.
- They provide attack modeling and intrusion detection, identifying cyber-physical system (CPS) vulnerabilities before exploitation.

On the other hand, DTs can induce some new challenges in the industrial systems and smart grids:

- Expanding Attack Surface.
- DTs introduce cascading cybersecurity risks by integrating IT and operational technology (OT).
- Unauthorized access to DT models can lead to security breaches.
- Lack of Standardization:
- No unified security framework exists for DT-based cybersecurity.
- Need for international cybersecurity standards (e.g., NIST, ISO).
- Privacy & Data Protection:
- DTs process vast amounts of sensitive data, requiring compliance with GDPR and cybersecurity regulations.

ECSO defines some future recommendations to enhance cybersecurity and DTs roll-out:

- Developing Secure DT Architectures.
- Ensure secure data transmission between physical and digital components.
- Implement multi-layered cybersecurity defences.
- AI-Powered Threat Detection:
- Use AI-driven DTs to detect anomalies and prevent cyberattacks.
- Cybersecurity Training & Awareness:
- Expand DT-based cyber training programs for businesses and industrial sectors.

ECSO concludes the paper expressing that DTs are a powerful tool in cybersecurity, offering risk analysis, attack simulations, and defence mechanisms for critical industries. However, standardization, privacy protection, and security governance remain key challenges. Future efforts should focus on AI-driven detection, regulatory frameworks, and resilience strategies to fully leverage DTs in cybersecurity.

3.2 Research and innovation approaches to Digital Twins

DTs are attracting the focus of the research and academic community, publishing a wide spectrum of research applications and developments for electricity networks.

In the scope of BRIGHT Horizon project, the Bosch Engineering Centre and University partners [12] have presented an overview of the DTs application domains in the smart grid while analysing the state-of-the-art literature. They focus their review on DT on activities such as a) Asset Model: energy and performance assessment and management for grid components, b) Fault Model: diagnosis of errors/faults and security issues, c) Operational Model: optimal energy distribution, energy efficiency, and cost reduction, d) Business Model: innovative energy services and new business models.

In the same publication, several applications have been proposed for modeling and managing customer profiles. A user's DT profile incorporates selected flexibility assets; thus, it can increase the "smartness level" of buildings. The small-scale energy prosumer is enabled to trade their energy flexibility and participate in flexibility-driven demand response (DR) programs. The consumers, the owners of flexible assets, and energy stakeholders will cooperate to achieve community-level welfare or energy grid sustainability objectives. While the grid modelling DT activities are extensively elaborated in the TwinEU project, as a pan-EU electricity grid approach, the development of DT for residential consumers energy-related behaviour and flexible assets is not something in the scope of TwinEU.

In another publication [13], a systematic literature review on digital twin technology was also conducted, following the approach [14] proposed in "Cochrane Handbook for Systematic Reviews of Intervention", following the stages proposed by this methodology as: (i) identifying answerable research questions, (ii) developing a protocol, (iii) conducting systematic publication search operations, (iv) selecting studies to include, (v) conducting a comprehensive revision, (vi) extracting and synthesizing information, (vii) writing and publishing the review.

The research questions included (i) the state of the art of DT technology in implementing real-life applications, (ii) the challenges of implementing a DT-based system using the current technology (iii) the limitations when implementing a DT-based platform, (iv) the trends in the use of enabling technology for the future. Regarding the SotA of DT technology, it presents a great variety of DT applications in the areas of engineering, automotive, electric vehicles, freight logistics, and medicine. The evolution layers in the presented application include (a) the Digital model, where no automatic information flow is integrated from the physical entity to the virtual entity (b) the Digital shadow, where changes in the physical object automatically reflected in the 'shadow', (c) the DT, where Virtual and physical world interact in a bidirectional way.

The challenges identified are (a) Issues related to data (trust, privacy, cybersecurity, convergence and governance acquisition and large-scale analysis), (b) Lack of standards, frameworks and regulations for DT implementations, (c) High costs of implementation due to the increased amount of sensors and computational resources needed, (d) The use of AI and big data to satisfy the long-term and large-scale requirements for data analysis, (e) communication network-related obstacles.

In another scientific publication [15], the concept of “Digital Twin System (DTS)” has been introduced, to express the shift in operation strategies of power systems, embracing more intelligence and digitization, i.e. the Cyber-Physical System (CPS), which is needed to achieve an optimal, reliable and secure operation across all system levels (components, units, plants, grids) and exploiting the use of big data.

Going one step ahead, the authors bring up the idea of a “System of Digital Twin Systems” (SDTS), which is composed of modular Digital Twin Systems (DTSS) and based on a holistic framework architecture, allows for an arbitrary extension to an ultra-large-scale SDTS. The definition used is *“A digital twin system consists of a digital twin and its corresponding physical asset. The digital twin digitally runs alongside the physical asset. The digital twin is structured into three interconnected parts: Virtual Model, Data and Services. The physical asset and the parts of the digital twin are interconnected via Connections. The digital twin system can adapt and reconfigure itself to mirror the actual state of the physical asset during its life cycle and offers services to improve/extend the performance and capabilities of the physical asset.”* The proposed SDTS and its corresponding framework are generic in design, enabling services defined and provided by multiple stakeholders. Moreover, the proposed concept is not limited to power systems. The hierarchical and coordinated structure guarantees that each individual DTS can operate independently at their own relevant level (such as component, unit, plant, or system level). Meanwhile, data flow, communication channels, and computation/analysis can be orchestrated among these DTSS by adapting the current definitions to these requirements.

The five pillars identified for the DTSS are the following:

1. **Physical Asset:** it is the physical counterpart of a DT.
2. **Virtual Model:** it is a physics- and/or data-based model of the physical counterpart which usually runs digitally alongside the physical asset and generates virtual measurements.
3. **Data:** it represents the stored version of (real) measurements from the physical asset and virtual measurements from the virtual model.
4. **Services:** they provide the functionalities that add benefits and intelligence to the whole DTS
5. **Connections:** they stand for communication channels that are established and maintained between physical assets, data, virtual models and services.

Furthermore, the “System of Digital Twin Systems (SDTS)” concept is introduced and defined as: *“A system of digital twin systems consists of horizontally and vertically interconnected digital twin systems on all system levels such as component, unit, plant, and grid (system) level.”* The SDTSs can be realized with an open-source framework that serves as a central data and communication interface between different DTSS which can interact by “Reporting Modules” which are regulated by “Control Modules” (CMs). Exemplary application scenarios involving multiple system levels are discussed to illustrate the capabilities of the proposed SDTS concept. Concerning this characteristic and the requirements raised for the future power system, the following functions are put forward as necessary to support the SDTS framework:

- **Data exchange:** Data exchange between DTs and the corresponding physical assets, or even among different parts of the DTs is necessary.
- **Data persistence:** The capability of storing and retrieving the data instances of DTs during the evolution process of the models.

- **Data compatibility:** Different types of devices can be connected to the framework and the integration of already existing systems into the network should be possible.
- **Cloud-based access:** As the physical asset and its DT are not necessarily located at the same location, cloud-based access to the data is necessary as well.

The above-mentioned SDTS concept has been implemented in a cloud-based platform, whose main task is to provide a database for DTs and their physical assets that are connected to it and plays the role of a central communication hub (Figure 3). The open-source software Eclipse Ditto is considered, in its version 3.0.0, to provide standardized Application Programming Interfaces (APIs) on a database via multiple protocols such as HTTP, WebSocket, AMQP 0.9.1, AMQP 1.0, Kafka 2.x, MQTT 3.1.1, and MQTT 5. Finally, the proposed SDTS framework and systematic optimization, exploiting the benefits of DT technology, is feasible, is presenting three application scenarios for the power systems: (a) Economic Dispatch, (b) Load-Aware Wind Farm Control, (c) Fault-Tolerant Control of converters.

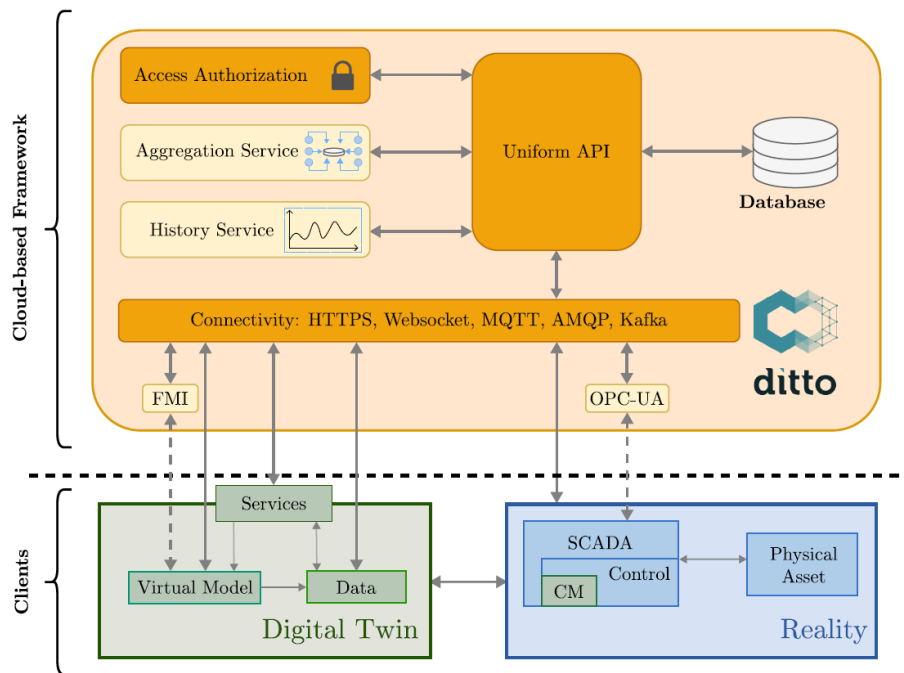


Figure 3: The cloud-based framework architecture of System of Digital Twin Systems (SDTS), connected to a single DTS [15]

In another publication [16], the authors present a DT framework designed to simulate DERs within distribution grids effectively, which is validated in case studies on two Danish distribution grids with scenarios incorporating rooftop PV systems, batteries, and electric vehicles, considering different combinations of these technologies.

The proposed framework is entitled DERInGrid is structured around four key modules and the respective agents: DERs (agents for: EV, roof PV, stationary battery), the electricity distribution grid (agents for: distribution grid, transformer, cable box, consumer connection point, cable), the energy management system (agents for: EMS, control strategy), and the consumers (agents for: residential consumer, base appliances). It incorporates a communication interface to facilitate interactions among these agents/modules and includes considerations for grid topologies and demand-side configurations. The framework allows for the exploration of various DER adoption rates and capacities. The validation of this framework

is done by developing digital twins and operational scenarios simulation for a period of 15 years, evaluating different paces of DERs adoption in the distribution grid. The real grid digital twins included areas connected with 10 kV/0.4 kV transformer sub-station that feeds the entire electricity distribution grid that connects residential consumers in the systems. These transformers are designed to support a nominal load of 400 kVA. The DT scenarios presented the results of operation curves for summer and winter weeks for residential consumers, transformer overloads, PV-battery operation curves,

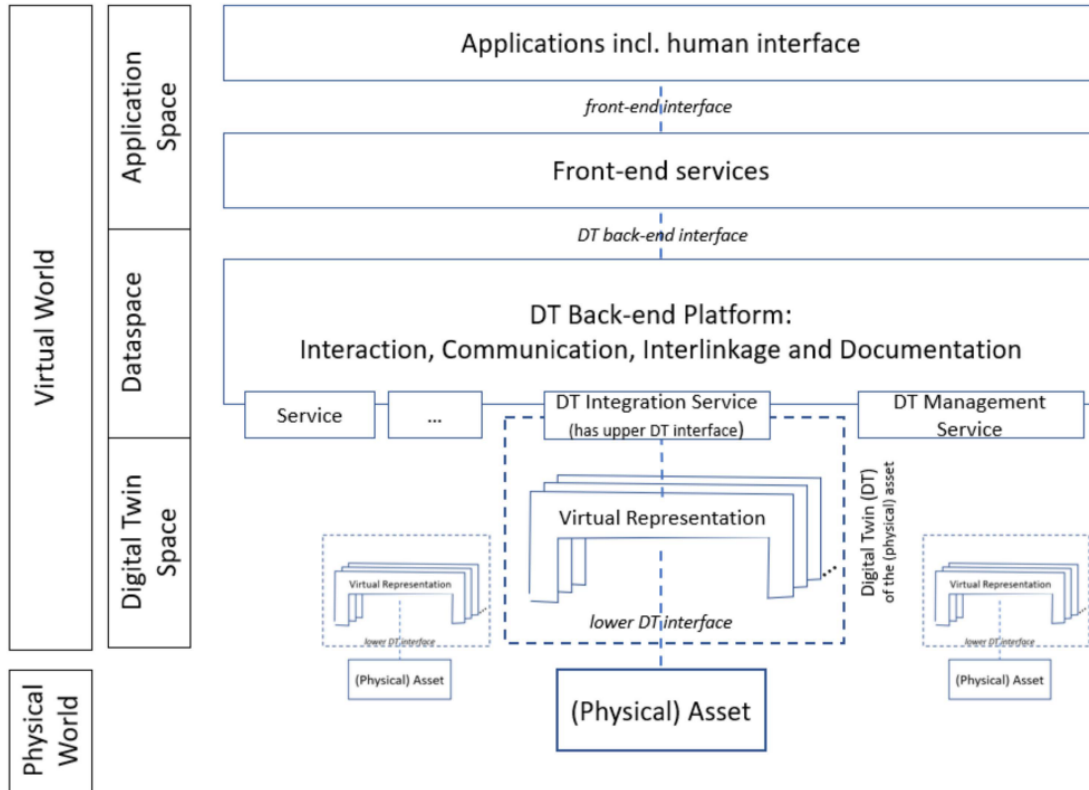


Figure 4: Digital Twin System Reference Model (DTS-RM) [17]

In another scientific publication [17], the authors present a symbiotic approach for DTs and Dataspaces, mainly addressing the overall challenges of industrial applications in the advent of Internet of Things and Industry 4.0. The paper provides a description of “Digital Twin” and “Dataspaces”, with a focus on the application domain of industrial production. Then it presents the approach of a reference model for digital twin systems that embraces both Dataspaces as well, elaborating on the focal thematic aspects to be considered and highlighting how digital twins can benefit from the emergence and availability of dataspace.

The publication analyses the DT concepts (i.e. Industry IoT Consortium, Digital twin Consortium, industrial Digital Twin Associations, ISO 23247 [18], European Data Strategy, IDSA, GAIA-X), and proceeds with the definition Digital Twin System Reference Model (DTS-RM) as reference model as a “meta-model for architectural specifications” in order to give some guide system engineers when defining the conceptual architecture of digital twin Systems. The DTS-RM divides the virtual world into:

- A Digital Twin Space, providing the DT instances;
- A Dataspace, providing the DTS-RM back-end platform comprising, among others’ management services for the DT instances and their interactions;

- An Application Space, providing the UC specific instantiations and the applications including the human interface.

3.3 The AIOTI approach

The Alliance for IoT and Edge Computing Innovation has published a report [19] that explores the intersection of DTs and Edge Computing in the distributed energy sector, particularly focusing on medium and low-voltage networks. Selected cases are provided where edge computing stands as an efficient solution for handling heterogeneous data with performance requirements such as low latency, crucial for the increasing controllability demands in low-voltage distribution networks. The integration of DTs at the grid edge is positioned as a key enabler for developing a more efficient energy ecosystem with evolving business models. The devices at the edges of electricity grids can serve as physical infrastructure for sector integration, connecting with electromobility and heating & cooling sector along with active buildings components.

DTs driven by edge computing are also expected to provide essential data for infrastructure planning across sectors, fostering the development of cross-sectoral business use cases. Several of the research and innovation projects are being presented with respect to the need for data interoperability between different sectors emphasizing also in the evolving business models.

Multiple challenges identified in the report are the lack of plug and play deployment tools, the technical maturity of DT technology, shortage of digital skills in the energy sector, regulatory issues, data privacy, and security concerns. The opportunities that arise for future growth are related to scalability, AI growth, federated DTs models, linkage to the European Data Space, and the need for determining useful data for collection.

The identified DTs Applications in Energy Systems have been the following:

- **Grid Optimization and Management:** DTs enable real-time monitoring of grid infrastructure, improving grid observability, especially at the edge of the grid where most DERs connect, facilitating improved infrastructure planning and development.
- **Predictive Maintenance and Fault Detection:** DTs can analyze real-time data from IoT sensors, allowing operators for preventive maintenance practices and efficient maintenance planning. This improves system availability, extends asset lifespan, and optimizes operational costs.
- **Energy Efficiency and Resource Allocation:** DTs can simulate and optimize microgrid configurations, aiding in energy independence, resilience, and cost savings. AI-driven models improve renewable energy forecasting, ensuring better matching of supply and demand, and optimize the operational cycles of energy storage systems.
- **Peer-to-Peer Energy Trading:** Using AI-driven digital twins integrated with blockchain technology, energy systems can facilitate secure, automated energy transactions among consumers and prosumers, enhancing decentralized energy systems.
- **Regulatory Compliance:** DTs provide detailed data analytics that help energy providers adhere to evolving regulations such as GDPR, Cybersecurity Resilience Act, and AI Act. They allow for advanced simulations to predict and ensure compliance with emerging energy policies.

The challenges identified in Implementing DTs:

- **Technical Maturity & Scalability:** DTs technology is still evolving, particularly in terms of performance, security, and scalability. There is a lack of standardized tools for easy deployment across diverse infrastructures.
- **Data Privacy and Security:** Handling sensitive consumer data requires stringent data protection and adherence to regulatory frameworks. Ensuring data accuracy for grid management is a critical concern, particularly with decentralized and small-scale energy assets.
- **Skill Gaps and Resource Constraints:** The European energy sector faces a shortage of digital skills, particularly for deploying advanced solutions like edge-driven digital twins.

The authors provided as future technological and business prospects for DTs in the energy sector:

- **Federated DTs:** Instead of a single digital twin for the entire European energy market, multiple DTs will be developed, enhancing interoperability and supporting diverse business models.
- **Edge-to-Cloud Continuum:** DTs will play a crucial role in managing the energy footprint of distributed cloud computing infrastructures, improving resource optimization and sustainability.
- **Advanced AI Integration:** Combining AI with digital twins allows for adaptive learning, real-time simulations, and dynamic decision-making, unlocking new avenues for demand-response programs and distributed energy resource management.

3.4 The VDE approach for the electricity network modernization

According to a report [20] published by the VDE ETG Task Force “Digital Twin”, the network and electricity industry is facing gigantic challenges. A look at the planned investment projects of the grid operators reveals the massive efforts in network reconstruction and expansion to implement the energy transition and thus decarbonization. The ambitious goals of the federal German government (6 million heat pumps and 15 million electric cars by 2030) clearly demonstrate how green electricity, especially (according to the Easter Package), with an annual addition of 22 GW of photovoltaic and 10 GW of wind power expansion by 2030, replaces conventional energy sources in sectors such as households, industry, commerce, and transportation, driving further investments in the grids. These increasing investments encounter processes and structures that have grown in isolated silos over decades.

Often, there was a lack of awareness that the introduction of digital technology and software, without sufficient coordination by management, leads to redundancies in data models. In overall operations, hidden productivity losses and difficult-to-manage projects are the result. Due to the numerous uncontrolled redundancies of these silos with their own data models, data is continuously manually validated and processed in many manual steps. Thus, there is neither trust in the data nor the ability to accelerate or automate processes to relieve skilled workers or achieve higher efficiency per worker. This is precisely what is necessary because the increased workload coincides with an already severe shortage of skilled professionals at all levels of the process chains. Moreover, it is foreseeable that this will be further exacerbated by the increasing retirement of many experts, competition from modern and digital industries, as well as ever-shortening employment relationships.

Within these framework conditions, the power grid must be completely rebuilt. From the VDE Task Force's perspective, network reconstruction and expansion cannot be achieved solely through more funding and the opportunities arising from the third industrial revolution (introduction of digital technology). The increased and more flexible new requirements for the grids specifically require intelligent and interconnected solutions to uncover and safely utilize the existing reserves in the power grid.

Working according to the methods of Industry 4.0, with solutions such as the Digital Twin in the network and electricity industry (DZiNE) presented here, addresses precisely this point. This interconnected simulation model, based on I4.0 methodology, forms the data foundation for continuous, data-driven processes from planning through operation to decommissioning. The implementation of weather-dependent overhead line operation (WAFB) is already a step in this direction, using interconnected simulation models to dynamically utilize the built-in reserves of the power grid. The classical planning methods of the past often included worst-case scenarios, which is why the resulting reserves can now be utilized through the introduction of DZiNE. The promised curative network management further builds on this approach. By means of DZiNE, controlled overloading of power circuits can be enabled through precise bottleneck analysis. Thus, while it cannot replace stalled network reconstruction and expansion, it can be reduced through intelligent and digital solutions.

The TwinEU project deep dives into the **weather-dependent overhead line operation (WAFB) with DTs valorising DLR technology for grid and market optimization**, as explained in Section 5 "TwinEU Use Cases" with UCs Hu1 and Hu2.

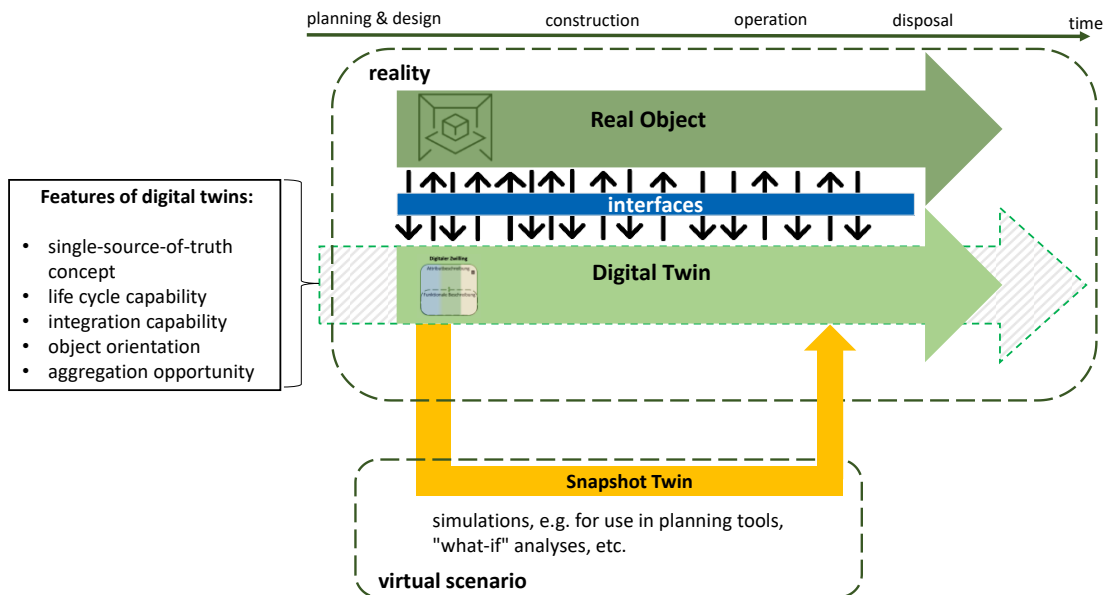


Figure 5: Interplay between real objects and DZiNE across different lifecycle phases

The foundation of such intelligent and digital solutions lies in data models consisting of valid and interconnected data that can be evaluated by algorithms - so-called Digital Twins. As one of the core results of this task force, a definition of DZiNE is presented, which differentiates it from conventional digital data models based on a series of characteristics. According to VDE approach, the DT:

- is a virtual representation of an existing or to-be-created real object;

- has attributes and a functional description;
- covers at least two domains of the real object;
- reflects the real object with continuous control and high fidelity;
- is closely coupled to the real object via communication infrastructure (up to real-time synchronization);
- accompanies the real object throughout its life cycles.

An overview of the VDE proposed DT concept is depicted in Figure 5 considering the whole product lifecycle as well as the strong entanglement between the real and digital.

In addition, interconnected DTs consist of a (hierarchical) linkage of multiple DTs and connect their components through communication connections as illustrated in an example in Figure 6.

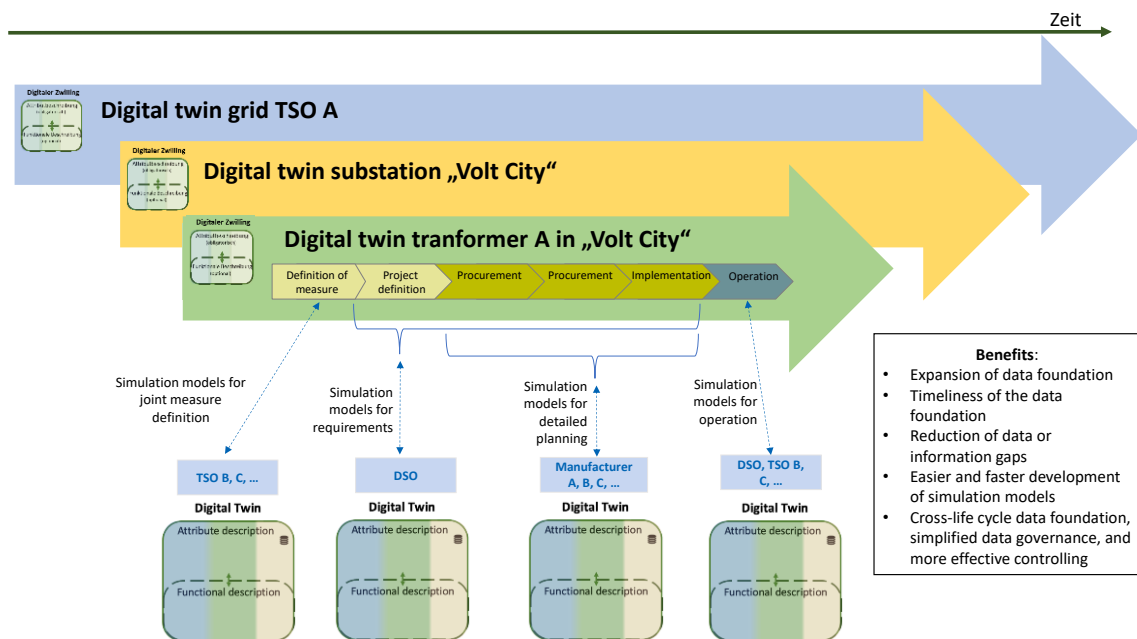


Figure 6: Exemplary interaction of multiple digital twins in the context of establishing a new transformer in a substation

When introducing digital twins, data inventory according to I4.0 is essential and can lead to short-term productivity improvements. As I4.0 methods have proven themselves in the industry for years, there are already models, data standards, and software that can be built upon. The task force has taken on the task of making the digital twin tangible in the network and electricity industry to provide impetus for implementation. The goal of the VDE report is to summarize and translate the concepts of I4.0, including the introduction of digital twins, for the network and electricity industry and to build competence. By showcasing practical use cases and providing recommendations, it aims to enable the development of digital strategies that bring direct benefits.

The intensive interdisciplinary collaboration within the task force has elaborated, based on practical use cases, how value is created within the life cycle (planning, commissioning, operation) of systems. These values were then qualitatively assessed in terms of costs, quality, duration, risk, and challenges. In general, the added values resulting from the introduction of DZiNE can be summarized as follows:

- Reduction of uncontrolled redundancies;
- Expansion of the data basis;
- Timeliness of the data basis;
- Reduction of data or information gaps;
- Easier and faster development of simulation models;
- Cross-lifecycle data basis, simplified data governance, and more effective controlling;
- Reduction of project duration, testing efforts, and costs through validated requirements;
- Seamless system integration through simulations with DZiNE, even with software patches;
- Reduction of errors through validated and consolidated data;
- Minimization of data maintenance efforts through interconnected DZiNE.

Furthermore, the VDE task force has formulated recommendations for action. Within the organization, this includes, for example, creating a migration path and initially starting with a limited UC while enabling employees through suitable training measures. Through the cross-functional collaboration of experts (modelling, standards, IT, etc.), further collected UCs can be prioritized and implemented. Digital system interfaces should be standardized and enable vendor-independent, modular system architectures that meet the needs of the UCs and align with the principles of the IEC 61850 [22] and IEC 61970 [23] standard families in terms of compatibility. Since there are currently no specific standardization initiatives beyond this scope in the IEC regarding DTs, it is necessary to develop a standardization roadmap. In addition, recommendations for action were also addressed to policymakers and regulators. With advanced risk management through DZiNE, methods such as curative network operation can be introduced, allowing the network to be utilized beyond the (n-1) criterion. However, the corresponding framework conditions need to be adjusted.

The discussions within the task force clearly demonstrate one thing: To reap the benefits of digitalization, management must make the introduction of DZiNE an organizational goal and coordinate it due to its cross-functional integration. Only in this way can uncontrolled redundancies be resolved and the methods of Industry 4.0 be introduced.

3.4.1 Continuation Through VDE ETG Working Group

Following the completion of this task force's work on DTs for electrical energy systems, its efforts are being continued under the newly established VDE ETG working group "Digital Twins in Electrical Energy Systems". This working group was formed to advance ongoing discussions within industry circles (e.g., distribution/transmission system operators) while fostering collaboration between research institutions.

Over 40 participants contribute expertise from diverse fields such as modelling standards development or IT/data management practices tailored specifically toward utilities/operators' needs!

Three subgroups focus on key areas identified during brainstorming sessions: Fundamental Concepts, Technical Implementation and Data Management.

The key initiatives of the working group include:

- Analysis of UCs: Existing UCs and those required by grid operators for DTs are being compared. The goal is to create a Fit-Gap analysis between operator requirements and manufacturer offerings.
- Development of Ontologies and Metrics: Based on the requirements of grid operators and the need for interoperability, necessary advancements in data models are being identified and pursued.
- Technical Implementation Aspects: Key questions under investigation include:
 - How can the digital product passports (DPP) now available from many manufacturers be integrated into a comprehensive concept for DTs at grid operators?
 - What role do European Data Spaces, as mandated and supported at the EU level (including those related to energy), play in this context?
 - How can interoperability among DTs be ensured? Are open-source solutions required for this? What interface requirements arise for individual modules?
 - What additional competencies must grid operators develop in the medium term to implement the systemic aspects of the DT concept?
- Preparation for Executive Level: The concept of DTs is being specifically prepared for company leadership to raise awareness at decision-making levels and drive implementation within organizations.

3.5 The manufacturers' approach

T&D Europe represents Europe's grid technology providers, including companies that develop and manufacture the products, systems and services that enable energy transition. It has issued a position paper analysing the main elements of DTs supporting Energy Transition [24].

According to the paper, digitalization is key. DTs will be crucial, connecting the physical and digital worlds to monitor, operate, coordinate investments, and drive the digitalization of the energy system, enabling grid transparency, efficiency and reliability, and improving asset and system availability.

Elements of this digitalization are already in place and will be integrated into future DTs. The DTs ecosystem must scale effectively and maximize synergies across the entire energy sector and among all stakeholders. Interoperability of DTs is essential to fully benefit from their implementation. DTs can share and continuously enrich data throughout their lifecycle, when they are implemented within an interconnected ecosystem of sectors, processes, and technologies that interact and collaborate.

DTs can enable smart grid functionalities such as monitoring and forecasting of assets, balancing generation and load, improved consumption estimation, aligned system operation across all grid levels, predictive system management.

To be effective, DTs should be focused on the reliability and security of electricity supply which heavily influence the actions and decisions of grid operators and must take under

consideration the shifting sector boundaries (increased electrification of mobility, buildings, and industry etc.).

Currently the digital world requirements are not as mature as they should be, with the transmission network digitalization being more mature than the distribution network. The adoption and integration of these technologies should be accelerated based on: User-friendly interfaces, Robust Computing Systems, Data Management and Analytics, Advanced algorithms (AI), Standardized data models.

The same is true for the physical world requirements: Systemwide rollout of measuring and communication devices, Remote controllable assets, Mature communications network, High performance computing systems and Scalable Infrastructure are needed for the full utilization of DTs.

The T&D Europe recommendations are:

1. Build out and upgrade hardware to leverage Digital Twins: Gateways, IoT sensors, wired + wireless network maturity, scalability of computing systems.
2. Enhance data availability, quality and interoperability. This can include, Data ownership and permissions clarification, Interconnectivity and avoidance of data silos, Data quality assurance, minimize transmission latencies, Flexible and Scalable IT infrastructure, Data Integration platforms, Adopt Single Source of Truth (SSOT) Concept).
3. Comprehensive deployment of Digital Twins in interconnected grids. This includes the development of a Data ecosystem, facilitating key information transfer, integrating lifecycle data for maximum asset liability, supporting cross-sector data exchange – including standardization of APIs.
4. Security and Privacy Concerns, and regulatory and compliance considerations: Implement robust cybersecurity measures, establish a clear data access framework, Address privacy concerns – safeguard sensitive data while maintain analytical value of the information, Conduct regular security assessments.
5. Support technical expertise and a motivated mindset: This can include several activities such as i.e. Encourage workforce upskilling, facilitate digital transition acceptance, promote awareness and prioritization e.g. of IoT devices,
6. Promote a Harmonized approach towards DT implementation across the EU and its Member States, i.e. monitor progress with Smart Grid Indicators (SGIs) across the Member States, develop a regulatory monetarization scheme to support and encourage Digital Twin adoption.

The TwinEU project will be developing federated DT architecture with an Energy Data Space approach, with security and privacy technologies implemented, addressing the above recommendations 2 and 4. This is also elaborated in Sections 3.6 - 3.7. The TwinEU will enhance significantly the technical expertise of system operators even with dedicated UCs e.g. FR01 Training Simulator, elaborated in Section 5 on the use cases

Several commercial products by big industry manufacturers leverage the benefits of digital twins. The **General Electric** is promoting “the GE digital grid solution” [25] that is based on advanced analytics leveraging AI and machine learning. The GE digital grid platform promotes end-to-end capabilities, native interoperability, advanced analytics, and the industry’s geospatial network modelling and management software.

The thematic areas of the platform provide digital solutions for planning, engineering, construction, distribution operations, transmission operations, vegetation management, network maintenance, field service & restoration. As disconnected data from various business process and operation can result in data disparities high response time, low observability and possibly errors, the digital twin developed for the electricity grid via the 'GE digital grid solution' platform can act as a single, complete network model—, from generation through transmission and distribution, including distributed energy resources (DERs), providing visibility and natively integrated applications and data, maximizing the value of grid investments.

GE Digital Grid delivers seamless integration across GIS, Outage Management System, and Advanced Distribution Management System, enabling workflow-driven integration across the entire business process. It streamlines the sharing of network model data across GE Digital Grid solutions, including advanced distribution management systems (ADMS), geospatial, mobility, grid analytics and more. It can also connect Distribution Optimization, Outage Response, and DER Orchestration, providing a holistic view of network resources. Based on their customers' feedback that have deployed a combination of GE Digital Grid's GIS and ADMS, there are substantial by the developed digital twin models in the IT/OT systems

Furthermore, Hitachi has launched IdentiQ [26], its digital twin solutions for high-voltage direct current (HVDC) and power quality solutions. IdentiQ is aiming to advance the world's energy system to be more sustainable, flexible and secure, accelerating the transition towards a carbon-neutral future. IdentiQ is the digital twin of a HVDC converter station, STATCOM or other power quality solution. It provides all the relevant asset information, analytics and operational data in an intuitive and easy-to-navigate dashboard, which users can customize to match their needs. IdentiQ includes 3D interactive visualization of the complete asset, combined with one-click access to all the associated plant and equipment information, including engineering documentation, operational and maintenance procedures, safety training and live operational data for monitoring and analytics. IdentiQ enables customers to improve the management of power grid assets by clustering all information into one digital location for seamless access by all operational functions.

The IdentiQ DT technology aims to make the HVDC and power quality grid assets:

- Sustainable and eco-efficient – by enabling comprehensive remote analysis and support and by digitalizing paper-based information on older installations;
- Flexible – by adapting to continuously changing asset performance needs over the entire lifecycle;
- Secure – by complying with industry-leading cybersecurity standards and protecting all asset data and information from being misplaced or destroyed; and safer, by providing virtual training on on-site procedures, required clothing and evacuation routes before visiting a site.

Moreover, Siemens Electrical Digital Twin [27] solution aligns real and virtual worlds by providing energy stakeholders with a single source of truth to model data across their IT landscape. Data is synchronized from various systems then standardized into one multi-user database via standards-based adapters / interfaces. The common network model facilitates grid simulation across all domains relevant for reliable, efficient and secure electrical system planning, operation and maintenance. The Siemens Electrical Digital Twin solution is vendor-neutral, highly customizable to specific needs and offers capabilities in the following areas:

- Transmission network model management across operations and planning
- Protection data management
- Streamlined renewable integration analysis using GIS data Siemens Electrical Digital Twin
- Automated operations planning case creation
- Data management for integrated T&D analysis
- Distribution planning model creation and synchronization with GIS, DMS, and MDM data

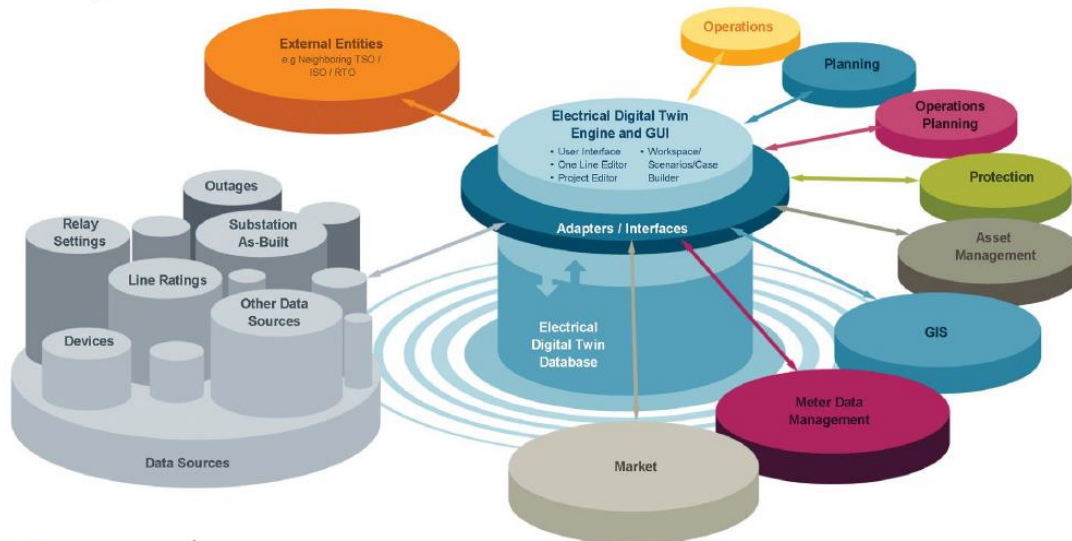


Figure 7: The Siemens Electrical Digital Twin ecosystem

Additionally, ENVELIO [28], as also one of the technology providers in the TwinEU project, offers a cloud-based digital twin tailored specifically to the needs of DSOs, with a particular emphasis on low- and medium-voltage networks. Unlike other solutions that often focus on transmission-level modeling or individual asset management, ENVELIO's Intelligent Grid Platform (IGP) targets data-intensive mass processes at the distribution level. It integrates and validates data from previously siloed systems such as GIS, MDM, and CRM into a central network model. Based on this, it enables modular use cases such as transparency on LV hosting capacity, scenario-based grid development planning, and streamlined connection request evaluations.

Moreover, by leveraging this central digital twin, ENVELIO introduces its PlanOps approach, which connects planning and operations teams through real-time data exchange. This ensures that both departments collaborate efficiently, share insights, and make informed decisions. For example, when a new heat pump is connected to the grid, the operations team can immediately assess its impact, providing valuable feedback to the planning team for refining long-term assumptions. This collaboration improves grid data quality, automates workflows, and enhances responsiveness—especially where distributed energy resources (DERs) significantly affect grid behaviour.

Lastly, Schneider Electric [29] is emphasizing their strategy and products on the systematic "value-driven" grid data management practices, that serve the electric distribution utilities by enhancing cost efficiency, reliability, resilience, sustainability, and affordability. The company provides model-driven grid management solutions for distribution utilities through

interoperable grid digital twins. These solutions are applied at the enterprise level, at the substation and feeder level, and at the connected asset level using its Digital Logbook, which is an online repository that keeps all equipment information, maintenance records, and project documentation received from all stakeholders in a more secure, easily accessible location. The logbook can be accessed using a variety of digital tools. For example, the digital logbook can be initiated by a panel builder using EcoStruxure™ Power Commission during switchboard construction. Then during the project handover, this digital twin can be shared with the contractor or directly with the utility. The digital twin enables personnel to keep record of important construction documentations, user guides, and maintenance schedules. This improves collaboration and insights, while lowering costs.

The EcoStruxure™ Grid focuses on 9 UCs for distribution utility functions: Asset Information Management, Distribution Analysis and Operations using network Model Management, Planning and Simulation, Asset Performance management and Asset Investment Planning, Substation Automation, Systems Engineering and Maintenance, Augmented Reality for System Operation, Maintenance, and Personnel Training.

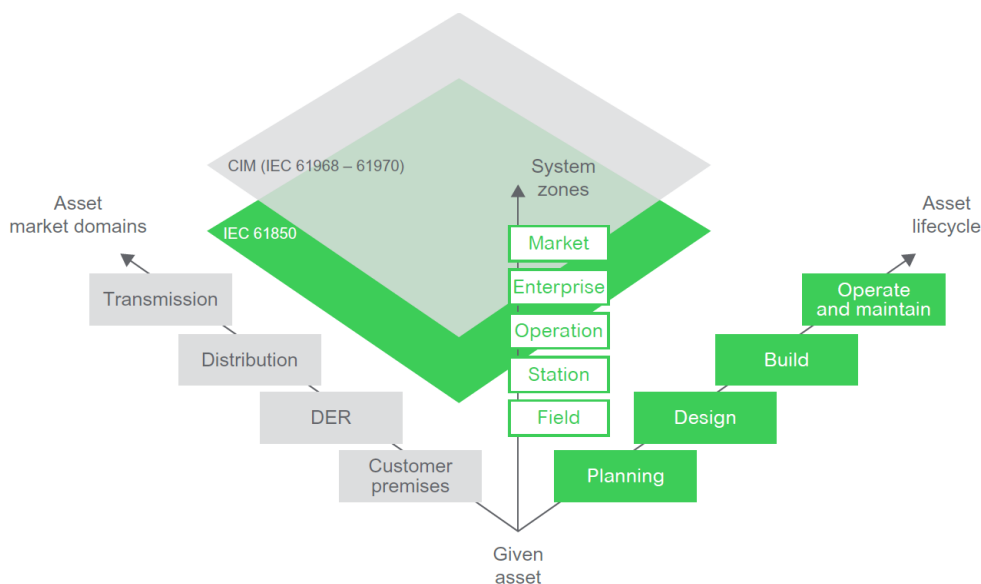


Figure 8: A digital twin for the electric grid can improve business process efficiency across multiple dimensions [Schneider Electric]

3.6 The federated DT architecture of the TwinEU project

The TwinEU architecture is designed to facilitate the seamless integration and virtualization of Europe's energy infrastructure using advanced DTs. By enabling these DTs to communicate and collaborate, TwinEU establishes a robust pan-European federated network. The overarching goal of TwinEU is to foster a resilient, reliable, sustainable, and innovative energy ecosystem, empowering efficient energy management and innovation across Europe. The TwinEU Reference Architecture is crucial in achieving these objectives, functioning as a standardized framework for seamlessly integrating DTs across diverse domains. By adopting a federated approach, it promotes dynamic collaboration among key stakeholders, including TSOs, DSOs, market operators, aggregators, and other entities within the energy ecosystem.

Furthermore, the architecture is designed with inherent flexibility, enabling it to address various multi-system UCs. It provides innovative modelling and simulation tools to evaluate

complex scenarios across the European energy grid, paving the way for more efficient, resilient, and sustainable energy management. The architecture supports advanced scenario modelling and simulation, enabling detailed and granular analysis of grid dynamics. This capability empowers stakeholders to comprehensively assess the effects of large-scale renewable energy integration, facilitating informed decision-making and strategic planning for a more sustainable and resilient energy future.

Regarding the interoperability of the system, by incorporating open standards such as NGSI-LD APIs, the Reference Architecture (RA) ensures seamless interoperability across diverse energy systems, creating a foundation for a robust and scalable data-sharing ecosystem. This standardized approach enables the comprehensive modelling of pan-European scenarios while effectively tackling the intricate challenges of grid operations and the interconnected energy markets, fostering efficiency and innovation across the continent. TwinEU architecture also adopts the Data Space structure regarding the data exchange and communication. By adopting Data Space architecture for DT federation communication, TwinEU significantly enhances data exchange capabilities, fostering greater visibility and seamless collaboration among stakeholders.

Through the integration of advanced data connectors and standardized models, the RA ensures secure, efficient, and transparent interactions between prosumers, network operators, and market participants. This approach strengthens trust, privacy, and cooperation across the energy ecosystem, enabling innovative solutions and driving sustainable progress. Finally, TwinEU's RA incorporates advanced tools for forecasting, anomaly detection, and identifying infrastructure bottlenecks, empowering stakeholders with the ability to engage in proactive grid planning. These capabilities enhance system flexibility and operational efficiency, resulting in a more reliable energy supply, significant cost savings, and a reduced environmental footprint, driving the transition to a sustainable energy future. A first description of the TwinEU RA will be finalized in deliverable D3.1 "TwinEU Open Reference Architecture ". For the scope of this deliverable there will be a brief, but comprehensive description presented in this section.

3.7 Core concepts

The TwinEU Reference Architecture contains the fundamental entity of the DT, the initial concept of the TwinEU Framework, a dedicated data exchange layer to facilitate cross-digital twin integration and cooperation and specific layer for AI and marketplace services, aligned with WP4 guidelines.

3.7.1 Digital twin federation

A fundamental concept introduced by the TwinEU architecture is the DT federation, envisioned as a network of interconnected local DTs that collectively form a cohesive system-of-systems. This concept is tasked with creating interoperable interfaces that enable seamless bidirectional data flow between physical and virtual entities. A principal element of this concept is the Adaptive DT which supports easily and effectively integration with various data sources and infrastructures independently of the structure and the format. By integrating with an extended version of the OneNet Connector (Onenet4DT), the DT federation layer leverages IoT, edge computing, and edge nodes to exploit data sources and devices effectively. This concept not only lays the foundation for the European DT network but also represents the first step toward building an integrated data value chain. This chain spans from the physical

layer through the federation and orchestration of data assets to targeted grid services and applications. At the core of this network is the DT Federator, a pivotal element designed to provide higher architecture layers with an advanced framework capable of:

- Integrating heterogeneous network models encapsulated within national DT clusters,
- Orchestrating data sharing and exchange processes among these clusters, and
- Incorporating real-world data to enhance simulation and analysis capabilities.

This holistic approach fosters collaboration, innovation, and efficiency across Europe's energy ecosystem, enabling a resilient, sustainable, and integrated energy future.

3.7.2 Data Space structure

The dataspace-enabled structure for data and model sharing forms a critical element of the TwinEU architecture. It involves the adaptation of the Energy Data Space to the specific context of TwinEU's DT network, creating a trusted and sovereignty-preserving layer for data and model exchange. This Data Space architecture incorporates a middleware that stands on top of the common infrastructure, ensuring secure and standardized communication between assets, systems, data sources, models, and energy stakeholders. This middleware facilitates seamless, efficient, and transparent sharing of data across the entire ecosystem. A key element of the TwinEU architecture framework is the extension and adaptation of the [OneNet framework](#). This framework will serve as the bridge between the DTs and the external environment, enabling the smooth and agnostic transfer of data and models both to and from the DT network. By ensuring compatibility and seamless flow of information, the OneNet Connector will play a vital role in driving efficient data integration and exchange across the energy sector. The OneNet Connector will be extended to support DTs context, keeping its core characteristics which allows us to implement a complete decentralized end-to-end data exchange while maintaining full control over data access and usage.

3.7.3 Service Workbench and AI tools

The TwinEU Service Workbench serves as a comprehensive platform where DT applications and services are developed, made available for future adaptation, and can be easily reused by other developers or third-party contributors. It provides access to a wide range of resources, including data storage, real-time computational capabilities, and the full IoT/edge/cloud continuum, as well as High-Performance Computing services, all orchestrated through a Service Orchestrator. This element is responsible for presenting and describing the federated pan-European services and applications, highlighting their interrelationships from an architectural perspective while ensuring alignment with compliance requirements and business objectives. It is particularly important for the development of advanced data-driven tools and applications that support the energy ecosystem.

The structure of the service workbench is designed to be modular and adaptable, allowing it to evolve over time. This flexibility enables it to integrate system changes such as the introduction of new components, interfaces, and connections to other services. At its core, the service layer promotes a decentralized and federated approach, ensuring that DT deployment can meet the needs of various stakeholders, from local to national, regional, and at the European level. This approach fosters scalability, resilience, and collaboration across the entire energy infrastructure.

3.7.4 TwinEU Reference Architecture

The TwinEU Reference Architecture serves as a blueprint for the TwinEU project, providing a standardized structure that guides the design, implementation, and operation of the project's system. The RA aims to enable consistency and scalability across all the TwinEU components, ensuring that the solution aligns with the objectives of the project, the requirements of the stakeholders, and adopts state-of-the-art practices. The TwinEU RA attempts to outline key components, such as core functionalities, data flow mechanisms, integration patterns, and interoperability standards, presented in diagrams and technical details. For the scope of that deliverable, the following high-level abstract diagram is presented that describes the core TwinEU components and layers.

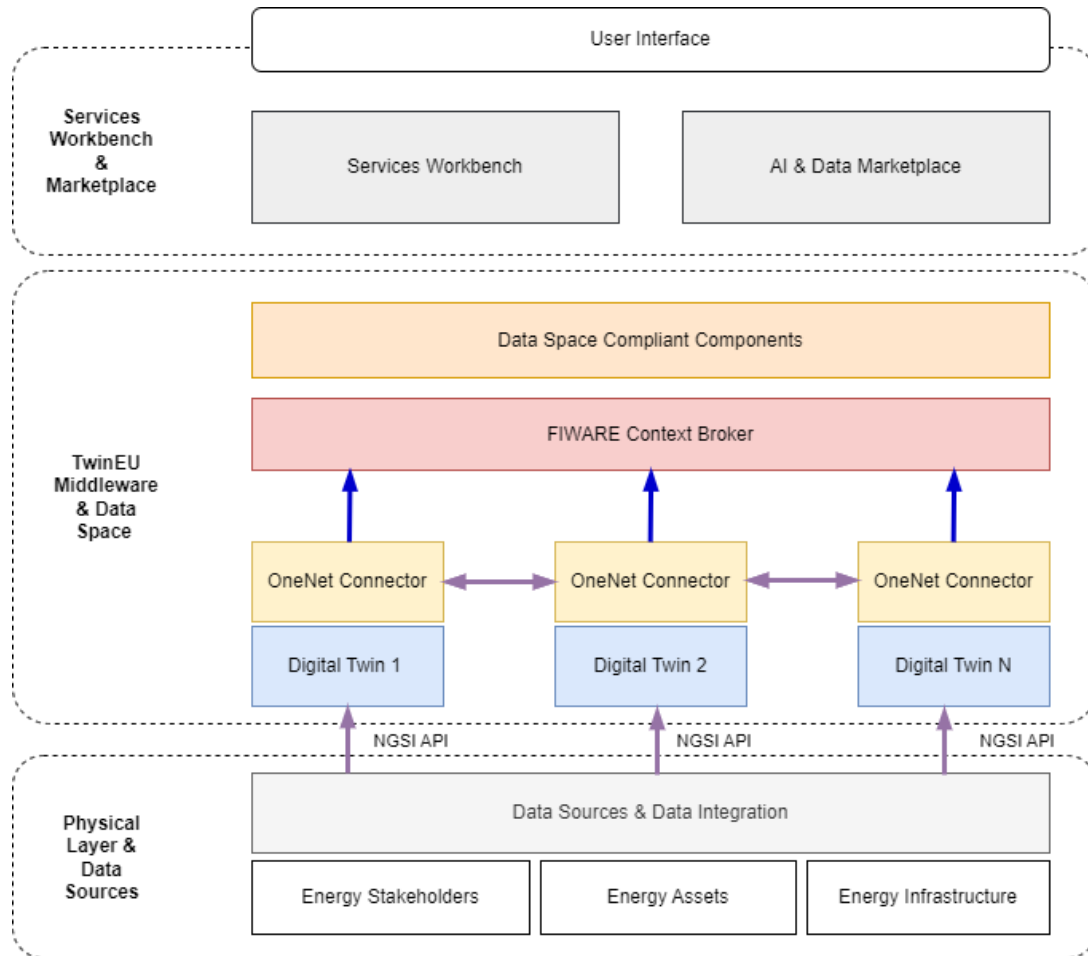


Figure 9: TwinEU architecture concept

As is shown in the diagram above, the initial TwinEU RA is structured into three logical layers:

Bottom Layer – Physical Layer & Data sources: This layer includes data sources, infrastructures, energy assets, energy stakeholders, TwinEU participants, and integrated data sources. The aforementioned entities and data sources of the TwinEU project are officially integrated in the TwinEU through Digital Twins that are connected to a specific OneNet Connector and constitute a data exchange network.

Middle Layer – TwinEU Middleware and Data space: This layer establishes the foundation of the TwinEU Data Space ecosystem, serving as the cornerstone for the creation of the

TwinEU Federation. It encompasses all Digital Twins actively engaged in data exchange and model sharing, seamlessly integrated through the OneNet Connector for DTs. As mentioned above, this interconnected framework ensures efficient collaboration and interoperability across the ecosystem, driving innovation and enabling the realization of a federated and cohesive Digital Twin network. The management and governance of the interconnection and data exchange takes place within the TwinEU Middleware which provides administrative components and services.

Additionally, to organize the integration with data space, this layer includes the alignment between the TwinEU Reference Architecture and the core components of the Data Space. The primary objective of the Data Space is to enable the efficient, secure sharing of data while maintaining control over the conditions of its exchange. These goals align seamlessly with the objectives of TwinEU, where a federation of Digital Twins can generate additional value through collaborative data exchange. To achieve these goals, a series of foundational building blocks and principles must be established. These concepts and principles are outlined below:

- **Data Sovereignty** ensures that data owners retain full control over how their data is used. This includes the ability to define and enforce specific usage policies, enabling compliance with the unique legal and regulatory requirements of each participant.
- **Decentralized Approach**, adopting a distributed model where data resides with the owner until it is shared with trusted parties. This approach eliminates the need for centralized storage, with sharing occurring in a strictly peer-to-peer manner between the provider and authorized consumers.
- **Interoperability**, using standardized protocols and information models to facilitate seamless data exchange across diverse systems and domains. This ensures compatibility and efficient integration, regardless of the underlying technology stack.
- **Trust and Security**, embedding robust mechanisms to establish trust among participants, such as certification processes and advanced security measures. Digital identification and the traceability of data transfers are pivotal in ensuring transparency and accountability, fostering a secure and trustworthy environment for data sharing.

Top Layer – Services Workbench and Marketplace: Defined as the TwinEU Framework, this layer serves as the core value-adding layer of the TwinEU Reference Architecture. It integrates all the components listed for implementation in the deployment stage within WP4, accompanied by comprehensive specifications. These include guidelines for service orchestration, workflow monitoring, data harmonization, the development of ontologies, data modeling, advanced analytics, and other critical services and functionalities that are planned to satisfy the TwinEU UCs.

4 TwinEU pilot technologies conditions and technical requirements

4.1 Methodological approach for the definition of TwinEU's key digital technologies boundary conditions and high-level requirements

Task 2.3 aims at delivering a set of requirements for the seamless coordination and cooperation of DTs within the TwinEU continuum. Considering that the task started in M1, a holistic approach had to be designed to accompany pilot partners and technology providers through the earliest stages of the project to define these requirements and boundary conditions in parallel to the development of other key foundation tasks such as the definition of the project UCs and the KPIs.

The project defined a four-step methodology that assessed the technologies and communication flows already in place as well as the necessary further developments to be in the position to implement and undertake the proposed use cases. That process included an exhaustive analysis that examined constraints in existing DTs and restrictions when employing the foreseen digital technologies. The outcomes of that gap analysis drew a blueprint on which should be the final development and configuration status of the Pilots.

The last step of the methodology provided the main outcomes of the task focusing on identifying a set of requirements ensures seamless coordination and cooperation of DTs within the TwinEU continuum.

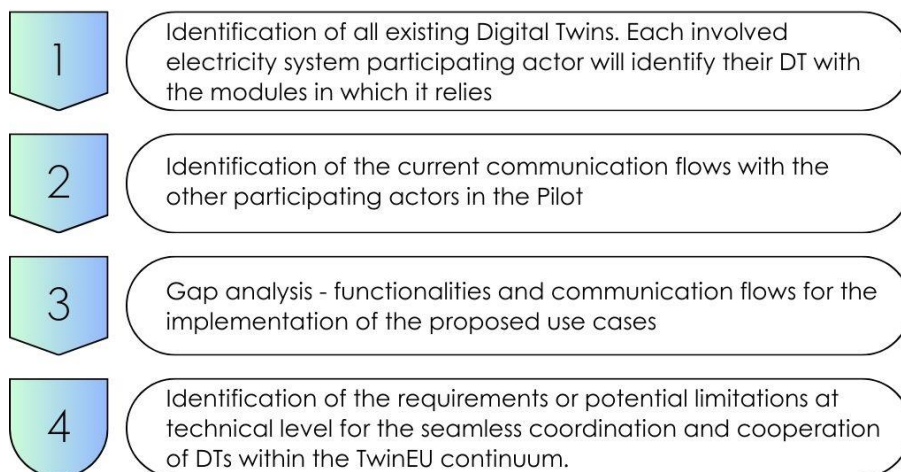


Figure 10: Four-step methodology followed for the development of T2.3

4.2 Summary of technologies involved and communication flows and their gap analysis result per pilot

This section is a detailed report on the implementation of DTs in various interconnected European electricity regional systems as part of the TwinEU ecosystem. It focuses on different pilot sites across multiple countries, including Spain and Portugal, the Eastern Mediterranean Pilot (Greece and Cyprus), Hungary, Bulgaria, Germany, Italy, Slovenia, the Dutch-French Pilot.

Each Pilot Site outlines the configuration of their collaborating DTs, the partners involved, and their roles as well as how these digital twins and systems interact with each other, covering established and planned communication flows between TSOs, DSOs, MOs, and any other Market Players or service providers.

GAP Analysis: An assessment of the existing challenges, missing technologies, and functionalities needed to fully implement the TwinEU ecosystem.

In essence, the document provides a technical and strategic roadmap for deploying Digital Twins to enhance grid management, market operations, and energy system interoperability across Europe.

4.2.1 Iberian Pilot Site

The Iberian Pilot in TwinEU brings together actors across the whole value chain in the Iberian electricity system.

At transmission level, REE (Red Eléctrica De España) is the TSO demo partner in the Spanish side of the Pilot, operating its Transmission System DT as end-user and is supported by CIRCE for some of the technical developments required for the demonstration of TwinEU's DT-based Use cases. In the case of the Portuguese side of the Pilot, REN (Rede Eléctrica Nacional) is the TSO demo partner and DT end-user and operator, supported by R&D NESTER on the IT side concerning their DT. Additionally, INESC-TEC implements an upper-level DT of the Iberian electricity system in connection with the Central-European System.

At market level, OMIE is the NEMO, DT operator and end-user, as well as its IT provider.

At distribution level ETRA is the main developer of ÉTER, which is the core of ANELL's DT. ADAION will take part, along with Cuerva as main developers of Cuerva's DT. Additionally, two more DSOs, electricity producers and retailers, are part of the Iberian Pilot as Associated Partners without involving any DTs for the demonstration activities, (represented through their DSOs in their holding respective groups) i-DE and EDRD.

Gap analysis summary for the involved technologies and DTs in the Iberian Pilot

This section summarizes the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

REE's Transmission Grid DT

The two DTs to be developed and tested under Spanish transmission system aim to work in the identification of one of the biggest challenges for power system operation: to enhance system development and operation under massive presence of variable renewable power generation.

- **DT Renewable resources profiles tool:** this tool aims to be a digital twin of renewable power resources used in power system studies and analysis. The main idea behind this DT is to be able to forecast different synthetic profiles of renewable generation that can be used as an input in multiple other power system tools that use as input renewable generation resources data – accuracy of the input data is determinant. In particular, the synthetic series will be used as input for planning decisions and for probabilistic operation scenarios generation.

- DT Control Centre and remedial actions identification: the increase of massive variable renewable energy to decarbonize the power sector introduces a relevant increment in the complexity of decision-making for power system operation and control centre operators. Incorporation of new technologies such as AI can represent an improvement in the decisions to be made in this framework, and this is the idea of this DT: to explore application of AI to support decision making in control centre for effective and secure power system operation.

REN's Transmission Grid DT

The demonstration of the use case (UC) UC Ib10 in the Iberian pilot aims to enable the development of digital twin to model a probabilistic cross-border capacity estimation tool for coordinated cross-border capacity allocation between the Portuguese and the Spanish control areas. Additionally, UC Ib11 will provide a flexibility needs assessment tool that will exploit possible scenarios for cross-border pre-qualification and flexibility provision to solve the identified needs and, expectedly, improve the consumption of renewable energy by reducing curtailment. Within the federation framework of the TwinEU project, a federated digital twin will also be developed to simulate the functionalities of a TSO-DSO-MO-Prosumer framework in UC Ib12. The UC Ib13 will improve the models for short-circuit analysis at the TSO-DSO interface.

Hence, there is the need to improve the tools for probabilistic cross-border capacity estimation, flexibility assessment and short-circuit analysis at the TSO-DSO interface, while developing an appropriate data exchange mechanism enabling the connection of the DTs within the same control area (namely Portugal), as well as, the connection of the Digital Twin for cross-border probabilistic capacity allocation and flexibility assessment with the Digital Twins of the adjacent control areas (in this case only Spain, which we propose to do by using ENTSOe's TYNDP data) and with the Digital Twin of the Iberian Market Operator.

OMIE's Electricity Market DT

OMIE, as a MO, is actively participating in the use case related to cybersecurity in energy markets. The great challenge in the implementation of this use case is the coordination among all the stakeholders involved, especially the DSOs involved in the LFM UCs (ANELL), to evaluate a communication and action plan against cyberattacks.

ANELL's Distribution Grid DT

The integration of digital-twin based models of renewable energy generation plants for reinforced forecasting of the electrical distribution grid export-related parameters is yet to be performed in ÉTER for ANELL's grid.

This integration will allow UC-Ib06 to undertake different plant topologies and will leverage the potential of the DT at distribution level to provide a pre-validation stage for connection points for renewable energy plants being requested in different nodes of the grid.

Cuerva's Distribution Grid DT

The analysis of the DT distribution network highlights several gaps that need to be addressed to fully leverage digital twin technologies and improve network operations, renewable energy integration, and cybersecurity.

Ib08 - Long term flexibility in MV: ADAION has developed an algorithm for calculating short-term flexibility requirements in low voltage. Specifically, it forecasts short-term congestion problems, determines the flexibility requirements needed to solve them, and analyses the flexibility offered by the area's distributed resources to propose solutions to these requirements. However, the solution has not been extended to the case of medium voltage, nor has the algorithm been developed for long-term estimates.

Ib09 - Flex Connections: As part of the ADAION planner for charging stations, the solution analyses the maximum charging power limits (which would be the basis for determining flexible connections in Smart Charging systems). However, ADAION does not currently have solutions for planning and/or operating with flexible connections.

INESCTEC's Iberian Electricity System high-level DT

The UC Ib03, within the Iberian Pilot, relies on the development of a DT that accurately represents the dynamic behaviour of the Iberian System interconnected with the central European system. The DT enables the assessment of the frequency stability of the Iberian System when facing significant disturbances.

The adherence of the DT to the Iberian System dynamic behaviour is highly dependent on proper parametrization. Therefore, calibrating the DT using a parameter estimation methodology that tunes the model frequency response with the real system frequency response during large disturbances is crucial for the DT accuracy.

An initial parameter identification (involving evaluation of inertias, dampings, generating units' droops and synchronizing coefficients) was performed exploiting real data of the Iberian System frequency behaviour during a disturbance related with the sudden loss of 1 GW of Active Power, following the disconnection of the Almaraz II Nuclear plant in October 2011. The relevant system parameters can afterwards be modulated using engineering judgment to evaluate the frequency behaviour for the scenarios of future years.

To demonstrate the proposed UC Ib03, the current version of the DT must undergo further calibration throughout the project using more recent data from frequency behaviour in the Iberian system and Central European system following large disturbances. Access to the Iberian System and Central European System frequency behaviour data poses as a pivotal requirement for the quality of the results obtained when using this DT.

Communication flows overview and gap analysis in the Iberian Pilot

TSO-DSO communication

In the framework of TSO-TSO collaboration, the Iberian Pilot partners have a set of already existing communication flows established.

- **For the purposes of Network Planning:**

REN published the 2024 Interchange Capacities for Commercial Purposes [30]. This document is the result of calculations that determine the maximum limit of power interchange that can be expected during the year based on different scenarios of performance for both the Portuguese and Spanish grid. The procedure is further detailed in a joint agreement between REN and REE which stated that the operators will need to exchange among them the following information:

1. Grid Topology
2. Generation/Consumption Scenarios
3. Generators' merit order under import and export scenarios
4. Maintenance plan for grid elements and generators

In addition, the document Interconnections Characterization [31] published by REN, details information regarding transmission lines in the Portuguese grid including those connected to the Spanish grid where aspects such as summary of the interchanged power, events and future plans are presented. In relation to the last topic, calculations are being undertaken to find maximum capacity of the interconnections. For that, it is mentioned that both Portuguese and Spanish system operators need to interchange monthly information relative to forecast generation that could affect the calculation previously mentioned.

From REE side, they presented the Transmission Grid Development Plan for 2021-2026 [32] where they aligned the planning of the grid in terms of environmental goals alongside with Ministry of Ecology. One of the assumptions on which many of the calculations were based is to determine the actual state and capacity of interconnections with other grids. In particular, the need for the detailed Portuguese transmission grid as planned in the year 2025 is mentioned. With the previous information, it is possible for REE to “identify the needs for improvement and development of our (REE) transmission grid”. Furthermore, joint plans for coordination among system operators from Portugal and France, including a revision of generators dynamic Power System Stabilizers are mentioned.

- **For the purposes of Operational Planning:**

TSO-TSO operational planning activities specifically refers to the day-ahead and intraday capacity calculation, day-ahead congestion forecast until real-time operation security management. This data helps both TSOs plan for grid stability and energy transmission based on predicted electricity demand and generation.

For the SWE TSOs (REN and REE) Spain-Portugal interface, at the end of 2019, Coreso was officially appointed as the Coordinated Capacity Calculator (CCC). In 2019, Coreso was able to provide D-1 (Day-Ahead, i.e. one day before real time) Security Analysis and coordination services every day for the eleventh consecutive year. Since 2009, the SA services in Coreso have been set up bilaterally with the TSO shareholders. RCCs receive information from TSOs, perform advanced analysis and recommend to TSOs relevant remedial actions for cross-border exchanges. They also coordinate with other adjacent RCCs, especially for the short timeframes.

For the day-ahead market time-frame, individual values for cross-zonal capacity for each day-ahead market time unit shall be calculated using the common capacity calculation methodology started in D-2. For the intraday market timeframe, individual values for cross-zonal capacity for each remaining intraday market time unit shall be calculated using the common capacity calculation methodology performed in the end of D-1 on Day-ahead Common Grid Model. Considering the geographical and electrical distance between the SWE CCR and all other CCRs, the power flow capability of critical network elements will not be shared among different CCRs [33].

A dedicated telecommunication network enables TSOs to provide RCCs with their most updated grid data. Then RSCs are in the position to monitor the quality of the data provided

and convert it into a unique common grid model. Finally, RCC uses this model as reference for all services provided and makes it available for all TSOs and other RCCs.

1. Step1: Each TSO delivers a dataset which includes their best detailed forecasts. This dataset is called Individual Grid Model (IGS). Each individual grid model shall represent the best possible forecast of transmission system conditions for each scenario specified by the TSO at the time when the individual grid model is created.
2. Step2: Then, the RCC merge these Individual Grid Models into a Common Grid Model to get an overview of the interconnected European grid.

The document [34] from REN, details the sharing of technical information related to the capacity and operational status of interconnections between Portugal and Spain. This includes data on the thermal limits of interconnection lines, the maximum and minimum power transits, and the actual use of interconnection capacities. Additionally, updates on network element availability that could influence interconnection capacities are shared.

The operators of the system, REN and REE, exchange information regarding the predicted generation that could influence the capacity of the interconnection on a weekly basis. This includes updates about the availability of network elements that may impact the interconnection capacity, with inputs required by 3 PM every Tuesday for the following week. Moreover, the document mentions that capacities for commercial interconnection purposes are communicated mutually every Thursday by 1 PM for the two weeks ahead, starting from the subsequent Saturday.

For capacity calculations, SWE Region TSOs must monitor operational security limits and network contingencies that are significantly affected by cross-zonal power exchanges. They must annually update the selection of critical network elements and contingencies through a sensitivity analysis. This analysis considers various network states such as the base case, post-contingency, and following the activation of remedial actions in line with information available at article 17 in SWE TSO Common Capacity Calculation methodology document [35].

The implementation of the Capacity Calculation process in this CCR is the first using the Common Information Model (CIM) format. The Day-Ahead Capacity Calculation (DA CC) process performs the calculations for 4 hours and then, those results are extrapolated to 24 hours of the day. As part of the process, TSOs can validate the results provided by Coreso and to consider latest information appearing since the beginning of the computation process. Results from the calculation are published by TSOs ex-post on a weekly basis to facilitate the transition of market parties from weekly to daily calculations [36].

REE and REN will both define generation and load shift keys based on a merit order list, aimed at accurately forecasting market behaviour for each market time unit, incorporating all loads and generations eligible for balancing markets. Additionally, REN will specify load shift keys for loads not participating in balancing markets, proportionate to base case scenarios for each market time unit, reflecting REN's best market behaviour forecast.

REN and REE shall coordinate, prior to the capacity calculation, the remedial actions that can be shared with each other to maximize the available cross-zonal capacities for the PT-ES border with market time unit resolution and review the list of remedial actions at least once a year.

For every market time unit, SWE TSOs (REE and REN) shall provide the following information daily using standard channels for delivery of information to market participants (such as the JAO platform) one hour before the day-ahead market gate closure time:

- TTC – total transfer capacity
- NTC – Net transfer capacity
- The most limiting CNE - Critical Network Element (only one)
- Fmax of CNE in MW and its location
- Zone to Zone Power Transfer Distribution Factors (PTDF) for each CNE associated with a contingency used in capacity calculation (CNEC).
- Margin from coordinated capacity calculation (MCCC) of the CNEC.
- Margin (%) = MCCC/Fmax
- Margin available for cross-zonal trade (≥ 70 : YES, otherwise NO)

Table 1: Data exchanges between RSCs and TSOs for Operational Planning

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
REN/REE and CORESO			
Daily capacity calculations using the Common Grid Model (CGM)	Daily	REN and REE > CORESO (and vice versa)	CGM via Operational Planning Data Environment (OPDE)
Updates on generation and load shift keys (based on merit order list)	Daily, before day-ahead market time frame	Mutual between REN and REE > CORESO	Not specified
Updates on network element availability impacting interconnection	As required for capacity updates	REN and REE > CORESO	Not specified
Remedial actions in capacity calculation	As needed, with changes reported in a timely manner	M Mutual between REN and REE > CORESO	Not specified
Between REN and REE			
Updates on planned and unplanned unavailability of network elements impacting interconnection (are validated before passing on information to CORESO)	As needed, with updates reported in a timely manner	Mutual between REN and REE	Email
Predicted generation and influence on interconnection capacity	Weekly (and Monthly)	Mutual between REN and REE	FTP

Commercial interconnection capacities	Weekly (every Thursday for the following two weeks) and Monthly	Mutual between REN and REE	Not specified

In the framework of TSO-DSO collaboration, the Iberian Pilot partners have a set of already existing communication flows established.

Attending to the time scale at which communication between TSO and DSO happens, we can devise three typical methods currently used for communication: Automatic, Market platform, and others (mostly file-based through email).

Automatic: TSO has an equivalent model of the distribution observable grid modelled in its control system. As such, measurements and grid status from the distribution observable grid reach the control centre in real time.

Market: The TSO's market platform provides the market players and others with an interface to communicate with the TSO. This platform also contains mechanisms for the DSOs to interact with the TSO for several scenarios such as the resolution of grid technical restrictions according to the grid codes.

Others: Lower frequency interaction such as sharing the planning grid or other types of communication happen through file sharing via email with agreed upon data formats.

Table 2: Data exchanges categories between TSOs and DSOs

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Measurements and grid status from the distribution observable grid	Real time	DSO > TSO	TSO's centralised control system
Resolution of grid technical restrictions according to the grid codes		TSO > DSO	ESIOS
Grid planning information	As needed	Bidirectional	Email

TSO-MO communication

The communication system among System Operators (SO) and Market Operator (MO) in the MIBEL bidding area (Spain and Portugal) is based on access via WWSS protocol to a cluster of servers of the System Operators' Information System. WWSS service is mounted on a high availability cluster. Communications use dedicated communication lines to guarantee continuous operation and, in the event of failure, a short period of unavailability.

Table 3: Data exchanges between TSOs and MO

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Result of the matching of the day ahead market, intraday or continuous intraday auctions, which will be communicated to the corresponding SO.	Daily / 6 times per day / h -55'	MO -> TSO	dedicated line
Confirmation of the result of the Technical Restrictions Resolution process to MO.	Daily / 6 times per day / h -55'	TSO -> MO	dedicated line

Information exchange between System Operator and Market Operator is based on “schedules”. These schedules correspond to files that contain the hourly schedules of the programming units of the Spanish or Portuguese peninsular electrical system for a specific period of a certain day with the energy matched in each market session round of the following markets:

- MO Day-ahead market
- MO Intraday auction market
- Closing of Continuous intraday market round
- Resolution of SO Technical Restrictions to the base daily operating schedule.

Exchange of schedules must be communicated to the other operator as soon as it has been completed and has been resolved according to the times stipulated in the market rules.

Table 4: TSO-MO communications

Communication	Communication publication (indicative)
Matching up	≤ 13:00
PDBF	≤ 13:30
PDVP	≤ 14:45
Intraday 1	≤ 15:06
PHF-1	≤ 16:45
Intraday 2	≤ 17:56
PHF-2	≤ 19:45
Intraday -3	≤ 21:56 D
PHF-3	≤ 23:45 D
Intraday -4	≤ 01:56 D
PHF-4	≤ 03:45 D
Intraday -5	≤ 04:56
PHF-5	≤ 06:45 D
Intraday -6	≤ 09:56 D
PHF-6	≤ 11:45 D
Intraday (Continuous)	≤ H - 55
PHFC	No application

The communication happens via the control system, the ESIOS [37] platform and email.

MO-Market Player communication

Technology Web Services for any market participant who wants to connect automatically to the energy auctions.

If the market participant wishes to increase the degree of automation of its processes by creating a connection between its systems and the OMIE system, it must carry out development to include Web Services technology.

OMIE facilitates this integration by providing a client interface (API) - with source code included - that can be used in the integration, minimizing, and facilitating the necessary adaptations.

Services for trading in the markets through the Web Services interface.

The services that have been implemented to use the SIOM functionalities and that can be invoked through the Web Services interface are:

- Insertion of operational data (offers, disaggregation, committed energies)
- Queries for sent data.
- File download.
- General inquiries about market information
- Notification services for newly published information

Gap analysis summary for the Iberian Pilot

DSO-MO communication

The main identified gap in for the Pilot implementation and use cases demonstration is related to the communication between the MO and the DSOs.

The Digital Twins of the distribution grids will be able to communicate with the digital twin of the Local Flexibility Market for grid planning purposes or for activities related to the cyber-resilience of the grid.

For such purposes, the communication in between the client (DSO's DT) and the Local Trading system – LTS (MO's LFM DT) will be established through the AMQP protocol. Most likely, the AMQP server utilised will be RabbitMQ, and the content of the messages, both sent and received, will be modelled in JSON format.

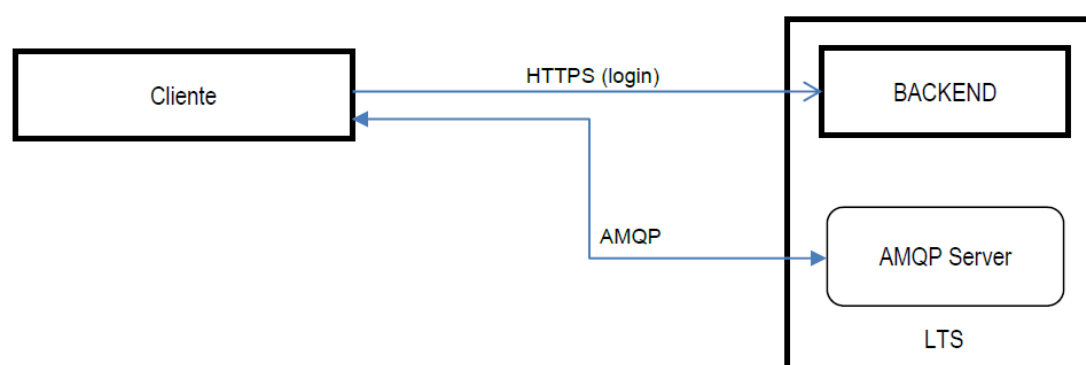


Figure 11: Client-server scheme example

As per the information exchanged in relation to the grid planning activities, in the case of the distribution level, it is focused on the settlement of Local Flexibility Markets that enable, based on an active response from the demand, higher capacities in the grid. More specifically, the main information exchanged will be:

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Request for the opening of a LFM session	On-demand	DSO -> MO	tbc
Confirmation of the LFM session opening	On-demand	MO -> DSO	tbc
Flexibility request and zones able to bid in the session	On-demand	DSO -> MO	tbc
Result of the LFM clearing process	On-demand	MO -> DSO	tbc

Table 5. Data exchanges between DSOs and MO

The specific information exchanged for enhancing the cyber-resilience of the Distribution Systems cannot yet (at this stage of the use cases definition – business use cases) be defined.

4.2.2 Eastern-Mediterranean Pilot Site

The Eastern Mediterranean Pilot Site brings actors from across the entire electricity system value chain in Greece and Cyprus. The involved partners and their role in the Greek implementation of the TwinEU Continuum are:

HENEX (Hellenic Energy Exchange) as responsible for the development of the day-ahead module of the Electricity Market DT (data, assumptions, coding).

UPRC (University of Piraeus Research Centre) that will coordinate the overall implementation of the Greek DT, develop the balancing market module of the Electricity Market DT and run different scenarios on the needs of market participants and system operators. UPRC collaborates with 3SI, TGT, CINT in developing the scenarios for the market services integration, network modelling and power system analysis.

IPTO (Independent Power Transmission Operator) as developer and operator of the Greek Transmission System DT and will also provide the necessary technical data.

HEDNO (Hellenic Electricity Distribution Network Operator) as developer and operator of the Greek Distribution System DT.

RAAEY (Regulatory Authority for Waste, Energy and Water): RAAEY will provide information regarding the applied regulatory framework of the balancing market operation and regulatory market recommendations.

The involved partners and their role in the Cypriot implementation of the TwinEU Continuum are:

UCY (KIOS Centre of Excellence), responsible for the Cyprus digital twin implementation and operation, development of solution for facilitating the integration of real time measurements to the digital twin. UCY collaborates with 3SI, TGT, CINT in developing the network modelling, coordination with the interconnected market and power system analysis.

Transmission System Operator Cyprus is responsible for the provision of data (measurements, network topology and parameters) for the Cyprus transmission system.

Electricity Authority of Cyprus (DSO Cyprus, Owner of the Cyprus power system) is responsible for the provision of data (measurements, network topology and parameters) for the Cyprus distribution grid.

Gap analysis summary for the involved technologies and DTs in the Eastern Mediterranean Pilot

This section summarizes the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

DT of the HVDC interconnection between the mainland Transmission System of Greece and the insular Transmission System of Crete

The HVDC electrical interconnection between the island of Crete and Attica is the first HVDC grid in the Mediterranean that uses the most advanced converter technology of the Voltage Source Converter (VSC) type. This interconnection is currently the largest investment in electricity transmission to take place in Greece, with the goal of ensuring Crete security of supply enabling export of the vast RES island potential and shutting down conventional power stations. The interconnection consists of two submarine HVDC cables, approximately 328 kilometres long, with a rated power of 1000 MW in bipolar operation (2 x 500 MW). This is one of 5 projects (with VSC technology) with the highest voltage (500kV) in Europe and a transmission capacity of 1000 MW, which is the highest in Europe for interconnection with an island.

The project is expected to be completed in June 2025, in which extensive testing and validation period. Key gaps include the need for enhanced sensor networks along the transmission line for real-time data acquisition, integration of existing SCADA systems with the DT platform, and advanced modeling tools to simulate environmental impacts, load variations, and system behaviour under various scenarios. Additionally, improvements in data governance, ensuring data quality and consistency, and upskilling personnel to manage and operate the DT are essential for the full realization of the system's potential. Addressing these gaps will enable the digital twin to optimize operations, improve fault detection, and provide predictive insights for the HVDC interconnection.

Greek Transmission System DT

Limited Real-Time Monitoring and Automation: Although IPTO has implemented SCADA systems, there is limited real-time monitoring and automation in certain parts of the transmission network. This hampers the ability to quickly identify and respond to faults or fluctuations, reducing operational efficiency and increasing downtime in case of failures.

Coordination between TSO-DSO: As distributed energy resources (e.g., rooftop solar, wind) increase, coordination becomes even more critical to balance the intermittent nature of renewable generation at both distribution and transmission levels. Without effective cooperation, it becomes difficult to predict generation patterns accurately, leading to imbalances, congestion, and potential curtailment of renewable energy.

These gaps can slow down progress and limit the ability to create a coherent and well-functioning transmission network.

Greek Distribution System DT

After the balancing market has cleared, the DSO can perform a post-processing step to identify any congestion issues that may arise from the accepted bids. This involves analysing the impact of the scheduled activations on the distribution grid. If the DSO detects potential overloading of lines or transformers, it can request adjustments to the balancing market results. This may involve:

- Rejecting or modifying bids that would exacerbate congestion
- Activating additional bids to relieve congestion, even if not selected in the balancing market

In parallel, the DSO can provide the balancing market with information about distribution grid limitations. This allows the market to take congestion into account when selecting balancing bids.

The DSO can specify the limits on the total amount of upward or downward regulation that can be activated in a congested area and the specific bids that are limited or prohibited from being activated due to grid constraints. By providing this information, the DSO ensures that the balancing market selects a portfolio of bids that is feasible from a distribution grid perspective.

However, there are some challenges with this approach:

- The DSO must have sufficient visibility and control over the distribution grid to accurately specify limitations
- Providing limitations may reduce the liquidity and efficiency of the balancing market
- Coordination between the DSO and TSO is critical to ensure a coherent process

Cyprus Power System DT ecosystem

In order to have a realistic implementation of the TwinEU ecosystem in the Eastern-Mediterranean pilot site the following areas are identified as being important (in the national and regional level) for the Cyprus digital twin through the Gap analysis that was performed.

In the case of the national level (Cyprus digital twin) the following requirements are identified:

- **Stability of the Cypriot digital twin:** The Cypriot digital twin was implemented in an electromagnetic (EMT) simulation framework to have a realistic response of the Cyprus digital twin in grid disturbances and captures the dynamics of the system during faults. However, the realistic models of the two power stations (including the dynamic models of synchronous generators) should be fine-tuned in order to ensure the stability of the grid under any frequency and voltage events.
- **Incorporation of live PMU and SCADA measurements to the digital twin:** PMU measurements are available from 18 substations of the actual Cyprus power transmission system. These measurements should be seamlessly integrated to the Cyprus digital twin transmission grid to replicate realistic operating conditions to the digital twin framework. In the same context, SCADA and smart meter measurements will be incorporated to the distribution grid digital twin to emulate realistic conditions at the distribution level as well.
- **Development and integration of the HVDC link:** Detailed development of the HVDC link in an EMT simulation framework including grid forming and grid following capabilities for the power electronics converters. Integration of the HVDC link model in the already existing digital twin and validation of the proper functionality of the Cyprus digital twin.
- **Emulation of Ancillary services market:** Emulation of an ancillary services market that is dedicated for the Cyprus distribution grid digital twin. This market will trade the provision of congestion management services from the FSPs at the distribution level.
- **Development of a DSO-level controller to coordinate FSP for congestion management:** At the DSO, a real-time controller will be developed to coordinate the

activation of the available active and reactive power flexibility by FSPs in a cost-effective manner to relieve congestion.

In the case of the regional level (interconnection of Greek and Cypriot power systems) the following requirements are identified:

- **Emulation of the Regional Security Coordination (RSC) framework and its associated energy market:** The emulation of the RSC framework will be defined and emulated to enable the exchange of information between the two systems and the bilateral provision of Frequency Containment Reserve (FCR) services. Further, a regional coordination market will be defined and developed to enable the trade of frequency support services that will be provided between the two systems to ensure the operational limits of the two systems.
- **Enable the wide area communication between the two sides:** In the case that one of the two sides of the HVDC link operates in Vdc&Q (VSC VQ) control mode, the provision of frequency support to the other interconnected system should be done by adjusting the HVDC converters. This can be done through the generation of a wide area signal by a regional wide area controller and sent to both sides of the HVDC link.

Greek Electricity Market DT

To support the effective implementation of the Greek Electricity Market DT, the following key areas have been outlined:

- **Simulation of the Greek Day-Ahead Electricity Market:** The Day-Ahead Market (DAM) simulator is being enhanced to account for projected changes leading up to 2030, focusing on the evolving generation mix, the construction of new interconnectors and the transition to 15-minute time resolution products. These updates introduce higher complexity into the market's algorithm, thereby increasing operational granularity. To address this, the DAM simulator will incorporate innovative trading products, including scalable complex orders and storage orders, tailored to the characteristics of new energy sources. Additionally, the setup will establish a connection between the DAM simulator and the Balancing Market simulator (BMO) to enable information exchange between the two DT subsystems. This ensures that DAM outputs are effectively utilized as inputs for the BMO, improving interoperability and market efficiency.

Communication flows overview and gap analysis in the Eastern Mediterranean Pilot

The following table describes the communication flows between MO, TSO, and DSO within the Greek power system digital twin ecosystem.

Table 6: Data exchanges between MO, TSO, and DSO in Greek DT

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Market Clearing Prices for the Greek bidding zone $\forall$ MTU (Market Time Unit)	Daily	MO $\rightarrow$ BMO	json
Asset market schedule including interconnector flows $\forall$ asset, MTU (alias	Daily	MO $\rightarrow$ BMO	json

for asset, thermal unit, hydro, res aggregator, interconnector, etc)			
Technical feasibility check of the solution provided by the balancing market operator	3 times (according to the ISP schedule) ISP1: 16:45 EET on calendar day D-1 ISP2: 00:00 EET on calendar day D ISP3: 12.00 EET on calendar day D	BMO → TSO	json/xml
Technical feasibility check of the provided schedule by the balancing market operator	Daily	BMO → DSO	json/xml

The following table describes the communication flows between MO, TSO, and DSO within the Cypriot power system digital twin ecosystem.

Table 7: Data exchanges between MO, TSO, and DSO in Cypriot DT

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Planned Load and Generation (day ahead)	Daily	MO → TSO	API (json)
Cleared FCR (MW/Hz) for each FSP (ancillary services)	Every 3 hours	MO → TSO	API (json)
Planned power exchange at each HV/MV interconnection (day ahead)	Daily	TSO → DSO	API (json)
Cleared congestion services for each FSP (ancillary services)	Hourly	MO → DSO	API (json)

Gap analysis summary for the Eastern Mediterranean Pilot

The table below describes the communication flows that will need to be established between TSOs (in Greece and Cyprus) and RCC for the HVDC interconnection use case between the two countries.

Table 8: Data exchanges between TSOs and RSC in Greece-Cyprus HVDC interconnection use case

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Planned power exchanged (day-ahead)	Daily	TSO → RSC	API (json)
FCR request from side A (CY) and side B (GR) of the HVDC	Every 3 hours	TSO → RSC	API (json)

FCR provisioning limits by HVDC from side A (CY) and side B (GR)	Every 3 hours	TSO→RSC	API (json)

The following table describes the missing communication flows within the Cypriot digital twin that will need to be developed in the TwinEU project.

Table 9: Gap analysis for the communication flow in Cypriot DT

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Cleared FCR settings (MW/Hz) sent by the TSO to each FSP within the digital twin (ancillary services)	Every 3 hours	TSO→FSP (digital twin)	API (json)
Activation signals for active and reactive power flexibility sent by DSO to each FSP within the distribution grid for coordinating congestion services.	Hourly	DSO→FSP (digital twin)	API (json)

4.2.3 Hungarian Pilot Site

Four DTs are involved in the project implementation in the case of the Hungarian Pilot:

- DT1: MAVIR's transmission system DT
- DT2: E.ON EED's distribution system DT
- DT3: APG transmission system DT
- DT4: HUPX (HU NEMO) DT

F4STER, apart from being the Pilot leader, is the technology provider of the neural network-based conductor temperature calculation and DLR DT in T6.8 and the market platform solution, the digital twin 4 of day-ahead auction in T7.3.

BME coordinates the work of T6.8 from the technical side and will be responsible for coordination of algorithm development and its fine tuning in the framework of T7.3.

MAVIR as Hungarian TSO, participates in the work of T6.8 providing the infrastructure necessary for a successful demonstration (transmission line, line monitoring sensors, weather stations, server, database, etc.) and will support the development of T7.3 providing information on timelines and scheduling to ensure compatibility of the demonstration with future TSO processes and on transmission capacity methodology and will identify potential increments to flow-based methodology considering DLR upsides

APG as the Austrian TSO, participates in the work of T6.8 providing support in the form of consultancy and observer roles to help with the demo development.

E.ON EED as a Hungarian DSO, participates in the work of T6.8 by providing the infrastructure necessary for a successful demonstration (132 kV distributional lines, line monitoring sensors, weather stations, server, database, etc.) and supervising the development and operation of their Digital Twin.

ARTELYS as an IT technology provider, especially with its expertise on mixed integer programming solutions for market algorithms, will contribute with impact assessment and the implementation of a flow-based capacity calculation methodology, based on a detailed grid representation.

HUPX as Market Operator of the Hungarian power markets, provides its expertise on day-ahead and intraday energy exchange operation and will supply market participants with a DT tool, supporting them to make significantly better decisions when they step into transactions. User access would be granted via REST API/web API solutions, where the system would enable users to access close-to-real time, assembled and structured data.

APG, CINT, UCY take the role of consultants and observers to ensure compatibility with key project decisions, including transmission capacity calculation models (APG supporting MAVIR), algorithm and solution development (UCY supporting BME) and project management (CINT supporting F4STER tasks) while also providing additional information on local energy markets. In the exploitation, they will deliver future regulatory and energy producer policy recommendations based on the results and experiences.

Gap analysis summary for the involved technologies and DTs in the Hungarian Pilot

This section summarizes the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

DT1: MAVIR's transmission system DT

Building, integrating and operating DTs for capacity calculations of an extra-high voltage system is three-fold.

The DT should always be identical to the overhead line it represents, so changes in the line parameters and in the network topology should immediately be followed by reconfigurations on the DT side. The widespread deployment of hardware sensors necessitates frequent maintenance interventions that could impact system reliability via power line downtimes. The susceptibility of physical sensors to environmental factors, including calibration drift and weather-related damage, introduces uncertainty into capacity calculations. Furthermore, the substantial lifecycle costs are associated with sensor replacement and maintenance strain operational budgets and resource allocation.

SCADA integration also poses a substantial challenge for DT implementation. The prevalent legacy SCADA infrastructure lacks the ability to utilize contemporary digital twin platforms. The modular architecture of modern DTs represents a fundamentally different approach, thus can create interoperability challenges and security issues. Special attention should be paid to data format standardization, communication protocols also to the cyber security aspects of all the above.

Using weather forecasting in the capacity calculation processes also introduces a few critical gaps. Spatial resolution of available weather data falls short of requirements for precise capacity calculations, especially concerning micro-climate variations that significantly influence wind parameters at the height of the phase conductors, which greatly alter the results of the ampacity calculations. Regional security assessments and market operations are based on this dataset so calculating these values accurately is in fact a top priority. This implies that special rules and reserves should be made to avoid possible overloads.

DT2: E.ON EED's distribution system DT

In the case of E.ON EED, the development of the existing pilot DLR system of E.ON EED will continue with the expansion of additional 3 overhead lines in 2025. In 2024, the E.ON EED pilot system expanded from 1 overhead line to 3 monitored overhead lines. Therefore, by the end of 2025, E.ON EED will have a total of 6 monitored 132kV overhead lines in the DLR system. In addition, our system has the following gaps compared to the ideal vision:

1. The DLR system is not extended to all strategically important 132kV overhead lines in the three domestic E.ON DSOs:

- Regulation of overhead lines to an operating temperature of 60 or 80°C
- Establishment of standard sag values
- Determination of critical pole spans (for placement of DLR sensors)
- Installation of physical line sensors and weather stations - monitoring of load changes
- Transition to ANN sensors when the average load is less than 60% of the maximum static value after one year, while keeping the weather station; retaining the sensors over 60%

2. Increasing the accuracy of load forecasting with the help of better weather forecasting:

- Initiating joint research with HungaroMET (forecast provider) to achieve significantly more accurate weather forecasting for overhead lines
 - i. Improving the accuracy of HungaroMET's forecasts based on local measurements from weather stations installed by E.ON DSOs (correction)
 - ii. Synthesizing more accurate and reliable forecasts than the current ones from different weather forecast providers for the areas measured by DLR using an AI algorithm

3. Increasing the accuracy of contingency analysis and mobilizing reserves based on DLR system forecasts in normal, n-1, and n-1-1 conditions at the national level:

- Extending the DLR system to the 132kV lines of all six Hungarian DSOs and the whole TSO network to mobilize the reserves in Hungarian networks
- Integrating DLR into SCADA (Siemens) systems and exchanging data between neighbouring DSOs and TSO-DSOs

4. Storing and making aggregated DLR data accessible for non-operational analysis:

- Currently, the data generated by the DLR system is stored in its own closed SQL database, which is not accessible to other departments.
- The E.ON-wide Network Analytics Platform (NAP) is currently under development, which will store data from various sources in the cloud and provide access to certain parts based on permissions, along with an easy-to-use data analysis interface. Here, we also intend to store the weather forecast data, measured weather data, data from physical and ANN conductor sensors generated by the DLR system, measurement data from SCADA, and various calculated data.

5. Utilizing aggregated DLR data in long-term planning:

- Considering the free capacities measured by the DLR system in the development of the 132kV networks.
- Load analysis based on the measured and calculated values by the DLR system for previous years.

DT3: APG transmission system DT

For a nation-wide scaling of Dynamic Line Rating, physical sensors pose the greatest challenge. Physical sensors require physical installation and even in the event of a fault, maintenance of these devices can cause a line to be shut down or require major recovery operations in the mountains. For this reason, virtual representations (digital twins) can be an enabler for a fast and seamless scaling of Dynamic Line Rating in Austria. For the switch from physical to virtual sensors, the following are missing:

Creation of a simulation model using operational data: Currently, APG is using physical sensors with the disadvantage of high operational efforts. The full digitalization of these hardware devices would allow us to rapidly roll-out Dynamic Line Rating in Austria. For substituting these hardware devices, the demonstrator will use artificial neural networks to create Digital Twins.

Substitution of current weather data: Nowadays, APG is using mostly the weather data that is provided by sensors next to the power lines. With the novel Digital Twin concept these sensors will be replaced by virtual representants and cannot provide any weather data at all. To substitute these weather data, our local demonstrator will not just use weather stations that are next placed to the power lines but also trying to substitute these data with data service providers (e.g. Geosphere Austria). This allows us to enhance the amount of data to almost every spot in Austria. Future digital twins can benefit from this close-knit network of weather data, which allows sensors to be placed anywhere in Austria.

DT4: HUPX DT

The data platform will function as the primary interface for the developed IT infrastructure and optimization algorithm. It will be responsible for the storage and visualization of data generated from various sections of the demonstration. All relevant datasets will be maintained in a cloud-based infrastructure, organized in a specified structure, and accessible through API endpoints. Data export options will be available in multiple formats, including CSV, XML, and JSON. The simulation market results, along with the source datasets, will be stored in an Azure database and visualized using predefined plots.

The development of the data platform has already commenced, initially focusing on basic functionalities. The primary objective is to establish a cloud-based Azure database capable of storing all essential data structures for the simulation. Currently, the wholesale energy bids necessary for the auctions are located on an on-premises sFTP server of HUPX and will be automatically transferred to the data platform database after the development. The specifics regarding the import of other input files, such as TSO DLR inputs and balancing capacity bids for the auctions, have not yet been detailed. However, the platform will provide an option to upload files in various formats directly through the front-end to the Azure database.

Communication flows overview and gap analysis in the Hungarian Pilot

HU Demo employs three grid related digital twins (AT TSO, HU TSO and HU DSO grid) and a spot market-oriented platform for auction operation, data storage and visualization.

The following subsections cover the complete sequence of operation, not yet defining the boundaries between DTs and specific roles/systems.

TSO-RSC

Grid calculation related information is of regional concern thus in the ENTSOe capacity calculation regions it is considered as part of a regional grid security coordination task. RSCs are regional security coordinators, specific grid-related service providers for regional TSOs.

Table 10: Data exchanges between RSCs and TSOs

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Intraday Congestion Forecast Individual Grid Models	Hourly or every 8h	TSO > RSC	EH
Intraday Congestion Forecast Common Grid Models	Every 8h	RSC > TSO	EH
Planned load	Daily	TSO > RSC	Mail
Planned generation	Daily	TSO > RSC	Mail

TSO-DSO

HU demonstrator includes only cross-zonal transmission capacity optimization. Thus the DSO's role is not explicitly concerned. However, the multitude of DSO grid elements of the 132 kV grid, especially in the considered EON DSO network (EON EED – Northern Transdanubia) – that is adjacent to the Austrian grid – are potentially congestion factors. Also, distributed generators, and weather information may prove to be indispensable for the demonstrator's grid capacity calculation tasks in DTs 1...3.

Table 11: Data exchange between TSO and DSO – Hungarian Demonstrator's DTs

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Transmission capacity	Daily	DSO > TSO	Database export

TSO-MO

Co-optimization requires key coordination of balancing capacity requirements and subsequent bid matching and result communication. The Market Operator integrates the market optimization calculation: thus the TSO is a market participant of the auction with designated and special roles.

Table 12: Data exchange between TSO and Market Operators – Hungarian Demonstrator's DTs

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Transmission capacity	10-15 min	TSO > MO	Database export

Recalculated domain	FB	TBD	TSO > MO	TBD
BC demand (of HU TSO)		TBD	TSO > MO	TBD

TSO - Market Player

Market players, especially balancing service providers (BSPs) are the suppliers of the balancing capacity provision considered (focusing on aFRR and mFRR products).

As the TSO-TSO coordination model is the prevalent methodology for cross-zonal balancing market integration, the local TSO organizes the market entry point for the BSPs in each control zone (usually bidding zone as well) – so bid formation, acceptance, result communication is centred around the TSO for these products.

Table 13: Data exchange between TSO and Market players – Hungarian Demonstrator's DTs

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Transmission capacity	10-15 min	MO > TSO	Database export

MO - Market Player

Market players on the energy markets, both physical and financial players, are forming **supply and demand bids for** 60-min. / 15-min. scheduled energy deliveries in the concerned bidding zone.

In the co-optimized model, BSPs also can enter the FRR capacity markets through the Market Operator.

Gap analysis summary for the Hungarian Pilot

TSO-RSC

There are no plans to modify existing information exchange processes, only to complement the dataset with timeseries of overhead line ampacities.

Table 14: TSO-RSC gap in comm. flows

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Intraday Congestion Forecast Individual Grid Models	Hourly or every 8 hours	TSO > RSC	EH
Intraday Congestion Forecast Common Grid Models	Every 8 hours	RSC > TSO	EH
Planned load	Daily	TSO > RSC	Mail
Planned generation	Daily	TSO > RSC	Mail

TSO-DSO

Capacity information loop should be closed and again complementing the currently used dataset with time series of overhead line ampacities.

Table 15: TSO-DSO gap in comm. flows

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Transmission capacity	10 mins	DSO > TSO	SCADA - ICCC
Transmission capacity	10 mins	TSO > DSO	SCADA - ICCC

4.2.4 Bulgarian Pilot Site

In line with the specifications of the Bulgarian Demo of the TwinEU project, five partners are involved in it throughout the duration of the process:

- Software Company EOOD (SCBG), leader of the demo that will, as such, be in charge of the coordination of all of the activities foreseen within the scope of Bulgarian demo; in addition to this, SCBG will be involved in the creation of all of the foreseen DTs (also can be seen as responsible for the high-level digital twin, specified in the next section).
- Elektroenergien Sistemen Operator EAD (ESO EAD), as TSO demo partner, involved in the creation and testing of the DT of their transmission network.
- Electrodistribution Grid West AD (EDG West), as DSO demo partner, is heavily involved in the creation and testing of the DT of part of their distribution network.
- Yugoiztochnoevropeyska Tehnologichna Kompania OOD (SETECHCO), that will help in facilitating communication between SCBG and remainder of the partners and will, as such, be involved in the creation of all the foreseen DTs.
- Entra Energy (EE), as the market party that is participating in the demo, that will assist in the creation of the energy market digital twin (kept on the cross-border level).

Gap analysis summary for the involved technologies and DTs in the Bulgarian Pilot

This section summarises the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

DT of the Bulgarian transmission system

Regarding the DT of the Bulgarian power system, the format in which the system is modelled will not be changed in the scope of this demo. The model that is currently available (based on the information that was provided by the partners from Bulgarian TSO) was created in PSS/E software tool. As this tool allows almost all the calculations that are needed in the scope of the demo to be run and is also capable of high levels of automation, no major need was spotted to change that. However, the available models are based on the characteristic system regimes that need to be accurately decided upon and described previously. To change that and to allow the DT adaptability sufficient to simulate the situations in which something unexpected occurs in the grid and FSP services need to be activated, the next level of automatization needs to come to life. This will be done by the usage of Python scripts drafted particularly for this purpose.

Partial DT of the Bulgarian distribution system

As described for the DT of the Bulgarian transmission system, the partial DT of the Bulgarian distribution system will also be made in PSS/E software tool. This will improve efficiency when making the DT, as it will be based on the existing model provided by the

partners in the demo and enhance the level of matching between the TSO and DSO digital twins, making it easier to combine them for the sake of properly running some of the analyses foreseen through the Use Cases. The choice of this tool will allow for the planned automatization by using the Python codes to integrate new functionalities in the well-known grid model and attempt to emulate both the situations in which the distribution grid will be in need of flexibility and the situations in which resources connected to this grid can improve state of entire power system.

DT of the cross-border energy market

As this DT will mostly represent the source of the input data needed for the proper operation of the two previously described DTs, it will consequently need to be treated as such. Namely, once the creation of the model of the Bulgarian power system and the neighbouring systems of interest in ANTARES software tool is completed, the focus will need to move to the ways in which the results of the procedures run in this tool (such as productions of certain units or types of units, cross-border exchanges, and potential forced outages of some of the power plants in the system) can be efficiently implemented in the transmission and distribution system DTs. For that purpose, codes in either Python, VBA or R will need to be written (all are likely to be tested, after which the one estimated to be optimal from the functionality and ease-of-use sides will be selected), marking the prominent improvement in this area compared to the current state.

High-level digital twin of the Bulgarian power system

The fourth DT of the Bulgarian demo is the one for which the improvement (if compared to the current state) will be the easiest to achieve, simply because this kind of model doesn't exist in Bulgaria now. The idea behind this DT was to utilize the work that will be conducted on the previous three DTs to make a merged model that would not be too complex, but not too simple either. The model that would be too complex would also be rather complicated to use, whereas the model that would be too simplified could lose its purpose, with reliability of the results and the conclusions drawn from them put at risk. Since this model would primarily be intended for stakeholders or ministries, it is important to find the balance between those two extremes. This will be done in the PSS/E tool, accompanied once again by the Python codes for desired automation level.

Communication flows overview and gap analysis in the Bulgarian Pilot

TSO-DSO Communication Flow

The part of the communication flow between these entities that will be relevant for the demo is the one related to the exchange of the grid models and the potential for connection of new RES. In Bulgaria, the cooperation between the system operators comes to fruition over multiple processes, with the most prominent ones being directed by the state authorities, especially if the activity taking place is of importance for the official policies of the country. The planning processes of the transmission and distribution systems are harmonized in order to avoid efforts and investments that would be dedicated to sub-optimal solutions. The network models are not exchanged and merged on a regular basis, but solely when the need for that arises.

Table 16: Relevant data exchange between TSO and DSO – Bulgarian demo

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Grid models	When needed	TSO -> DSO	E-mail
Grid models	When needed	DSO -> TSO	E-mail

TSO-FSP/Aggregator Communication Flow

The exchange of information between TSO and the potential flexibility service providers that are connected to it happens regularly, with the flexibility service providers sending their data (such as forecasts of the production / consumption) to the TSO in the predetermined periods of time. The TSO, on the other hand, provides them with information regarding the capacity of the grid regularly. However, since this kind of information exchange is not in the focus of demo (which primarily targets the forecasting mechanisms themselves and the selection of location of the FSPs), there is no need to elaborate it in more detail in this place.

Table 17: Relevant data exchange between TSO and FSP/Aggregator – Bulgarian demo

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
FSP technical data	Periodically	FSP -> TSO	E-mail
Grid capacity	Periodically	TSO -> FSP	E-mail

DSO-FSP/Aggregator Communication Flow

The exchange of information between DSO and the potential flexibility service providers that are connected to it happens regularly, with the flexibility service providers sending their data (such as forecasts of the production / consumption) to the DSO in the predetermined periods of time. The DSO, on the other hand, provides them with information related to the capacity of the grid regularly. However, since this kind of information exchange is not in the focus of demo (which primarily targets the forecasting mechanisms themselves and the selection of location of the FSPs), there is no need to elaborate it in more detail in this place.

Table 18: Relevant data exchange between DSO and FSP/Aggregator – Bulgarian demo

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
FSP technical data	Periodically	FSP -> DSO	E-mail
Grid capacity	Periodically	DSO -> FSP	E-mail

Gap analysis summary for the Bulgarian Pilot**TSO-DSO Communication Flow**

To properly address this topic, it was, before everything else, necessary to decide upon the model of flexibility market that would be simulated in the Bulgarian power sector. Namely, the Use Cases defined for this demo request both the possibility of the system operators using the FSPs that are directly connected to their respective grids, but also the option of exchanging flexibility between the operators. To be accurate, one of the Use Cases requires application of FSPs connected to the distribution grid to resolve issues in transmission system. Hence, it was necessary to define communication flows that would allow this. This way of exchanging information is illustrated in the Figure 12. Here, the focus will be on the arrows connecting SOs.

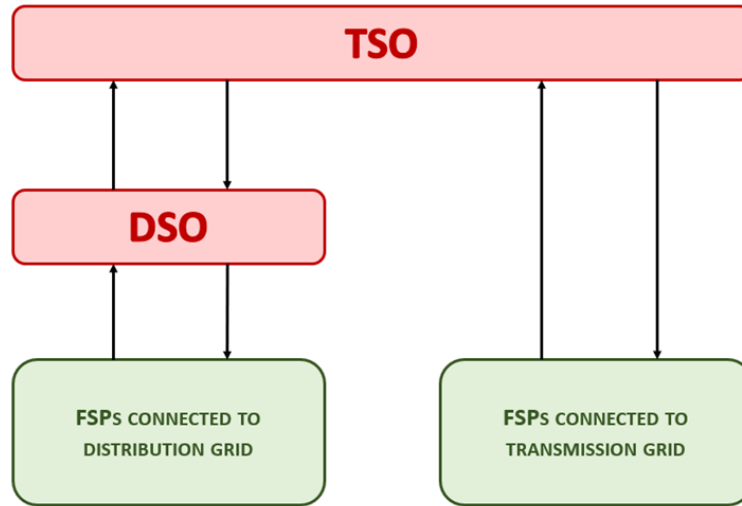


Figure 12: Proposed communication flows in Bulgarian demo

In that part of the communication, the DSO would have the option to offer services of the FSPs that are connected to it directly to the TSO. Of course, this could be done only after the DSO has already used the FSPs connected to it to resolve issues in its own grid. The services could either be offered as sent by the FSPs, or they could be aggregated based on the substation through which they would affect the transmission grid. Here, the TSO would need to validate that the provision of the service would not cause additional problems in the transmission grid, after which the offer would be considered. TSO would then inform DSO if the services offered would need to be provided. The prequalification of individual FSPs would not be done by the TSO, as those FSPs would have to pass the DSO prequalification process beforehand either way.

TSO-FSP/Aggregator Communication Flow

Referring to the Figure 12, one can see that communication is foreseen between the TSO and the FSPs (or aggregators) connected to it. The UCs included in the Bulgarian demo do not require the inclusion of the prequalification step, so it can be considered that all the FSPs that will be considered were prequalified before the initiation of calculations. In line with that, the first step of communication here would be one in which FSPs offer their services to the TSO. TSO would then need to validate the offer from two sides:

- First, the validation would need to be done from FSP capability point of view. As the TSO is set to have access to the advanced ANN-based weather forecasts, it would also be able to estimate if the FSP (in case FSP is WPP or SPP) is capable for the service that was offered. In case it is estimated that the offer is not realistic, it would be rejected automatically. The FSP would then be informed of this directly by the TSO.
- Second, the validation would need to be done from the transmission grid point of view. Namely, it would be necessary to check if the provision of the service would not cause additional problems with the grid. In case it would, the TSO would need to determine the maximal amount of the service that could be provided without new issues arising. This would be the value with which the offer would be considered in the continuation of the process. The FSP could (not mandatory) be informed of this situation in real-time.
- Finally, after the offers are validated (or reduced), some of the services offered would need to be provided to resolve the noticed problem in the grid. Those FSPs whose

offers for the provision of service would be accepted would be informed of this by the TSO.

DSO-FSP/Aggregator Communication Flow

Same as for the TSO/FSP communication, it can be considered that all the FSPs that will be considered were prequalified before the initiation of calculations. In accordance with that, the first step of communication here is that FSPs offer the services to the DSO. DSO would then need to validate the offer from two sides:

- First, validation would need to be done from FSP capability point of view. As the DSO is set to have access to the advanced ANN-based weather forecasts, it would also be able to estimate whether the FSP (in case FSP is WPP or SPP) is capable for the service that was offered. In case it is estimated that the offer is not realistic, it would be rejected automatically. The FSP would then be informed of this directly by the DSO.
- Second, the validation would need to be done from the distribution grid point of view. Namely, it would be necessary to check if the provision of the service would not cause additional problems with the grid. In case it would, the DSO would need to determine the maximal amount of the service that could be activated without new issues arise. This would be the value with which the offer would be considered in the continuation of the process. The FSP could (not mandatory) be informed of this situation in real-time.
- Finally, after the offers are validated (or reduced), some of the services offered would need to be provided to resolve the noticed problem in the grid. Those FSPs whose offers for the provision of service would be accepted would be informed of this by the DSO. In case some offers remain inactive, they could be forwarded to TSO for resolving issues in the transmission grid.

4.2.5 German Pilot Site

The German demonstrator, coordinated by E.ON One, focuses its activities on key extensions towards grid monitoring, grid planning and an end2end flexibility management with focus on congestion management.

E.ON will make use of the digital twin within the LV and MV level that will be based upon the existing solution of envelio's Intelligent Grid Platform (IGP), a highly scalable platform selected as the standard digital twin solution for all E.ON DSOs. Also at distribution level, Westnetz, provides its DT of the HV grid, for which the grid automatization and digitization processes are based upon envelio's IGP.

As TSO, Amprion will contribute via data exchange to the market operator E.ON Energie Deutschland (EDG), who offers flexibility to the TSO on a future flexibility market exchange.

The Demonstrator will include flexibility providers from distributed, residential sources such as electric vehicle charging stations, all already installed in various previous activities, including the E.ON Lab, the testing environment within two of E.ON's DSOs, Westnetz being one of them.

The Technical University of Dortmund will provide conceptual assistance and guidance during the project, and Fraunhofer FIT will provide the control room environment so that an instance of the IGP can be connected via standard interfaces using SOGNO, an open-source

software product developed at RWTH and further developed within the Linux Foundation Energy Framework.

Gap analysis summary for the involved technologies and DTs in the German Pilot

This section summarises the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

In the case of the German Pilot Site, the following table summarises the technologies gap analysis:

Table 19: German Pilot gap analysis summary

Relevant partner / DT	Description
DSO/ Market aggregator	Smart Load Management Systems: Technologies to automate and optimize load shifting based on grid conditions
Market aggregator	Dynamic Tariff Management: Tools to dynamically adjust tariffs based on load shifting needs and grid conditions
DSO/TSO/ market aggregator	Comprehensive Impact Analysis: Tools to analyze the impact of load shifting on grid stability and expansion costs
Market aggregator	Advanced Aggregation Platform: Platform to aggregate flexibility from various sources and manage it effectively
DSO/TSO/ Market aggregator	Secure Communication Protocols: For reliable and secure communication between aggregators and the TSO
DSO/TSO/ Market aggregator	Advanced Cybersecurity Measures: To protect the integrity and confidentiality of exchanged data
DSO/TSO/ Market aggregator	Regulatory Compliance Tools: Automated tools to ensure compliance with regulatory requirements and standards
Market aggregator	Collection of customer data and user preferences participating in flexibility program (UC6) (Regional allocation for balancing groups, Redispatch-regions, controllable assets with power, contract)
Market aggregator	Prequalification and concept of Proof-of-delivery (preparation)
Market aggregator	Forecasting of flexibility of customer (UC 6)
Market aggregator	Consideration of grid-restrictions in price-optimized charging (UC 5)
Market aggregator	Concept for price-optimized charging to help customer save money and support grid (UC 5)
Market aggregator	Identify grid-restriction per customer based on the envelope curve (UC5)
Market aggregator	Aggregation of the customers in different clusters(multi-use case approach (mFRR, redispatch, energy only)) (UC 6)
Market aggregator	Disaggregation of the traded energy/tranches at individual customer level (UC6)
Market aggregator	Steering of customer assets (UC6)

Communication flows overview and gap analysis in the German Pilot

Data exchanges between TSO and DSO

Table 20: Data exchanges between TSO and DSO

Data exchange description	Frequency of exchange
Real-time data	Real-time
Network time series and master data	Upon modification
EEG master data	Upon modification
Profile data of the grid operator	Upon modification
MaBis-Data	Daily
Network models	Upon modification
KWEP-Data	Daily
Renewables-Generation	Daily

DT Software IGP - DSO

First integration of the source data is performed between the DSO and the DT SW IGP. In general, the data integration process is described as an ETL pipeline with the steps of extracting, transforming and loading the data. This involves running through various processes that extract the data from the sources, transform it into a different format and save it in a target database in the final step. This allows the data integration process to be generally structured and the further processing of the data to be ensured based on standardized data formats and structures.

The process of integrating the source data into the IGP in the data shipper is based on the process of an ETL pipeline. The ETL process is extended with the steps of data preparation, i.e. the elimination of data errors and a consistency check, which minimizes potential errors and ensures the import of a coherent data set.

Then, a regular synchronization ensures that the data model in the IGP is always updated to the current status of the source system and that the IGP runs on the basis of the current data. To speed up the process, only the changed and new data in the IGP data model is updated during synchronization. Synchronization starts automatically at a specified time.

Table 21: Data exchange between DT Software IGP and DSO

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
first integration of the source data	once	DSO → IGP	Data Shipper
sync source data	usually weekly (daily - monthly)	DSO → IGP	Data Shipper

Communication flows via APIs

The following data transfers / communication flows can be set and used automatically by the DSO if the DSO wants to use the provided APIs. The communication flows vary accordingly depending on the DSO

Table 22: Communication flows via APIs

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system	Process description
CGMES export	on demand (pull)	IGP/API → DSO	API	The use of the API and the corresponding communication flow can be set and used automatically by the DSO if the DSO wishes and sets this itself. The communication flows vary accordingly depending on the DSO.
Connection Requests Import	on demand (push)	DSO (e.g. Web portal) → IGP	API	new connection requests are transferred to IGP for technical assessment
Connection Requests Export		IGP/API → DSO	API	Export of Connection Requests results and corresponding reservations
Measurement data integration	variable between 1s and 1h, typically 1min	DSO → IGP	API/IEC 104/MQTT	IGP receives (real-time) measurement data, such as voltage, power, etc., from grid assets (e.g. transformer) and grid customers (e.g. smart meters / AMI).
Measurement data integration	Online Monitoring App: every minute Time Series Control App: every 15 min	IGP/API → DSO	API	Export of historical and live measurement data
Load mgmt. (Curative)	1 min	IGP → MPO	API	In case the congestion management application detects a limit violation (e.g. overutilization) the controllable loads that impact this part of the grid receive a curtailment signal from the IGP via the MPO

Gap analysis summary for the German Pilot

Table 23: Communication flows gap assessment summary for the German Pilot

Actors	Description	Purpose
DSO/TSO	Real-time data on generation and consumption, joint planning, and forecasting tools	
DSO/TSO	Real-time communication systems, joint grid monitoring and control strategies, emergency plans	Grid congestion and voltage fluctuations can be managed more effectively + Faster resolution of grid faults and emergencies
DSO/TSO/ Market operator	Standardized communication protocols and interfaces	
DSO/TSO/ Market operator	Data on load shifts and reductions	More efficient use of flexibility options to relieve the grid
DSO/TSO	Long-term planning data on expansion and maintenance measures in distribution and transmission grids	Coordinated investment plans between TSO and DSO.
DSO/TSO/ Market operator	Information on local energy and flexibility markets, data on market prices and the supply/demand situation	Promotion of participation in local markets and use of flexibility services and improving market transparency and efficiency
DSO/IGP	More standards regarding grid model data exchange. This should include grid assets, loads, generators, batteries especially for medium and low voltage grids	
DSO/IGP	Standard format for load and generator elements from a grid perspective with all calculation-relevant information, including types, timeseries/measured values, annual energy and control behaviour.	
DSO/IGP	Standardization: - Availability of specific API endpoints, e.g. list of all available measuring devices and inputs - Structure (which data fields are available in the API responses and how are they named), granularity (e.g. TAF7 or TAF10, i.e. in which resolution the data is available), metadata (e.g. what is the ID called that creates the mapping to the grid assets for us, which is e.g. the GIS ID for us)	

Market Aggregator	Communication of substation-focused envelop curve between IGP and Market Aggregator (either through Smart Meter Gateway or API)	

4.2.6 Italian Pilot Site

The Italian cluster involves two system operators, for acting towards an improved TSO/DSO interaction, including new emerging technologies and paradigms, in strict cooperation with the Italian research institutions and universities, which will provide their expertise and support.

Enel Grids and Terna are developing two BIM-based approaches for power plant design validation—one for distribution networks (Enel) and one for transmission networks (Terna). Enel has already integrated a BIM tool into its enterprise systems to validate new distribution designs, while Terna is creating a similar tool for transmission infrastructure, ensuring compliance with grid requirements. Despite differences in distribution and transmission systems, a converged approach and a common information model are anticipated.

Additionally, Enel is exploring Digital Twins (DTs) for pre-qualifying Distributed Energy Resources (DERs) to help prosumers understand and participate in flexibility markets. This process, initially manual, will be enhanced with DTs for greater efficiency and adaptability to evolving European regulations. Collaboration among grid operators, retail operators, and aggregators will support the implementation of demand response frameworks.

Terna's second pilot focuses on Defence System measures to prevent large-scale transmission disturbances or blackouts. This includes automatic and manual control actions to restore grid stability. Ensiel and partner universities will contribute by designing and validating DT simulations, providing models, equipment, and simulators as needed. Additionally, DSOs will supply aggregated grid data to enable TSO-DSO interaction testing through local grid modeling.

Ensiel and the relevant universities involved in the project consortium will help the design and validation of the DT by working on simulation models implementation and participating in the simulation and validation phases, also making available equipment and simulators, if needed. In this pilot, the DSOs will cooperate to provide aggregated data from the distribution grid, like for example load data on historical basis, to allow the implementation of a model of a local grid portion, for testing the TSO-DSO interactions.

Gap analysis summary for the involved technologies and DTs in the Italian Pilot

This section summarises the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

Defence System Use Case

For what concern the TSO Defence System, the EAC relay (*Equilibratore Automatico di Carico* - automatic load balancer) is configured to open a feeder when a certain frequency threshold is reached. The amount of power/load in the MV network switched off is a static information and is updated two times per years, approximatively. This condition can impact

on the correct implementation of the Defence System action because is unknown the real load/power switched off after the EAC action.

Joining the simulation results obtained from the TSO and DSO models, we will be able to evaluate the impact of the defence system on the DSO network, highlighting the discrepancy, if any, between the model results in terms of power/load switched off in the distribution network and the static values used for the setup of the Defence System. Studies carried out within the T6.3 would be able to be used to update and improve defence logic implementation.

This second use case focuses on developing a Digital Twin (DT) of selected portions of the medium distribution grids, with a particular focus on integrating DERs, such as photovoltaic (PV) systems and electric vehicle (EV) charging stations. The objective is to evaluate operational challenges related to load and generation variability, ensuring secure grid operations, especially in high-density urban areas and rural zones.

The study will analyze the behaviour of the distribution network (high-density urban networks and rural areas with complex configurations) when working in (virtual) islanding mode, to understand the impact on the distribution system operation of the DER intervention.

The simulation framework will aim to enable the communication between portion of the system simulated by ENSIEL (at the Politecnico di Torino facilities) and TRI (if feasible in terms of security). The interconnection could be established either by exploiting the VILLAS framework, which enable the connection with the remote simulator, using the remote model as a black box without directly impact on the laboratory facilities. A second alternative could be the point-by-point approach (through the dedicated communication blocks of OPAL-RT).

Design Validation

On TSO side, the current communication flow uses technical response times. When the design supplier provides the project, the TSO analyse the same to check with TSO standards, rules and laws. The current communication flow could be integrated with automatic checks on the project, developed in BIM, minimizing trades.

For the DSO, the actual implementation only allows asynchronous interactions between the designer and the validator. The foreseen implementation will allow a synchronous access for the different users to the elements, in any stage of the validation phase.

A joint effort will be dedicated to investigating the similarities between TSO and DSO needs, in terms of data models and formats, so that designers could benefit from a common layer.

ENEL's Distribution Grid DT for Design Validation

Design validation needs a Common Data Environment where actors that work on the project can upload BIM files and have the possibility to do activities that can be related to project management (e.g. open issues if the files are not correct). In addition to the collaborative space, the Design Validation will have a specific section where models can be validated, offering to a user a report where the validation results can be seen.

The validation tool is based on a rule engine, a tool where users can write rules that will be used to validate the models. In fact, the validation tool will extract metadata from the models, apply the rules from the rule engine and export a report of results.

Communication flows overview and gap analysis in the Italian Pilot

TSO-DSO

The exchange of information between TSOs and DSOs is a common practice, and it is mandatory to guarantee the congestion management and, more in general, the system security. Currently, the typical set of data automatically exchanged between TSO and DSO are listed in following table

Table 24: Data exchanges between TSO and DSO

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
P, Q, U, I	20 sec	TSO > DSO	SCADA system
States I/O (e.g. breakers position)	Real time	TSO > DSO	SCADA system

The information is exchanged using a dedicated communication line to guarantee the security of the communication and a short time of unavailability in case of failure.

TSO-Design supplier

For the exchange of documentation, any market participant, today, use a dedicated Terna portal and e-mail.

Table 25: Data exchanges between DSO and design supplier

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
The design supplier delivers project documents (upload)	According to schedule	Design supplier → TSO	Online portal – E-mail
Any document integration (upload)	Occasionally if necessary	Design supplier → TSO	Online portal – E-mail
The TSO provides technical details for the project (download)	Occasionally if necessary	TSO → Design supplier	Online portal – E-mail

DSO-Design supplier (ENEL's Transmission Grid DT for Design validation [ENEL])

At the actual stage, designers have a dedicated profile in Enel's integrated design platform, in which they can access the relevant elements and implement the BIM design of grid power plants. Currently the tool doesn't allow to operate in a synchronous manner. The operators (in both DSO and designer sides) can only act through defined status (i.e., draft complete, review, approved, in verification and so on). This is due to the complexity of the integrated Enel's group systems, as the design phase is just the starting point of the implementation process.

DSO-MO

Since the DERs prequalification is far from being implemented, there are no communication flows between the two actors for this specific purpose.

4.2.7 Slovenian Pilot Site

The Slovenian Pilot bring together a set of actors from transmission to market operation and distribution systems.

ELES (TSO): As the pilot's backbone, ELES will be instrumental in leading the initiative, leveraging its comprehensive understanding and access to the transmission system. ELES will provide vital infrastructure data, oversee the integration of the DT technologies with the existing grid, and ensure that the project aligns with national and European regulatory standards.

EG (Elektro Gorenjska DSO): EG will focus on the distribution aspects of the electrical grid, contributing detailed operational data from the distribution networks. This partner's contributions will be crucial for incorporating the distribution level into the DT models, ensuring that the models accurately reflect the realities of distribution network operations. EG's involvement ensures that the digital twin technology accounts for the variabilities and specific challenges faced at the distribution level.

UL FE (University of Ljubljana) and EIMV (Elektroinstitut Milan Vidmar RI) will bring research capabilities to the project. Both organizations will contribute to the development of innovative modeling techniques, simulation tools, and analytical frameworks necessary for DT's functionality. Their work will focus on enhancing static and dynamic models of the power system, developing tools for assessing system dynamics and new system services.

HSE (market): HSE will represent the market aspects of the energy sector within the project. This partner will analyze the implications of integrating DT technologies into the energy market, focusing on market dynamics, and the development of new market services like FFR.

Gap analysis summary for the involved technologies and DTs in the Slovenian Pilot

This section summarises the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

The Slovenian pilot project implementation aims to demonstrate state-of-the-art network operation and management processes in the Slovenian distribution and transmission network. The project involves several key activities, each with specific objectives, inputs, and expected outputs. Here, we identify the gaps in the stability models required for successful project implementation.

Interoperability: One significant gap is the need for standardized formats and protocols for data exchange, such as CIM for both distribution and transmission models. This standardization is crucial for ensuring seamless integration and communication between different systems. The development of methodologies for creating equivalent models for aggregated generation and consumption is essential. These methodologies will enable a more accurate representation and analysis of the grid's dynamics, facilitating better interoperability across the network.

Dynamic Model Accuracy: Improving the accuracy of dynamic models is another critical gap. Current models must be enhanced to, for example, account for seasonal and weekly variations within the distribution system. This involves integrating frequency and voltage-dependent consumption models, which are vital for reflecting real-time operational

conditions more accurately. These improvements are particularly pertinent for tasks such as the Development of a Distribution Network Dynamic Model and the Upgrade of the Transmission Network Dynamic Model.

Real-Time Data Integration: Enhanced real-time data integration from SCADA/EMS systems is necessary for achieving more accurate simulation. Leveraging measurements can significantly improve dynamic model calibration. This is crucial for activities like Data Definition and Management and the Development of a Static and Dynamic Security Assessment Tool, which rely on accurate and up-to-date data for their analysis.

Scenario Analysis and Planning: The development of scenario-based methodologies for future network conditions is another area requiring attention. Enhanced tools for detailed load flow calculations and RMS dynamic analyses are necessary to facilitate better planning and management of the grid under varying operational conditions. This requirement is addressed in tasks such as the Upgrade of the Transmission Network Harmonic Model and the Development of a Static and Dynamic Security Assessment Tool.

Technical and Functional Requirements: Defining and implementing technical requirements for new services like Fast Frequency Response (FFR) is essential. Ensuring that simulation tools can handle extended models incorporating detailed distribution equivalents will allow for more accurate assessments and management of the grid's stability.

Communication flows overview and gap analysis in the Slovenian Pilot

TSO-DSO

The control centres of the TSO and DSO are connected via the SCADA protocol ICCP (Inter-Control Centre Communications Protocol or TASE.2). This protocol facilitates the real-time exchange of measurements, control messages, alarms, switch statuses, and other relevant data. The information is exchanged using a dedicated communication line to ensure the security of communication.

Table 26: Data exchanges between TSO and DSO

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Control messages	Real-time	TSO-DSO	TASE.2
Alarms	Real-time	TSO-DSO	TASE.2
Switch positions	Real-time	TSO-DSO	TASE.2
Measurements (P, Q, U, I)	15 min	DSO-TSO	ECCo SP (AMQP)

TSO-MO

ECCo SP is a communication platform owned by ENTSOe, based on the MADES specification. Its primary purpose is to facilitate connections between TSOs and TSOs to RSCs. For example, the TSO sends Individual Grid Models (IGMs) to RSC through this platform.

In Slovenia, all five Distribution System Operators and other market participants, such as HSE, are connected to ELES (the Slovenian TSO) via ECCo SP. DSOs send solar production measurements for installations above 100 kW (with the threshold gradually decreasing) every 15 minutes (near real-time). Communication uses the AMQP protocol within ECCo SP.

Table 27: Data exchanges between TSO and MO

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
measurements	15 min	MO-TSO	ECCo SP

MO- Market Player

The communication between the SCADA system and the controllers on the generation units is realized through an industrial communication channel based on the IEC 104 communication protocol.

For possible connections for a pilot within the TwinEU project, ECCo SP is likely the most logical platform to use. For the exchange of larger files (e.g., network models), a shared folder (FSSF interface in ECCo SP) can be used.

Table 28: Data exchanges between MO and Market Player

Data exchange description	Frequency of exchange	Direction of exchange	Exchange system
Control commands	Real-time	MO-Market Player	IEC 104

Gap analysis summary for Slovenian Pilot

Effective communication flows are critical for the successful implementation of the Slovenian pilot project. The project's activities involve numerous data exchanges between various stakeholders, including the Transmission System Operator (TSO), Distribution System Operator (DSO), and market players. Here, we identify the gaps in the communication flows necessary for project success.

Integration: Establishing reliable and secure channels for file exchanges between the TSO and DSO is essential. Ensuring compatibility of communication protocols, such as ECCo SP for broader use cases, must be guaranteed to facilitate smooth data exchange across different systems. This is especially important for tasks such as Data Definition and Management and the Development of a Distribution Network Dynamic Model.

Data Exchange Frequency and Accuracy: There is a need for more frequent and precise data exchanges to support dynamic system analyses. Incorporating real-time data from various sources can improve system responsiveness, ensuring the grid operates efficiently and securely. This gap affects activities like the Upgrade of the Transmission Network Dynamic Model and the Development of a Static and Dynamic Security Assessment Tool, which relies heavily on accurate and timely data.

Scalability and Flexibility: Developing scalable communication infrastructures to handle increasing data volumes is essential as the grid evolves. Ensuring that the communication system is flexible enough to integrate new services and participants will support the long-term adaptability and efficiency of the grid.

Standardization and Compliance: Adhering to European regulatory standards for communication and data exchange is necessary. Implementing standardized protocols ensures seamless interoperability between various system components.

4.2.8 Dutch-French Pilot Site

The Dutch-French pilot is a collaborative effort among TU Delft, TenneT, Alliander, Stedin, Jedlix, and RTE.

- **Delft University of Technology - (TUD)** is overseeing the entire Dutch–French pilot and leads the Dutch part of the pilot. TUD leads the development of the digital twin for both the Dutch transmission and distribution grids. It also provides the demonstration platform, Control Room of the Future (CRoF) supported by an emulator of IT-OT communication networks, and a power system simulator. TUD's research focuses on enhancing power system stability and cybersecurity. Additionally, TUD provides support to RTE by suggesting interfaces that could be used for SCADA in their digital twin operator training.
- **TenneT**, the sole Transmission System Operator (TSO) in the Netherlands, is pivotal in developing the transmission network models. TenneT's role encompasses foundational support and advisory services, contributing to model creation and the generation of synthetic data that accurately represents the physical transmission system.
- **Alliander** is a Distribution System Operator (DSO) in the Netherlands. Alliander contributes to the development of distribution network models, providing datasets and feedback on the results obtained.
- **Stedin** is a Distribution System Operator (DSO) in the Netherlands. Stedin aids in the development of distribution network models by supplying datasets and offering feedback on the obtained results.
- **Jedlix**, as a pioneer in smart electric vehicle (EV) charging solutions, is instrumental in the development of a digital twin for future transmission and distribution grids with a high penetration of renewable sources and a high demand from power electronic loads.
- **Collaborative Research for Energy System Modelling (CRESYM)**, is steering the French demonstrator. Cresym will coordinate tasks among the collaborators, be responsible for validating deliverables, monitoring deadlines and leading the project team until the project's completion.
- **Réseau de Transport d'Électricité (RTE)**, the transmission system operator for France, leads the French portion of the pilot. RTE is responsible for developing a digital twin of the French transmission grid with the main goal of facilitating operator training under complex and critical scenarios. RTE supplies this endeavour with the necessary models, datasets, and simulation tools for the demonstration.
- **Fraunhofer IEE (FHG IEE)** provides support in developing the Grid Simulator by defining the simulator requirements, implementing the detailed simulator and testing and validating the implementation
- **Rheinisch-Westfälische Technische Hochschule (RWTH)** provides support in defining and developing the Game Master module which can generate the scenarios.

Gap analysis summary for the involved technologies and DTs in the Dutch-French Pilot

This section summarises the gap analysis main findings for the involved DTs in the Pilot. For the full description of the DTs, please visit Annex A.

Stability models for the Dutch digital twin implementation

The implementation of the Dutch digital twin stability demonstrator necessitates addressing several gaps identified in the current stability models. These gaps need to be resolved to ensure the accurate and efficient functioning of the Dutch digital twin.

Transmission and Distribution Models Accuracy and Detail: The existing stability models lack the required accuracy and granularity to simulate high-fidelity transient stability events. The current models often use simplified assumptions that do not capture the complete dynamics of the power system, especially under transient conditions. Since the reduced models may overlook certain dynamics, the simplifications can lead to discrepancies in how the digital twin reacts on system's behaviour under certain load conditions and attack scenarios. Additionally, the DT might not be able to scale efficiently with increased data inputs or more complex grid models.

Data Generated from Synthetic Model: Ensuring data used by the DT is of high-quality, accurate and reflects current state of the physical system is essential. Data generated from the synthetic model that represents the physical system is critical for stability and cyberattack studies. However, data that truly represents time responses of actual power systems can be challenging to generate and the data might not fully capture random variations, noise, and non-linear behaviours typical in real power systems.

Performance and Scalability of Cyber Layer Network Modeling: Dutch DT apply Mininet, to run multiple network components on a single machine using Linux containers, can scalability limitations due to resource contention when simulating large-scale topologies with detail components. Real-world networks use dedicated hardware optimized for high-throughput and low-latency, and they naturally scale across geographically distributed nodes. Performance is influenced by physical factors such as distance, hardware quality, and environmental conditions. Mininet's performance is constrained by the host machine's CPU, memory, and network I/O, leading to bottlenecks under high traffic. Additionally, its software-based link latency and bandwidth emulation cannot fully replicate the variable delays seen in real-world hardware which can have issues such as signal interference, cable faults, and other physical factors.

GAP analysis for the implementation of the TwinEU ecosystem in the French Pilot Site

SCADA: to be implemented, based on PowSyBI framework

CPS-CAS: to be implemented

CPS-GS: Already implemented as a simulator. Must be improved on following aspects:

- Performance (ability to do a 1s simulation in less than 1s);

Orchestrator: to be implemented

Game master: to be implemented

Communication flows overview and gap analysis in the Dutch-French pilot

Communication flows in the Dutch DT in the Dutch-French pilot

The Dutch DT would be the integrated transmission and distribution grid and the communication flow between physical model representation and digital twin are specified in Table 29.

Table 29: Data exchange between physical model and digital twin

Data Exchange Description	Frequency of exchange	Direction of exchange	Exchange system
P,Q,V, theta (time-series measurements)	(Near) real-time	Steady-State & RMS Models -> SCADA	OPC UA Server 1
Control commands/setpoints	As needed	SCADA -> Steady-State & RMS Models	OPC UA Server 1
Network Topology/Model/Status/Measurement Changes	As needed	SCADA -> RMS Model	OPC UA Server 2
Calibration Data, Validated Models/Simulation Results	As needed	RMS Model -> SCADA	OPC UA Server 2

Communication flows in the French DT

Table 30: French Pilot Data exchange between physical model and digital twin

Data Exchange Description	Frequency of exchange	Direction of exchange	Exchange system
Telecommands/setpoints	As needed	SCADA -> Orchestrator	REST API
Statuses/measurements	1s	Orchestrator -> SCADA	REST API or message broker
Statuses/measurements	As needed	CPS-CAS -> Orchestrator	REST API
Telecommands/setpoints	As needed	Orchestrator -> CPS-CAS	REST API
Dynamo scenario	1s	Orchestrator -> CPS-GS	files
Events/measurements	1s	CPS-GS -> Orchestrator	files
Initial grid model	On start	Game master -> Orchestrator	REST API
Grid model modification	As needed	Game master -> Orchestrator	REST API
Grid model update	1s	Orchestrator -> Game master	REST API

Gap analysis summary for the Dutch-French pilot

Data exchange, Integration, and Processing: Current transmission and distribution models face challenges in integrating real-time data from various sources, which is crucial for the functioning of the digital twin. The inability to dynamically update models with live data could hinder accurate real-time-updated simulations. In addition, DT might have issues with latency in data exchange and processing, especially when handling large volumes of data or executing complex simulations, leading to delays in some decision-making.

Communication Protocol between components: The current digital twin communication utilizes protocols like OPC UA industrial protocol. It facilitates secure and reliable data exchange between the components included in Dutch DT architecture for cybersecurity assessment. It acts as a central communication hub, ensuring interoperability and data consistency. The OPC UA server supports (near) real-time data acquisition and monitoring from the physical system (client) to be accessible by other clients involved in the system. However, current implementation doesn't consider advanced encryption or other security measures. To perform different attack simulations to perform impact analysis and cascading failure analysis, we assume attackers are already inside the system and can perform different attacks. DT can incorporate robust security certificates to ensure secure authentication, encryption, and integrity of communications between system components and seamless integration and operation of digital twin.

4.3 Technical requirements to enable the seamless coordination and cooperation of DTs in the TwinEU Continuum

Each regional implementation of the proposed use cases by the project Pilots, as well as the pan-European scenarios, can have a set of local technical requirements for the specific implementation of the associated ecosystems, however, a set of horizontal requirements able to canalise a general approach for taking part in the TwinEU Continuum must be put in place.

Such list of horizontal technical requirements is presented below in Table 31 as an exercise enabled by the findings obtained from the methodology proposed. After the assessment of (1) the technologies and communication flows already in place, (2) the gap analysis that spotted the necessary developments in both fields yet to be performed in order to end-up undertaking the proposed use cases, and the (3) combined assessment of the technological boundaries of proposed Twins with the defined Use Cases, TwinEU's consortium developed a set of technical requirements that is feed with key insights from Pilot partners (WPs 5 to 8) and horizontal technology developers (WPs 3 and 4). These are:

Table 31: Set of technical requirements to enable the seamless coordination and cooperation of DTs in the TwinEU Continuum

Technical requirement ID	Name	Description	System	Involved DTs
Tech_01	All DTs should have the capacity to be connected to the TwinEU's dataspace	Task 4.5 will adapt the current dataspace based on IDSA to work with the TwinEU continuum. This adaptation will define data models, the data sharing governance, the data integration and homogenization mechanisms and the extension of a data connector to support the required features.	General	All DTs integrated in the federated ecosystem (TwinEU continuum).
Tech_02	Real-time Data Synchronization	TwinEU DTs may implement real-time data synchronization mechanisms to keep all DTs updated with the latest information.	General	All DTs involved in RT operations-related UCs / pan-EU scenarios
Tech_03	Decentralized Data Architecture	Use decentralized data architectures to enable efficient data sharing and reduce bottlenecks in communication.	General	All DTs integrated in the federated ecosystem (TwinEU continuum).

Tech_04	DTs must incorporate secure protocols	Digital Twins integrated into the TwinEU Continuum ecosystem should incorporate robust security protocols to ensure secure authentication, encryption, and integrity of communications between system components and seamless integration and operation of the systems.	General	All
Tech_05	TwinEU must ensure a certain level of Data Quality and its validation	The project architecture must establish mechanisms for data validation and quality assurance to ensure the accuracy and reliability of inputs used in DT simulations and analyses.	General	All
Tech_06	Automated Data Exchange Interfaces	The DTs in the TwinEU continuum must be provided with automated interfaces for data exchange via de data space, reducing manual intervention and ensuring timely updates.	General	All DTs integrated in the federated ecosystem (TwinEU continuum).
Tech_07	Dynamic Data Sharing Policies	Develop dynamic data sharing policies to control access and ensure data is shared appropriately among DTs.	General	All
Tech_08	Hybrid employment of edge and cloud computing mechanisms	TwinEU's DT can be architecturally conceived with a balance between using cloud-based platforms for scalable and flexible data exchange among DTs and employing edge computing to process data locally, always aiming at reducing latency and improving response times for the DT coordination. This does not exclude any DT to be developed fully locally or in the cloud.	General	All
Tech_09	Data Exchange Performance Metrics for Continuous Improvement	The TwinEU dataspace must implement monitoring performance metrics for data exchange to ensure efficiency and effectiveness in DT collaboration.	General	All DTs integrated in the federated ecosystem (TwinEU continuum).
Tech_10	Data Exchange Feedback Loops for Continuous Improvement	The TwinEU dataspace must implement feedback loops to continuously improve data exchange processes and address emerging challenges in DT coordination.	General	All

Tech_11	Data Space federation techniques and data exchange infrastructure	TwinEU's data space must employ data federation techniques to provide unified access to distributed data sources across DTs as well as design a scalable infrastructure to support growing data exchange needs as more DTs are integrated.	General	All
Tech_12	Inter-Twins Data Sharing Agreements	Beyond enabling a context-aware data sharing to provide relevant information to DTs based on their operational needs and scenarios, TwinEU must implement data sharing agreements among stakeholders to define roles, responsibilities, and data access rights.	General	All
Tech_13	Secure Data Transmission Protocols	TwinEU must employ secure data transmission protocols to protect data integrity and confidentiality during exchanges. The implementation of multi-layer security measures to protect data at rest and in transit between DTs should be studied.	General	All
Tech_14	Event-Driven Data Exchange	TwinEU's architecture must facilitate event-driven triggers based on specific conditions or changes in the system.	General	All
Tech_15	API-driven data space connectors compatibility	The TwinEU Data Space Connectors must provide an API for the generation of offers and contracts	General	All DTs integrated in the federated ecosystem (TwinEU continuum).
Tech_16	Access Control Mechanisms	Establish robust access control mechanisms to ensure that only authorized users and systems can access the TwinEU continuum and its services.	General	All
Tech_17	Secure Software Development	The TwinEU DTs and related services (via the data space implementation) must be developed according to the secure software development principles to minimize vulnerabilities in the ecosystem.	General	All DTs integrated in the federated ecosystem (TwinEU continuum).
Tech_18	Compliance with Data Protection Laws	All Use Cases must ensure compliance with relevant data protection laws and regulations, such as GDPR, to safeguard	General	All

		personal and sensitive information.		
Tech_19	RT data sharing and coordination	TSOs and DSOs DTs must enable sharing of operational data to improve cross-grid visibility, while ensuring interoperability between both systems to facilitate seamless communication and coordination.	TSO, DSO	TSOs and DSOs DTs involved in RT operations-related UCs / pan-EU scenarios
Tech_20	Grid planning service enablement through TSO-DSO coordination in the TwinEU architecture	The TwinEU reference architecture must ensure the enablement of services and business models in an interoperable way and in real time. The TwinEU architecture must allow joint grid planning and development processes to align infrastructure development and ensure efficient integration of resources.	TSO, DSO	TSOs and DSOs DTs involved in grid planning UCs and pan-EU scenarios
Tech_21	Powerflow optimisation service enablement through TSO-DSO coordination in the TwinEU architecture	The TwinEU reference architecture must ensure the enablement of services and business models in an interoperable way. The TwinEU architecture must allow the establishment of coordinated congestion management strategies to optimize power flows and minimize grid bottlenecks.	TSO, DSO	TSOs and DSOs DTs involved in RT powerflow optimisation UCs and pan-EU scenarios
Tech_22	Enhanced shared situational awareness service enablement through TSO-DSO coordination in the TwinEU architecture	The TwinEU reference architecture must ensure the enablement of services and business models in an interoperable way. The TwinEU architecture must allow enhanced shared situational awareness through integrated monitoring and control systems for better decision-making.	TSO, DSO	TSOs and DSOs DTs involved in UCs and pan-EU scenarios including RT situational awareness services
Tech_23	Grid stability enhancement service enablement through TSO-DSO coordination in the TwinEU architecture	The TwinEU reference architecture must ensure the enablement of services and business models in an interoperable way. The TwinEU architecture must allow the integration and implementation of collaborative forecasting tools with the TwinEU Continuum to	TSO, DSO	TSOs and DSOs DTs involved in RT grid stability enhancement UCs and pan-EU scenarios

		align demand and generation predictions, enhancing grid stability.		
Tech_24	DSO-TSO data shared on grid observability	DSOs and TSOs must share relevant calculation results enhancing cooperation and grid observability	TSO, DSO	TSOs and DSOs DTs involved in RT operations-related UCs / pan-EU scenarios
Tech_25	TSO-DSO data shared on technical restrictions	TSOs must make available to DSOs the grid technical restrictions and their real-time recalculations and modifications according to the grid codes	TSO, DSO	TSOs and DSOs DTs involved in UCs and pan-EU scenarios including RT technical restrictions calculations
Tech_26	Data exchange improvement for RT DTs operation between TSO through RSC	Currently, there are still gaps in standardizing data formats and in ensuring interoperability between TSOs and RSCs. TwinEU's reference architecture must provide a common model for coordination between TSOs DTs while guaranteeing data integrity during data exchanges and scalability to handle increased data volumes and system complexity.	TSO	TSOs' DTs
Tech_27	Interoperability of MO's systems with TSO/DSO Systems	MO's DTs must ensure interoperability with TSO and DSO systems to enable seamless data exchange and coordinated market operations. For such purpose, MO's DT must be fully integrated in the reference architecture of the TwinEU continuum, implementing the Data Space adaptation.	MO	MO's DTs
Tech_28	AI models Real-Time Data Integration	AI models must be integrable and processable with dynamic data from Digital Twins to provide insights and predictions. Additionally, AI models must establish feedback loops where Digital Twins provide data to refine and improve AI models.	TSO, DSO, AI services	Spanish TSO (REE) DT Spanish DSO (CUE) DT Hungarian DT for power line monitoring Bulgarian TSO (ESO) DT Bulgarian DSO

				(EDG West) DT Bulgarian Cross-border market (CBME) DT
Tech_29	AI services integration with DTs	The AI services can be either directly integrated with the DTs via the software tool that embeds them or via the TwinEU services marketplace defined by the TwinEU reference architecture	AI services, all DTs	Spanish TSO (REE) DT Spanish DSO (CUE) DT Hungarian DT for power line monitoring Bulgarian TSO (ESO) DT Bulgarian DSO (EDG West) DT Bulgarian Cross-border market (CBME) DT
Tech_30	Data models for the AI services	All AI services must be compliant with the data models proposed in the TwinEU reference architecture and the DT federation technical specifications for a smooth integration into the TwinEU reference framework.	AI services, all DTs	Spanish TSO (REE) DT Spanish DSO (CUE) DT Hungarian DT for power line monitoring Bulgarian TSO (ESO) DT Bulgarian DSO (EDG West) DT Bulgarian Cross-border market (CBME) DT
Tech_31	Communication models	All AI services must be compliant with the communication models proposed in the TwinEU reference architecture and the DT federation technical specifications for a smooth integration into the TwinEU reference framework.	AI services, all DTs	Spanish TSO (REE) DT Spanish DSO (CUE) DT Hungarian DT for power line monitoring Bulgarian TSO (ESO) DT Bulgarian DSO (EDG West) DT Bulgarian

				Cross-border market (CBME) DT
Tech_32	HPC infrastructure Dynamic Resource Allocation / Resource management	The HPC infrastructure must allow the TwinEU federation to allocate computational resources dynamically based on the varying workloads of different digital twins. A unified system for job submission and scheduling, like SLURM, is needed to manage workloads across the federation.	HPC services	DTs that require / aim at using HPC
Tech_33	HPC services Real-Time Processing and timely data availability	The HPC environment must support low-latency, high-speed computation to meet real-time or near-real-time requirements for simulations and analytics. For that purpose, data for HPC jobs must be uploaded to a local shared parallel filesystem (e.g. LUSTRE), through a login node, which is a slow, time-consuming process.	HPC services	DTs that require / aim at using HPC
Tech_34	HPC Services data transfer and interoperability services	The HPC infrastructure should be connected/synchronised to a common data-sharing framework to facilitate easy communication across the federation. Efficient mechanisms for moving data between federated sites are required for complex workflows and data-intensive computing.	HPC services	DTs that require / aim at using HPC
Tech_35	HPC System Security and Compliance	The HPC system must include authentication and authorization with robust encryption, access controls, and monitoring, aligning with regulatory requirements. These measures are essential to protect sensitive data.	HPC services	DTs that require / aim at using HPC
Tech_36	HPC System Scalability and Load Management	The HPC system should be able to scale to handle diverse and growing workloads from the TwinEU federation.	HPC services	DTs that require / aim at using HPC
Tech_37	HPC System support for Distributed Computing	To leverage HPC resources effectively, applications (e.g. Digital Twin components) need to be compatible with distributing computing frameworks, namely MPI/OpenMPI)	HPC services	DTs that require / aim at using HPC
Tech_38	HPC System support for	For computing tasks to leverage the parallel computing of GPUs these need to be compatible with	HPC services	DTs that require / aim at using HPC

	Parallel Computing	computing frameworks such as CUDA)		
Tech_39	HPC Services compatibility with Batch Processing Model	Applications/tasks need to conform to a batch processing model, which is non-interactive, using job management frameworks such as SLURM.	HPC services	DTs that require / aim at using HPC
Tech_40	HPC Services compatibility with hard time limits	When a running job reaches a predefined time limit, its execution is interrupted, so checkpointing should be used to ensure intermediate results are not lost if the time limit is reached, and execution can be resumed from the checkpoint in another job.	HPC services	DTs that require / aim at using HPC

5 TwinEU Use Cases

TwinEU leverages the expertise of grid and market operators, technology providers, and research centres to develop a Pan-European DT concept. This initiative, based on the federation of local DTs, ensures reliable, resilient, and secure infrastructure operation while fostering innovative business models to accelerate renewable energy adoption across Europe.

TwinEU demonstrates its value through eight pilots and a wide array of UCs developed, deployed across interconnected control regions. These UCs encompass multiple spatial and system aggregation levels, ranging from dynamic multi-area European systems to localized energy community operations. Their key aim is to assess the reliability and resilience of integrated power systems on both national and European scales, leveraging spatially and temporally simulated scenarios to evaluate performance under various conditions.

The UCs defined and developed under WP2 and particularly under Task 2.4 will be described in Chapter 5.4

To achieve T2.4 objectives, a high level of coordination between Work Package 2 (WP2), and the demonstration pilot WPs (WP5-8) was necessary. Thus, the following 3-level coordination process was adopted:

- **WP2-Level Coordination:** To ensure alignment across all WP2 tasks, we established recurring meetings to facilitate seamless information flow and analysis of results.
- **Horizontal Coordination with Other WPs:** We participated in cross-WP meetings with demo WPs to effectively coordinate and streamline the collection UCs.
- **WP2-Pilots Coordination:** We actively engaged in meetings to address pilot-specific issues. Analysing topics related with WP3 and WP4 activities on architecture development and integration, these meetings also covered UC-related aspects for each pilot.

5.1 Use Case Definition Methodology

A UC describes how a system interacts with stakeholders and components to fulfil specific objectives in a structured, real-world context. These stakeholders, which may include users, external systems, or internal subsystems, play vital roles in achieving the system's goals. UCs are essential tools for analysing and designing systems, offering practical insights into how the system will function and deliver value in operational scenarios. By providing a common framework, UCs facilitate effective communication between technical teams and stakeholders, assisting on bridging the gap by ensuring a shared understanding of system behaviour, purpose, and intended outcomes [38]. Added value delivered by the UCs methodology can be identified as follows:

- UCs play a critical role in defining the project scope, providing clear understanding of the scenarios' capabilities and limitations. This clarity enables more informed decision-making regarding which features should be considered, helping to prevent unplanned scope expansion. By offering a structured approach, UCs reduce the risk of incorporating additional features without thorough evaluation, ensuring the project stays on track and aligned with its objectives.
- Well-defined UCs serve as a blueprint, ensuring that architects, designers, developers, and testers are aligned in their efforts. Through developing clear guidance, UCs streamline the development process, reducing misunderstandings and minimizing the

need for revisions or rework, delivering more efficient workflow with clear understating of responsibilities and contributions to the project's success.

- UCs act as a bridge between technical and non-technical stakeholders, enabling clear and effective communication, by simplifying complex technical concepts into easily understandable terms, helping business users make informed decisions.
- Implementation of UCs minimize ambiguities by clearly outlining system behaviour through detailed interactions. They describe how users, external systems, or other actors engage with the system throughout its processes, eliminating uncertainty about the roles of each actor, reducing the risk of misinterpretation and preventing errors during implementation.
- UCs serve as a foundation for validation and verification by defining clear criteria for evaluating the system's performance. During testing, these criteria ensure that the system functions as intended, allowing any discrepancies to be identified and addressed early. This approach helps prevent costly defects from progressing to production, ensuring a reliable and high-quality final product.

In TwinEU, UCs detail the application of digital twin technologies to tackle real-world challenges. These descriptions include specific scenarios, actions, and interactions that illustrate how the project's solutions address complex issues while aligning with its broader goals. This approach ensures that the technologies proposed are practical, impactful, and tailored to real-world needs. In that scope, T2.4 aims to establish the reference scenarios and UCs that form the foundation of the TwinEU project. This task builds upon the results of all preceding WP2 tasks, integrating insights from the analysis of digitalization challenges and opportunities (T2.1), the evaluation of stakeholder requirements (T2.2), and the identification of technological requirements (T2.3). By leveraging these comprehensive inputs, the UC developers defined and developed several UCs for the eight pilot sites, ensuring alignment with the project's objectives.

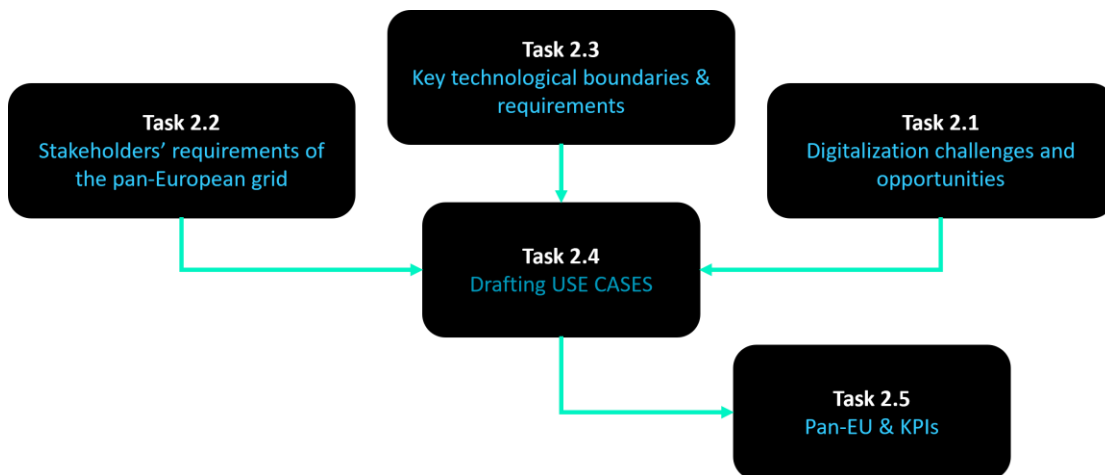


Figure 13: Interactions between WP2 tasks

UCs will be instrumental in defining acceptance criteria, evaluating user and service-centric performance, and ensuring that the solutions align with the identified scenarios and requirements. They are typically developed from an abstract business case that outlines overarching objectives without including deep technical specifics. These UCs serve as a bridge between business goals and actionable implementation strategies, structured across varying levels of granularity. According to Gottschalk, “the use case and smart grid architecture model approach” [39], the UCs are categorized into four main types:

- **High-level UCs**, which provide a broad overview of objectives and scope.
- **Generic UCs**, which outline common functionalities, or solutions applicable across multiple scenarios.
- **Specialized UCs**, which address specific business requirements or contexts; and
- **Individual UCs**, tailored to applications or unique circumstances.

The categorization of UCs is influenced by their specific objectives, the roles and perspectives of the stakeholders, and the degree of detail necessary. Their development can follow a **top-down methodology**, which begins with overarching business objectives and cumulatively breaks them down into detailed, actionable plans, or a **bottom-up approach**, which starts with detailed individual UCs and synthesizes them into a broader framework that aligns with overall goals. This hierarchical structure promotes adaptability and ensures that diverse business requirements are effectively addressed.

TwinEU UCs definition was designed primarily to incorporate High-level UCs or Business Use Cases (BUCs) that define generic functional specifications for the business layer across the European pilot cases. Additionally, they aimed to capture end-user requirements, focusing on both functional needs and the value provided by the solution and the system. Finally, some key functional building blocks were identified to ensure the project's successful delivery of outcomes.

TwinEU adopts the **top-down methodology** for the definition of its UCs, reflecting a strong alignment with the overarching vision, working systematically to address specific needs while ensuring that high-level objectives drive the creation of modular, scalable solutions (Figure 14). This approach emphasizes the structured transition from abstract concepts to actionable, detailed solutions, with the generic use cases providing “reusable templates” that are adapted into specialized implementations, tailored to meet specific scenarios.

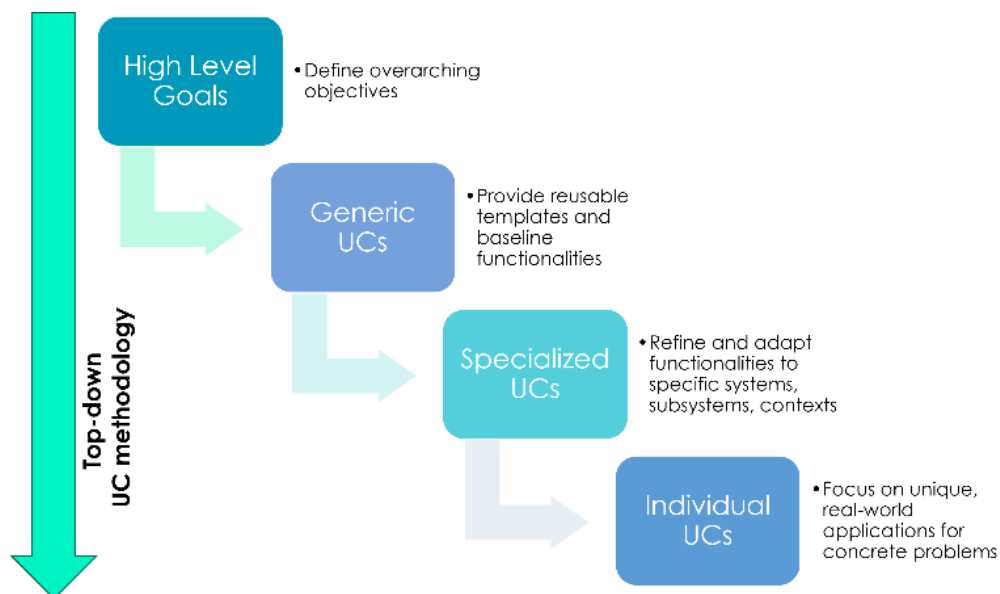


Figure 14: TwinEU top-down UC approach implemented

The TwinEU project utilizes the IEC 62559 standard [40] as a framework for crafting UCs. This methodology ensures a structured and standardized approach, promoting clarity and uniformity throughout the documentation process. Adhering to this standard enhances

communication, fosters better collaboration among partners, and streamlines the design, development, and assessment of the project's solutions.

5.2 The IEC 62559 template

By the name "Use Case Methodology", the IEC 62559 standard provides an advanced and systematic approach to the formulation and documentation of UCs in systems engineering. This framework is designed to methodically capture the functional requirements of a system, ensuring they are well-structured and comprehensive. By facilitating precise communication among diverse stakeholders, the standard establishes a shared understanding of system functionalities, reducing ambiguities and fostering alignment across technical and non-technical domains. It is divided into **five fundamental Parts**:

- **Part 1** establishing the concept and core fundamentals of the UCs and including the UC description with all the general information regarding the objectives of the UC,
- **Part 2** facilitating content transfer to engineering systems like those based on Unified Modeling Language (UML) diagrams,
- **Part 3** defining technical details, actor and system lists,
- **Part 4** extending the application of the UC methodology to projects and scenarios offering recommendations for project-specific developments, and a step-by-step analysis of the scenarios,
- **Part 5** documenting the information being exchanged among the actors for each step of the scenarios.

5.3 Task 2.4 Workflow

Defining the TwinEU UCs is one of the core objectives of the current deliverable. To this aim, a structured approach was followed, which is illustrated in Figure 15.

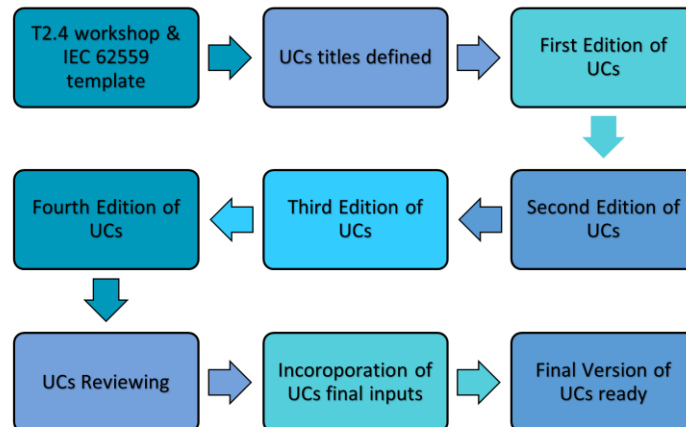


Figure 15: T2.4 workflow towards final version of TwinEU UCs

The workflow of T2.4 included the following steps:

1. A workshop was held in March (M03 of TwinEU), launching T2.4 activities, providing UC developers with a detailed, section-by-section walkthrough of the IEC 62559-2 UC template. To ensure an effective and practical outcome, the [OneNet](#) project's UC "Congestion management in distribution grid under market conditions", was used as a reference.

2. A detailed time plan for T2.4 was created to streamline ongoing work and divide the UC development into efficient and manageable modules (Figure 16). The plan strategically allocated work time based on the complexity and workload of each activity module.

Activity	Mar M03	Apr M04	May M05	Jun M06	Jul M07	Aug M08	Sep M09	Oct M10	Nov M11	Dec M12	Jan M13	Feb M14
IEC 62559-2 template shared among the UC developers												
First Edition of UC, addressing part 1 of IEC addressing the description of the UC.												
Second Edition of UC, finalizing part 1 of IEC; considering also KPIs part, and initiate part 2, addressing diagrams.												
Third Edition of UC, finalize part 2; and finalize part 3, completing technical details.												
Fourth Edition of UC, address and finalize part 4 and 5, completing step-by-step analysis and information exchange.												
UC assessment and finalization												
Development of T2.4 part for D2.2, exchanging feedbacks												
Finalizing the development of T2.4 for D2.2												

Figure 16: T2.4 time-plan depicting development steps of UCs

3. Pilots prepared the initial drafts of their UCs by first defining the titles while getting familiar with the IEC 62559-2 template. This initial input, referred to as the **First Edition** of the TwinEU BUCs, focused on outlining the general information of the BUCs, including their scope, objectives, and the short narrative description. By the end of April 2024 (M04 of TwinEU), an assortment of **50 First Editions** of UCs from the 8 TwinEU pilots had been gathered.
4. By the end of June 2024 (M06 of TwinEU), the UC developers finalized the general information of the IEC template, including the comprehensive narrative description, and initial KPI formulation, thereby completing the **Second Edition** of the TwinEU UCs.
5. The **Third Edition**, encompassing the finalization of KPIs, the UML diagrams, and the development of the technical details chapter, was completed by the UC developers by the end of August 2024 (M08 of TwinEU).
6. Then, the UC developers completed the step-by-step analysis and filled in the information exchange tables of the IEC 62559 template by the end of September 2024, completing the **Fourth Edition** of the TwinEU UCs.
7. Feedback was consistently provided during the T2.4's dedicated discussions in the recurring WP2 meetings and through direct communication with UC developers.
8. The **review of the complete UC** documents began in August and was finalized by the end of November 2024 (M11 of TwinEU).
9. The pilots provided the finalized versions of their UCs by the end of December 2024 (M12 of TwinEU) and are hosted in the online repository of TwinEU's SharePoint.

5.4 TwinEU UCs overview

In total **50 UCs** were defined from the **eight different TwinEU demonstration pilots**. All the UCs have been detailed using the IEC 62559 template. In this section, their key characteristics are presented, including UC's scope, objectives, short description, and their level of depth according to the UCs categorization. The full description/version of each UC using the IEC-62559-2 template is available in Annex B of the current document.

5.4.1 Bulgarian Pilot Site UCs

Table 32: Bulgarian Pilot's – BG01 UC overview

UC ID	BG01			
UC name	Establishment of the data exchange between the Digital Twins			
Scope	Establishment of the desired level of communication between the DTs that will be made in the scope of both tasks falling under the Bulgarian pilot. This will be one of the necessary prerequisites before the initiation of the procedures included in those tasks. As stated in this Deliverable 2.2 in which the communication flows between the DTs are defined, this will mostly be done by using special codes fit for purpose.			
Objective(s)	The objectives of this UC are to deliver: • Validation of the DTs created in the scope of the Bulgarian pilot; • Establishment of the data exchange between those Digital Twins; • Confirmation of sufficient quality of data exchange for foreseen tasks.			
Short Description	This Use Case will be founded on establishing the proper connection and determining the information flow among created DTs in the Bulgarian pilot. The outcomes of this Use Case should encompass the streamlined and automatized flow of information from one DT in the pilot to another, with DT CBME and ANN-trained DTs feeding the information into the DTs TSO and DSO as inputs for the calculations.			
Level of depth	Generic UC			
UC Diagram	<pre> graph TD subgraph IT_Provider [IT Provider] START([START]) S1[Sending the developed Digital Twins] S2[Sending the verified communication codes for data exchange between DTs] end subgraph TSO_DSO [TSO, DSO] R1[Reception of the developed Digital Twins] V1[Verification of the developed Digital Twins] S3[Sending the feedback on the developed DTs] R2[Reception of the verified communication codes for data exchange between DTs] end subgraph FSP [FSP (or Aggregator)] R3[Reception of the feedback on the developed DTs] R4[Reception of the verified communication codes for data exchange between DTs] end subgraph Weather_Forecast [Weather Forecast] END([END]) end START --> S1 S1 --> R1 R1 --> V1 V1 --> S3 S3 --> R3 R3 --> S2 S2 --> R2 R2 --> R4 R4 --> END </pre>			

Table 33: Bulgarian Pilot's – BG02 UC overview

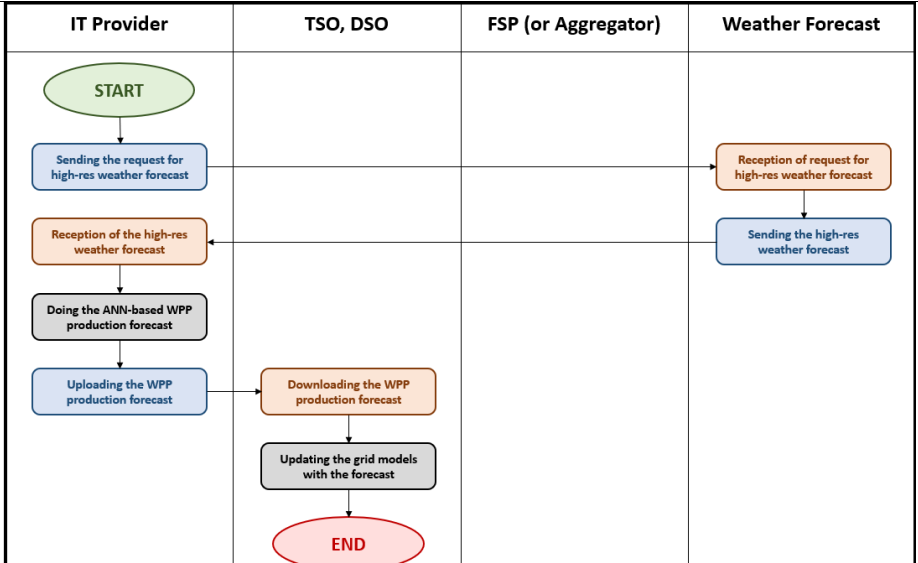
UC ID	BG02			
UC name	AI-Improved Forecast of Wind Power Plants (WPPs) Production			
Scope	The scope of this task will be the usage of the fit-for-purpose AI techniques in order to improve the quality of the forecasts of the production power of selected capacities in the grid. In this case those will be Wind Power Plants (WPPs). This is bound to provide the system operators with much clearer image of the potential FSPs in the grid, all that while allowing them to evaluate offers for services made by those FSPs.			
Objective(s)	- Improved forecast of the WPP production power; - Enhanced identification of the potential FSPs in the grid; - Avoidance of congestions through better management of the FSPs; - Avoidance of voltage issues through better management of the FSPs; - Enhancement of system stability via better management of the FSPs; - Cost-efficient operation of the discussed system; - Improvement of the outage management in the system; - Application of the cutting-edge techniques for TwinEU goals.			
Short Description	The use case will be based on the application of the AI-boosted algorithms and high-resolution weather forecasts for improvement of the existing methods of WPP production forecasting. This is expected to provide the system operators and the owners of those facilities with much clearer picture of the way those sources will behave and mitigate issues related to their variability and unpredictability.			
Level of depth	Specialized UC			
UC Diagram	 <pre> graph TD subgraph IT_Provider [IT Provider] START([START]) --> S1[Sending the request for high-res weather forecast] S1 --> R1[Reception of the high-res weather forecast] R1 --> P1[Doing the ANN-based WPP production forecast] P1 --> U1[Uploading the WPP production forecast] end subgraph TSO_DSO [TSO, DSO] D1[Downloading the WPP production forecast] --> U2[Updating the grid models with the forecast] U2 --> END([END]) end subgraph FSP_Aggregator [FSP (or Aggregator)] R2[Reception of request for high-res weather forecast] --> S2[Sending the high-res weather forecast] end subgraph Weather_Forecast [Weather Forecast] R2 S2 end S1 --> R2 S2 --> R1 U1 --> D1 </pre>			

Table 34: Bulgarian Pilot's – BG03 UC overview

UC ID	BG03			
UC name	AI-Improved Forecast of Solar Power Plants (SPP) Production			
Scope	The scope of this task will be the usage of the fit-for-purpose AI techniques in order to improve the quality of the forecasts of the production power of selected capacities in the grid. In this case those will be Solar Power Plants (SPPs). This is bound to provide the system operators with much clearer image of the potential FSPs in the grid, all that while allowing them to evaluate offers for services made by those FSPs.			
Objective(s)	- Improved forecast of the SPP production power; - Enhanced identification of the potential FSPs in the grid; - Avoidance of congestions through better management of the FSPs; - Avoidance of voltage issues through better management of the FSPs; - Enhancement of system stability via better management of the FSPs; - Cost-efficient operation of the discussed system; - Improvement of the outage management in the system; - Application of the cutting-edge techniques for TwinEU goals.			
Short Description	The use case will be based on the application of the AI-boosted algorithms and high-resolution weather forecasts for improvement of the existing methods of SPP production forecasting. This is expected to provide the system operators and the owners of those facilities with much clearer picture of way those sources will behave and mitigate issues related to their variability and unpredictability.			
Level of depth	Specialized UC			
UC Diagram	<pre> graph TD subgraph IT_Provider [IT Provider] START([START]) --> S1[Sending the request for high-res weather forecast] S1 --> R1[Reception of the high-res weather forecast] R1 --> P1[Doing the ANN-based SPP production forecast] P1 --> U1[Uploading the SPP production forecast] end subgraph TSO_DSO [TSO, DSO] D1[Downloading the SPP production forecast] --> U2[Updating the grid models with the forecast] U2 --> END([END]) end subgraph FSP_Aggregator [FSP (or Aggregator)] R2[Reception of request for high-res weather forecast] --> S2[Sending the high-res weather forecast] end subgraph Weather_Forecast [Weather Forecast] R2 S2 end S1 --> R2 S2 --> R1 U1 --> D1 </pre>			

Table 35: Bulgarian Pilot's – BG04 UC overview

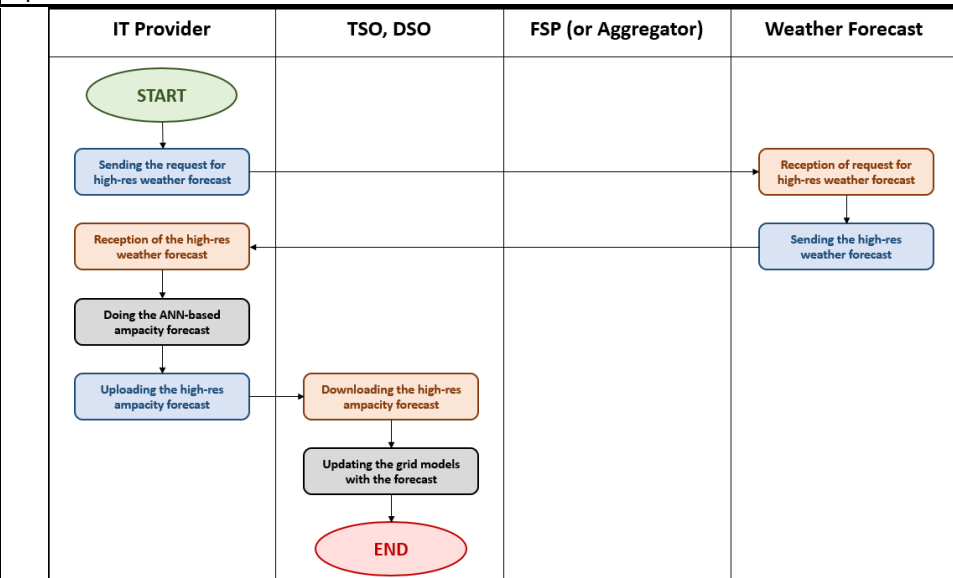
UC ID	BG04				
UC name	AI-Improved Forecast of Overhead Lines (OHL) Ampacity				
Scope	This Use Case will be focused on the benefits of the accurate determination of line rating based on the weather conditions that are valid in the locations of interest. It will be revolving around two main points – the ways in which the ampacity forecasts can aid in usage of power system infrastructure and development of the AI-boosted tool that will be able to calculate those ampacities in a swift and reliable manner.				
Objective(s)	- Improved forecast of the line rating by using AI; - Clearer gradation of the seriousness of the issues in the system; - Enhanced maintenance planning of the grid; - Improved overview of the system state and capabilities; - Cost-efficient operation of the discussed system; - Better investment planning due to higher utilization of existing elements; - Application of the cutting-edge techniques for TwinEU goals.				
Short Description	The Use Case will be based on using AI-boosted algorithms and high-resolution weather forecasts for improvement of the Overhead Lines (OHL) ampacity forecasts. In case seasonal ratings are used, lines can be underutilized due to the security precautions. This Use Case will be focused on determining the benefits of the accurate forecasts of the line ampacities in order to enhance the total system flexibility.				
Level of depth	Specialized UC				
UC Diagram	 <pre> graph TD subgraph IT_Provider [IT Provider] START([START]) --> S1[Sending the request for high-res weather forecast] S1 --> R1[Reception of the high-res weather forecast] R1 --> A1[Doing the ANN-based ampacity forecast] A1 --> U1[Uploading the high-res ampacity forecast] end subgraph TSO_DSO [TSO, DSO] D1[Downloading the high-res ampacity forecast] --> U2[Updating the grid models with the forecast] U2 --> END([END]) end subgraph FSP [FSP (or Aggregator)] % No actions in this lane end subgraph Weather_Forecast [Weather Forecast] R2[Reception of request for high-res weather forecast] --> S2[Sending the high-res weather forecast] end S1 --> R2 S2 --> R1 U1 --> D1 </pre>				

Table 36: Bulgarian Pilot's – BG05 UC overview

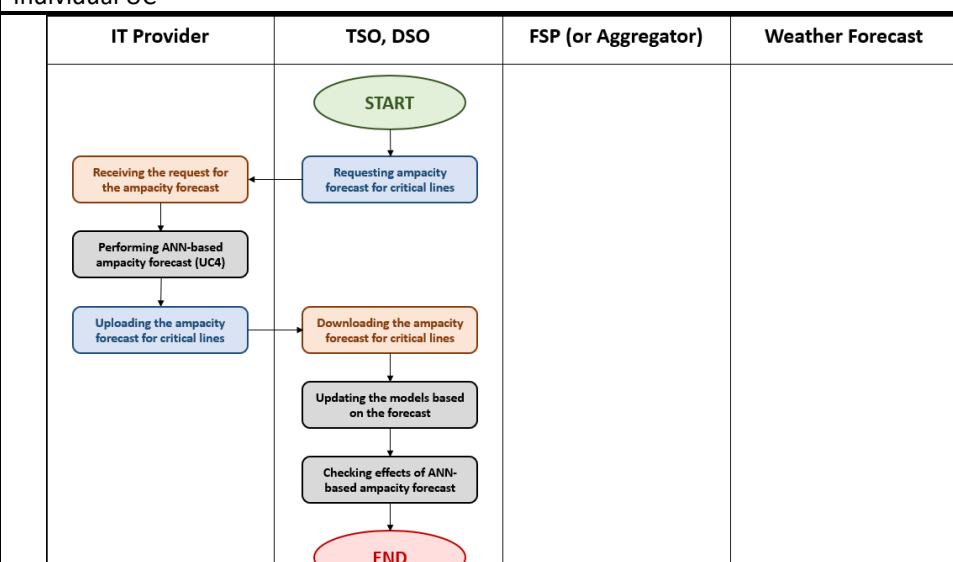
UC ID	BG05				
UC name	Increase of power flow on cross border transmission lines				
Scope	This Use Case will be rather similar to the Use Case Bg04, focusing, instead of the general approach, on the possibility of applying the created AI-based algorithm on the cross-border lines in order to enhance energy and flexibility exchange between the neighbouring systems for the sake of system stability and security.				
Objective(s)	- Improved forecast of the line ratings by using AI; - Enhanced energy exchange between the neighbouring systems; - Enhanced flexibility exchange between the neighbouring systems; - Improvement of the level of system stability and security; - Cost-efficient operation of the system; - Better investment planning due to higher utilization of existing elements; - Application of the cutting-edge techniques for TwinEU goals.				
Short Description	This Use Case will be based on the usage of AI-forecasted ampacity of the cross-border lines in order to improve their ability to respond to the ever-increasing needs for the energy and flexibility exchange among the neighbouring systems. Better utilization of these lines could aid with the security of supply and system stability issues without the need to invest time and money in building new infrastructure.				
Level of depth	Individual UC				
UC Diagram	 <pre> graph TD subgraph TSO_DSO [TSO, DSO] START([START]) --> Request[Requesting ampacity forecast for critical lines] Request --> Download[Downloading the ampacity forecast for critical lines] Download --> Update[Updating the models based on the forecast] Update --> Check[Checking effects of ANN-based ampacity forecast] Check --> END([END]) end subgraph IT_Provider [IT Provider] Receive[Receiving the request for the ampacity forecast] --> Perform[Performing ANN-based ampacity forecast UC4] Perform --> Upload[Uploading the ampacity forecast for critical lines] end Request --> Receive Upload --> Download </pre>				

Table 37: Bulgarian Pilot's – BG06 UC overview

UC ID	BG06
UC name	Determination of optimal locations for RES connection
Scope	This Use Case will be focusing on the determination of the optimal connection points for the RES capacities (either WPPs or SPPs) in the region of interest. An attempt will be made to take into consideration both the interest of the investors in the RES and the interest of the system operators (meaning that the reliable operation of the system cannot be put at risk due to the work of RES at any point).
Objective(s)	• Detection of the optimal connection points for the RES connection; • Achievement of the higher utilization factor of RES; • Reduction of the possibility of RES curtailments; • Better utilization of the potentials for RES construction; • Maintenance of the system security and reliability; • Usage of the optimization techniques for the connection point selection.
Short Description	In order to aid both the system operators and the potential investors in the RES-driven projects, this Use Case will focus on the evaluation of different potential RES connection points in the grid, using the optimization techniques to ensure reliability. This should lead both to the improved yearly capacity factor of those RES and also to the avoidance of the issues in the system as much as it is possible.
Level of depth	Individual UC
UC Diagram	<pre> graph TD subgraph IT_Provider [IT Provider] START([START]) --> Upload[Uploading the relevant forecasts WPP, SPP, amp] Upload --> TSO Receive[Receiving the updated models and requests] --> Opt[Performing the connection point optimization] Opt --> Deliver[Delivering the results of the optimization process] Deliver --> TSO end subgraph TSO_DSO [TSO, DSO] Reception[Reception of the input data for the Use Case] --> Update[Updating the grid model with the forecast] Update --> Send[Sending the updated models and requests] Send --> Receive Results[Reception of the results of the optimization process] --> END([END]) end subgraph FSP [FSP or Aggregator] SendReq[Sending the completed grid connection requests] --> Reception end subgraph Weather_Forecast [Weather Forecast] % No active processes in this column end Upload --> Reception Reception --> Update Update --> Send Send --> Receive Receive --> Opt Opt --> Deliver Deliver --> Results Results --> END </pre>

Table 38: Bulgarian Pilot's – BG07 UC overview

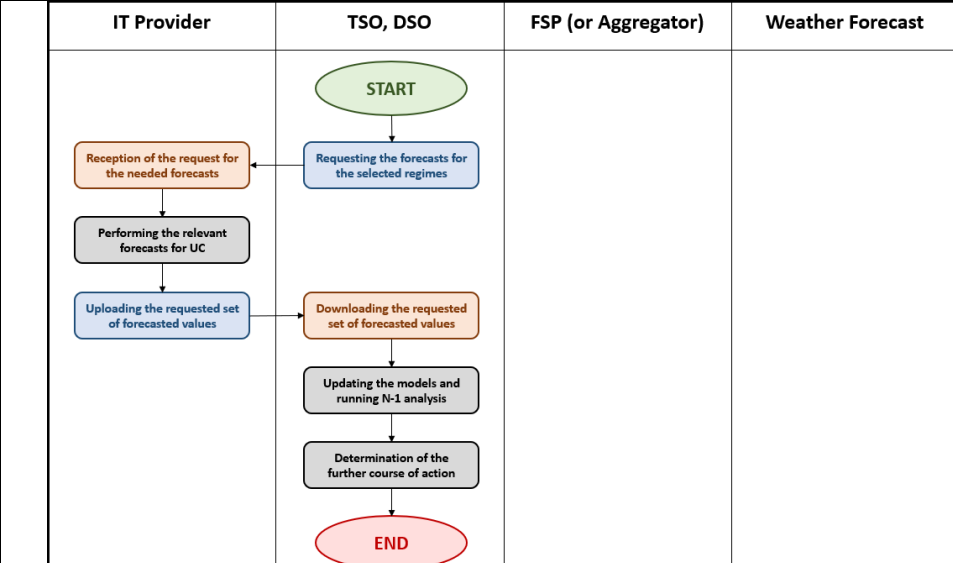
UC ID	BG07				
UC name	N-1 assessment on the DT level				
Scope	This Use Case will be created around the idea of detecting those elements in the transmission grid of Bulgaria whose outage could cause severe issues in the normal operation of the system. This can be used for the risk assessment and, in turn, can be an indicator of the potential action that would need to be taken by the Bulgarian TSO in the next couple of years in order to ensure the proper work of the system.				
Objective(s)	• Load flow calculations and detection of congestions; • Single element outage examination on the DT TSO level; • Enhancement of the system resilience; • Improvement of the level of security of supply; • Indication of the hot spots for investments in the upcoming period; • Risk assessment; • Easier maintenance and planned outages scheduling.				
Short Description	Here, the assessment of system reliability on the DT TSO will be performed. This will be done by simulations of single outages of every element in the grid of interest and checking if some problems occur in the system. After that, the recommendations regarding the operational measures that can mitigate those issues will be given where doable. The results of this Use Case will be used for risk assessment and improvement of the level of reliability that can be expected from the TSO grid.				
Level of depth	Generic UC				
UC Diagram	 <pre> graph TD subgraph IT_Provider [IT Provider] R1[Reception of the request for the needed forecasts] R2[Performing the relevant forecasts for UC] R3[Uploading the requested set of forecasted values] end subgraph TSO_DSO [TSO, DSO] S([START]) R4[Requesting the forecasts for the selected regimes] R5[Downloading the requested set of forecasted values] R6[Updating the models and running N-1 analysis] R7[Determination of the further course of action] E([END]) end subgraph FSP_Aggregator [FSP (or Aggregator)] end subgraph Weather_Forecast [Weather Forecast] end R4 --> R1 R1 --> R2 R2 --> R3 R3 --> R5 R5 --> R6 R6 --> R7 R7 --> E </pre> The diagram illustrates the process flow for the N-1 assessment. It involves four main entities: IT Provider, TSO, DSO, FSP (or Aggregator), and Weather Forecast. The process starts with the TSO, DSO requesting forecasts from the IT Provider. The IT Provider then performs the relevant forecasts and uploads the requested set of forecasted values to the TSO, DSO. The TSO, DSO then downloads the requested set of forecasted values, updates the models, and runs an N-1 analysis. Finally, the TSO, DSO determines the further course of action and ends the process.				

Table 39: Bulgarian Pilot's – BG08 UC overview

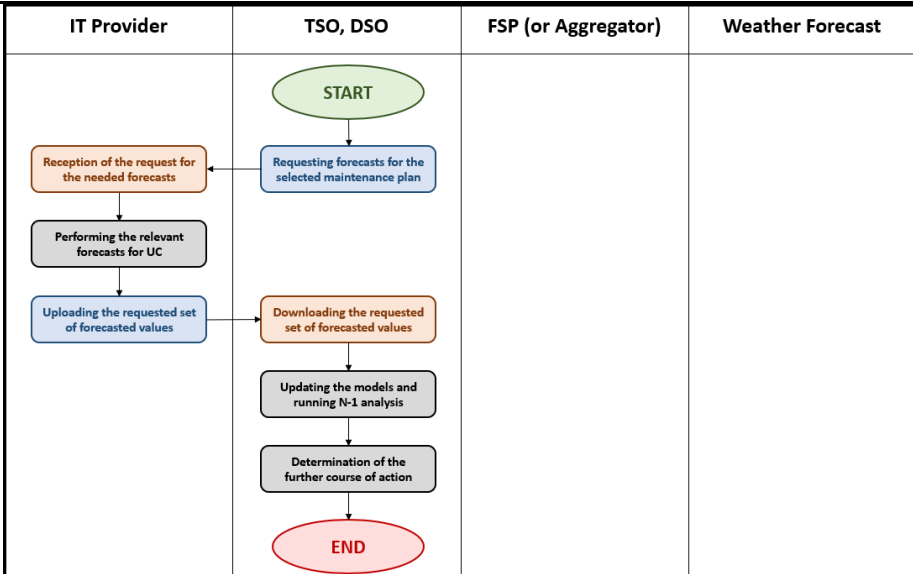
UC ID	BG08				
UC name	DT-based Maintenance plan of TSO grid				
Scope	This Use Case will deal with one of the major issues frequently spotted in the work of the transmission system operator – the problem of properly planning maintenance of the grid so that the minimal strain is put on the remaining elements of the grid. In order for that to be done, the N-1 analysis will be conducted for the situations in the grid in which some other element is already under maintenance. By doing this, the elements during whose maintenance the issues are the most likely to appear will be pointed out. This can be used for performing the proper risk assessment afterwards.				
Objective(s)	• Load flow calculations and detection of congestions; • Single element outage examination on the DT TSO level; • Enhancement of the system resilience; • Improvement of the level of security of supply; • Indication of the hot spots for investments in the upcoming period; • Risk assessment; • Easier maintenance and planned outages scheduling.				
Short Description	In the scope of this Use Case, the simulations of the planned maintenance activities in the DT TSO will be conducted. On each of the system states that occur once some maintenance action happens, N-1 reliability assessment will be conducted in order to determine the potential situations in which issues could happen while the maintenance is underway. This will also be used for risk assessment.				
Level of depth	Individual UC				
UC Diagram	 <pre> graph TD subgraph TSO_DSO [TSO, DSO] START([START]) --> Request[Requesting forecasts for the selected maintenance plan] Request --> Download[Downloading the requested set of forecasted values] Download --> Update[Updating the models and running N-1 analysis] Update --> Action[Determination of the further course of action] Action --> END([END]) end subgraph IT_Provider [IT Provider] Reception[Reception of the request for the needed forecasts] Perform[Performing the relevant forecasts for UC] Upload[Uploading the requested set of forecasted values] end Request --> Reception Perform --> Upload Upload --> Download </pre>				

Table 40: Bulgarian Pilot's – BG09 UC overview

UC ID	BG09				
UC name	Flexibility Requirements to Avoid Congestions				
Scope	The Use Case will address a scenario of the congestion in the distribution grid and explore potential solutions through the application of FSPs in the same region. The FSPs that will be considered here will be the ones connected to the distribution grid. The type of the FSP will depend on the analysed part of the grid, but can potentially include the WPPs, SPPs (paired with ANN-trained DTs) or controllable demand.				
Objective(s)	- Better utilization of the existing FSPs in the distribution grid; - Reduction of contingencies in the distribution grid; - Improvement of the security of energy supply to the customers; - Improvement of the level of system resilience; - Prevention of the issues in the DSO grid from affecting the TSO grid; - Cost-efficient operation of the system; - Avoiding potential investments needed for mitigating the congestion.				
Short Description	The situation that will be simulated here is the one in which the congestion happens in the distribution grid. After that, the appropriate flexibility measures will be applied to avoid the outages. Depending on the part of the grid, these measures could include the DSR or the modifications of the production the WPPs and SPPs in the area (depending on their capabilities determined in the ANN-trained DTs).				
Level of depth	Individual UC				
UC Diagram	<pre> graph TD subgraph IT_Provider [IT Provider] START([START]) Upload[Uploading the relevant forecasts (WPP, SPP, amp)] end subgraph TSO_DSO [TSO, DSO] Download[Downloading the relevant forecasts (WPP, SPP, amp)] Update[Updating model and detecting issue in DSO grid] SendInfo[Sending the information on the services needed] RecvOffers[Reception of the FSP offers] FindSol[Finding the best solution for the spotted problem] END([END]) end subgraph FSP_Aggregator [FSP (or Aggregator)] RecvInfo[Reception of information on the services needed] SendOffers[Sending the service offers (FSP in DSO grid)] end subgraph Weather_Forecast [Weather Forecast] end START --> Upload Upload --> Download Download --> Update Update --> SendInfo SendInfo --> RecvInfo RecvInfo --> SendOffers SendOffers --> RecvOffers RecvOffers --> FindSol FindSol --> END </pre>				

Table 41: Bulgarian Pilot's – BG10 UC overview

UC ID	BG10				
UC name	Inter-SO Flexibility Exchange				
Scope	The Use Case will address a scenario of the congestion in the transmission grid and explore potential solutions through the application of FSPs in the same region. The FSPs that will be considered here will be the ones connected to the distribution grid. The type of the FSP will depend on the analysed part of the grid, but can potentially include the WPPs, SPPs (paired with ANN-trained DTs) or controllable demand.				
Objective(s)	• Better utilization of the existing FSPs in the distribution grid; • Reduction of contingencies in the distribution grid; • Improvement of the security of energy supply to the customers; • Improvement of the level of system resilience; • Utilization of DSO-based FSPs for mitigating issues in TSO grid; • Cost-efficient operation of the system; • Avoiding potential investments needed for mitigating the congestion.				
Short Description	Here, the situation in the DT TSO will be simulated in which the congestion is spotted. After that, the appropriate flexibility measures will be applied to avoid the outages. The problem will not be solved by activating the flexibility resources connected to TSO grid, but by those connected to DSO grid. This will highlight the potential of TSO-DSO cooperation and coordination to avoid issues in the system, giving a boost to the flexibility exchange discussions in the process as well.				
Level of depth	Individual UC				
UC Diagram	<pre> graph TD subgraph IT_Provider [IT Provider] START([START]) Upload[Uploading the relevant forecasts (WPP, SPP, amp)] end subgraph TSO_DSO [TSO, DSO] Download[Downloading the relevant forecasts (WPP, SPP, amp)] Update[Updating model and detecting issue in TSO grid] SendInfo[Sending the information on the services needed] RecOffers[Reception of the FSP offers] FindSol[Finding the best solution for the spotted problem] END([END]) end subgraph FSP_Aggregator [FSP (or Aggregator)] RecInfo[Reception of information on the services needed] SendOffers[Sending the service offers (FSP in DSO grid)] end subgraph Weather_Forecast [Weather Forecast] end START --> Upload Upload --> Download Download --> Update Update --> SendInfo SendInfo --> RecInfo RecInfo --> SendOffers SendOffers --> RecOffers RecOffers --> FindSol FindSol --> END </pre>				

5.4.2 Dutch/French Pilot Site UCs

Table 42: Dutch Pilot's – NL01 UC overview

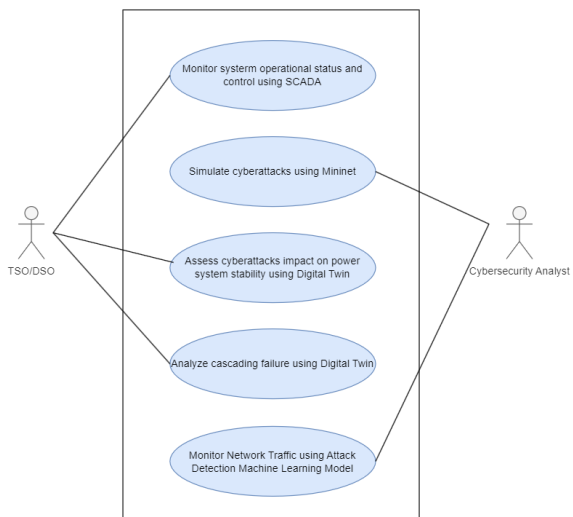
UC ID	NL01
UC name	DT-enabled real-time cyberattack detection and impact analysis on the operation of integrated power grid
Scope	The scope of this UC is to monitor and detect anomalies associated with cyberattacks, analyse the impact of cyberattacks on stability and cascading failures in real-time on the operation of interconnected power grids.
Objective(s)	The objective of this UC is to leverage the potential of the DT at TSO and DSO level to assess operation of power grids to various cyberattacks and analyse the impact of cyberattacks on system stability and cascading failures.
Short Description	In this UC, digital twin will be used to simulate the cyber-attacks and assess the impact of cyber-attacks on interconnected power grids. The UC will simulate real-time cyber-attacks to evaluate their effects, such as loss of generation capacity, effect on power system components, and the overall impact on power system operations. Additionally, the UC will investigate how cyber-attacks could trigger N-k contingencies, leading to cascading failures and a widespread blackout. Machine learning algorithms will also be used for real-time monitoring and anomaly detection, continuously analysing network traffic and operational data to quickly identify deviations from normal patterns.
Level of depth	Individual UC
UML Diagram	 <pre> sequenceDiagram actor TSO_DSO as TSO/DSO actor Analyst as Cybersecurity Analyst participant System as Monitor system operational status and control using SCADA Simulate cyberattacks using Mininet Assess cyberattacks impact on power system stability using Digital Twin Analyze cascading failure using Digital Twin Monitor Network Traffic using Attack Detection Machine Learning Model end TSO_DSO --> System Analyst --> System </pre> The UML diagram illustrates the interactions for the NL01 use case. It features two actors: 'TSO/DSO' and 'Cybersecurity Analyst'. A central system boundary contains five use cases: 'Monitor system operational status and control using SCADA', 'Simulate cyberattacks using Mininet', 'Assess cyberattacks impact on power system stability using Digital Twin', 'Analyze cascading failure using Digital Twin', and 'Monitor Network Traffic using Attack Detection Machine Learning Model'. Both actors are connected to the system boundary, indicating their involvement in the use case.

Table 43: Dutch Pilot's – NL02 UC overview

UC ID	NL02
UC name	DT-based dynamic stability assessment under active power flow changing events.
Scope	This use case aims to develop and implement a Digital Twin (DT) to assess and enhance the stability of power systems under various active power flow disturbances. The DT will model and simulate the real-time dynamics of the power grid, including interactions between Distribution System Operators (DSOs) and Transmission System Operators (TSOs). The study will focus on understanding the impact of events such as generation tripping, load shedding, transmission line faults, large-scale renewable integration fluctuations, and demand response events on system stability.
Objective(s)	Develop a Digital Twin (DT) capable of simulating the dynamic behaviour of power systems during active power flow disturbances. Calibrate the DT using generated signal records from simulations, accessible published databases, and parameter estimation techniques to obtain a numerically acceptable representation of real-time system dynamics.

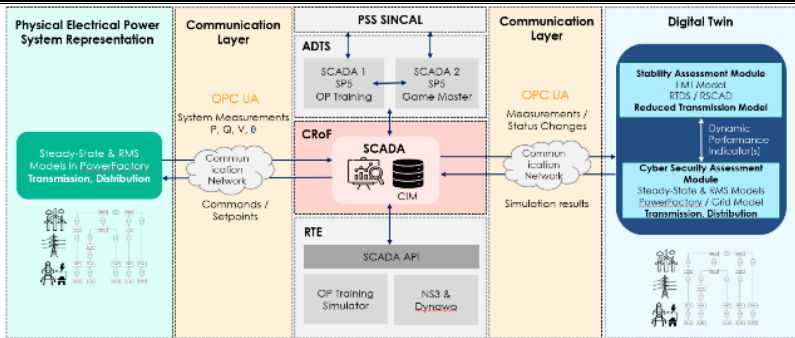
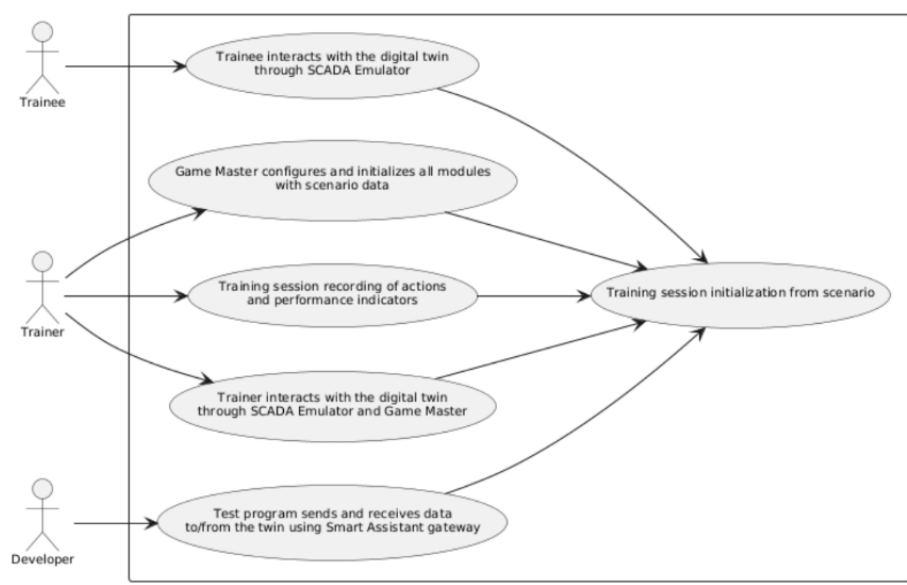
	Analyze the impact of various disturbance scenarios on system stability, focusing on frequency deviations, voltage stability, and power oscillations. Evaluate and propose control and mitigation strategies that enhance the coordination between DSOs and TSOs during disturbance events.
Short Description	Development and utilization of a Digital Twin (DT) to evaluate and enhance the stability of the power system under various active and reactive power flow disturbance scenarios, emphasizing the critical interaction between Distribution System Operators (DSOs) and Transmission System Operators (TSOs). The DT will simulate system responses to identify potential stability issues and propose solutions.
Level of depth	Generic UC
UC Diagram	 RTDS – Real-Time Digital Simulator CIM – Common Information Model OPC UA – Open Platform Communications Unified Architecture API – Application Programming Interface OP – Operators SPS – Spectrum Power 5

Table 44: French Pilot's – FR01 UC overview

UC ID	FR01
UC name	Power system training simulator for complex and critical situations
Scope	The scope of this UC concerns: Cooperative training sessions for system operators. Testbed for software or hardware modules.
Objective(s)	The objective of this use case is to improve the training of system operators on realistic network scenarios, involving power network as well as communication network events. The DT should be able to play scenarios and to record the results for debrief with trainees.
Short Description	The digital twin is meant for training system operators on stability-critical scenarios and for testing of new components (automata, software decision modules, etc.). It will include several modules within a co-simulator interfaced through an orchestrator module: Cyber-physical simulators to represent physical and cyber networks. SCADA that will display network state to operators and send orders from the operators to the cyber-physical simulators. A game master will supervise all the modules and will have the ability to run training scenarios. The twin provides input/output interfaces for interfacing software or hardware modules.
Level of depth	Individual UC
UC Diagram	 <pre> graph LR Trainee((Trainee)) --> UC1([Trainee interacts with the digital twin through SCADA Emulator]) Trainer((Trainer)) --> UC2([Game Master configures and initializes all modules with scenario data]) Trainer --> UC3([Training session recording of actions and performance indicators]) Trainer --> UC4([Trainer interacts with the digital twin through SCADA Emulator and Game Master]) Developer((Developer)) --> UC5([Test program sends and receives data to/from the twin using Smart Assistant gateway]) UC1 --> UC6([Training session initialization from scenario]) UC2 --> UC6 UC3 --> UC6 UC4 --> UC6 UC5 --> UC6 </pre>

5.4.3 Eastern-Mediterranean Pilot Site UCs

Table 45: Greek Pilot's – EM-GR-01 UC overview

UC ID	EM-GR-01
UC name	Congestion management in transmission and distribution grids through TSO-DSO coordination
Scope	This UC focuses on utilizing Distributed Energy Resources (DERs) and Industrial Demand Response to mitigate congestion in both local distribution and transmission grids. This involves analysing how DERs, such as solar panels, wind turbines, energy storage systems and electric vehicles, can be integrated and managed to alleviate grid stress during peak demand periods. This will be achieved by online coordinating DERs for upward energy balancing according to flexibility services availability. Additionally, the scope includes optimising industrial demand response to dynamically adjust and reduce energy consumption during peak periods, thereby enhancing grid stability and efficiency.
Objective(s)	• Active participation of DERs in the grid management process with potential economic benefits • Avoid voltage and thermal limits violations in distribution grids • Avoid congestion in distribution lines • Reduce grid energy losses • Reduce investments for grid reinforcement • Effective utilization of existing grid capacity • Enhance grid stability and efficiency through coordinated industrial energy management. • Integrate industrial demand response mechanisms to balance energy supply and demand dynamically.
Short Description	The integration of DERs into the electrical grid presents a transformative opportunity for enhancing grid flexibility, resilience, and efficiency. The high penetration of renewable energy resources in specific feeders causes local congestion problems (voltage and thermal limit violations) in the distribution grid. In this UC, we explore how DERs can play a crucial role in congestion management at the DSO level, leveraging a digital twin framework for the balancing market. DERs encompass a diverse range of distributed energy assets, including solar PVs, wind turbines, energy storage systems (ESS), demand response resources, and EVs. These assets have the inherent capability to adjust their operation in response to grid conditions, providing valuable flexibility that can be harnessed for balancing supply and demand and alleviating congestion in the distribution grid. In terms of the HV grid, industrial demand response can significantly alleviate congestion in the HV grid by adjusting the electricity consumption patterns of large industrial consumers. During peak demand periods or times of grid stress, industrial facilities can reduce or shift their electricity usage, thereby easing the strain on the HV grid. This flexible adjustment helps to balance supply and demand in real-time, reduces the need for costly grid upgrades, and minimizes the risk of blackouts. By participating in demand response programs, industries not only contribute to grid stability but also benefit from potential cost savings and incentives, enhancing overall grid efficiency and reliability.
Level of depth	High-level UC
UC Diagram	

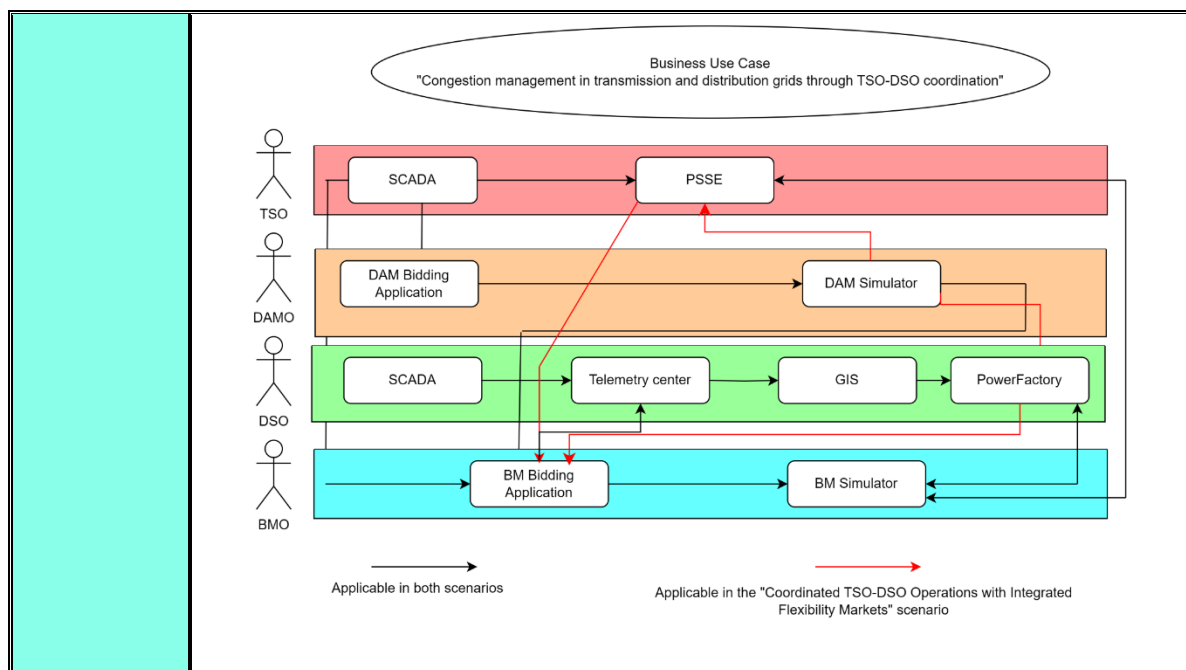


Table 46: Greek Pilot's – EM-GR-02 UC overview

UC ID	EM-GR-02
UC name	Fast Frequency Response for Effective Frequency Control through TSO-DSO coordination
Scope	The scope of this UC includes the essential role of Fast Frequency Response (FFR) in maintaining grid stability by rapidly addressing frequency deviations, the comparative advantages of FFR over Frequency Containment Reserves (FCR), the various technologies capable of providing FFR, and the modeling and optimization of FFR within the balancing market. It also covers the participation of different entities in providing FFR services and the regulatory considerations necessary to ensure reliable grid operation.
Objective(s)	• Ensure rapid and effective response to frequency deviations to maintain grid stability. • Provide faster primary reserves compared to traditional Frequency Containment Reserves (FCR). • Integrate various technologies, (mainly batteries) to deliver Fast Frequency Response (FFR). • Optimize the deployment of FFR resources using sophisticated algorithms to balance system requirements, grid conditions, and economic considerations. • Facilitate participation in the balancing market through accurate modelling of FFR capabilities and characteristics.
Short Description	The increasing penetration of renewables in power systems introduces new challenges for their control and operation. Conventional synchronous generators provide system inertia by storing or discharging kinetic energy with minimal changes in rotational speed. However, as these rotating generation units are increasingly replaced by wind and solar units, system inertia decreases, leading to a reduction in Frequency Containment Reserves (FCR), which are closely linked to inertia. Additionally, the rapid dynamics of energy storage systems and inverters necessitate new solutions to ensure effective system control within security and reliability constraints. Fast Frequency Response (FFR) offers a potential solution to these challenges. FFR can play a critical role in maintaining grid stability in modern power systems with high renewable energy integration and evolving demand patterns. Designed to quickly counteract frequency deviations caused by sudden changes in supply or demand, FFR helps to keep grid frequency within acceptable limits, thereby supporting overall system stability.

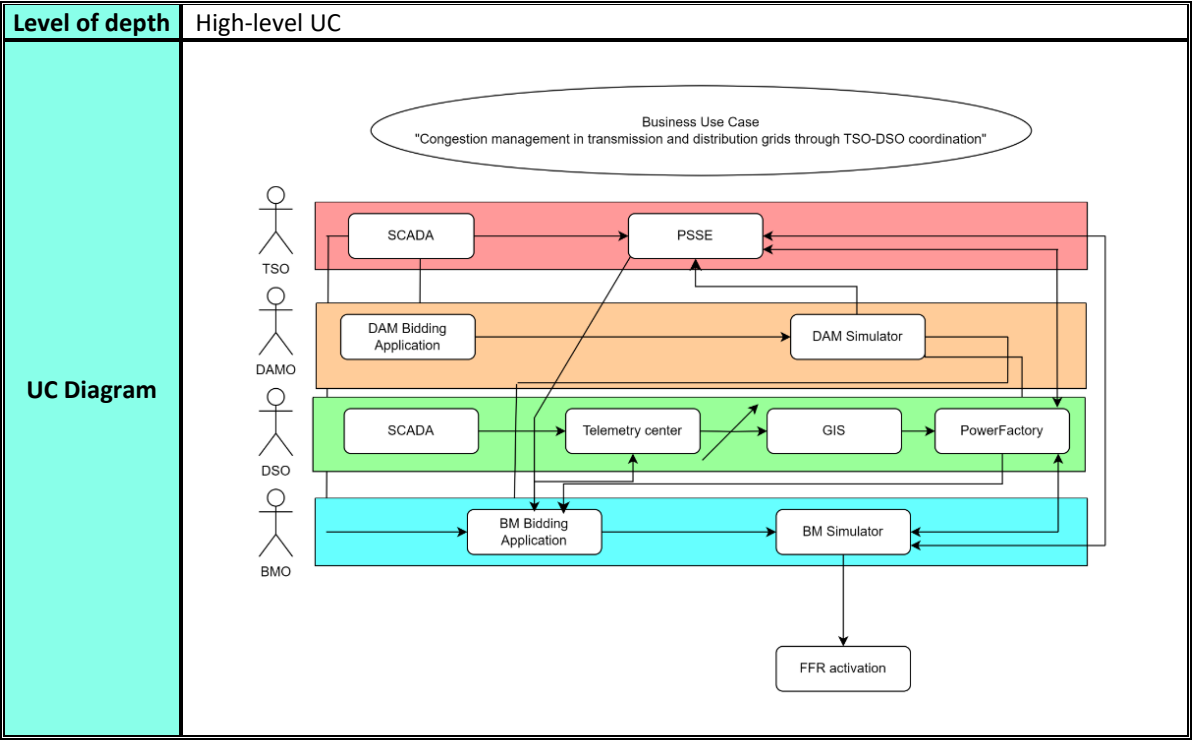


Table 47: Cypriot Pilot's – EM-CY-01 UC overview

UC ID	EM-CY-01
UC name	Congestion management in distribution grids through ancillary services
Scope	The scope of this UC concerns: - Cooperative training sessions for system operators. - Testbed for software or hardware modules.
Objective(s)	- Avoid thermal limit violation in local distribution grids. - Reduce of grid energy losses. - Reduce investments for grid reinforcement. - Effective utilization of existing grid capacity. - Active participation of DERs in the grid management process with potential economic benefits. - Showcase the cyberattack in active distribution grid management.
Short Description	Cyprus power system favours the massive installation of PV due to the climate conditions (abundant of sun) in order to achieve the national environmental target. The high penetration of renewables in specific feeders causes local congestion problems (voltage and thermal limit violations) in the distribution grid. Active and reactive power flexibilities provided by DERs will be coordinated by the DSO to relieve congestion and increase grid efficiency with the help of a digital twin framework. The management of flexibility services will be governed through a local ancillary services market.
Level of depth	High-level UC
UC Diagram	<pre> graph TD subgraph Business_Use_Case [Business Use Case "Congestion management in distribution grids through ancillary services"] DSO MO FSP end subgraph DSO_Box [DSO] S1[SCADA/smart meter monitoring system] --> S2[Execution of what-if scenarios using distribution grid digital twin] S2 --> S3[Procurement of congestion management availability products] S3 --> S4[Real time coordination for activating DERs flexibility] end subgraph MO_Box [MO] S5[Local ancillary service clearing mechanism] end subgraph FSP_Box [FSP] S6[Ancillary services bidding] --> S7[Control of active and reactive power according to DSO activation signals] end S3 --> S5 S5 --> S7 S7 --> S4 </pre>

Table 48: Cypriot Pilot's – EM-CY-02 UC overview

UC ID	EM-CY-02
UC name	Frequency support management of HVDC-interconnected systems at a regional level
Scope	Regional level coordination for the frequency support services of an HVDC link to enhance the stability of two interconnected systems (countries). A regional coordination framework will be established to manage the frequency support provision by considering the stability requirements and constraints at each side of the HVDC link. During an intense power imbalance disturbance, the stability of each country will be analysed through an interconnected digital twin environment.
Objective(s)	- Enhance frequency stability at each interconnected country, - Minimize cascading effect between countries during an intense power imbalance and showcase the potential impact of a cyber-attack in an HVDC link, - Effective regional coordination of an HVDC interconnection to support high-RES penetration in low-inertia systems.
Short Description	Cyprus power system prioritizes the massive installation of PVs to achieve the national climate targets. The high penetration of renewable energy sources (RES) in combination with the islanded nature of the system creates critical challenges related to frequency stability and balancing due to the unpredicted nature of RES and the low-inertia characteristics of the system. There is an undergoing project (i.e., Great Sea Interconnector) of great importance to interconnect the Cyprus and Greece power systems. In this context, a digital twin environment replicating the interconnected power systems will be developed, allowing different investigations and enabling the implementation of a regional coordination framework to enhance both systems' stability.
Level of depth	High-level UC
UC Diagram	The diagram illustrates the Business Use Case "Frequency support management of HVDC-interconnected systems in a regional level". It shows the interactions between five main entities: TSO at each country, MO at each country, RSC, HVDC operator, and FSP. Entities and their associated processes: TSO at each country: Procurement of FCR bids, Calculation of HVDC link constraints, Wide area monitoring. MO at each country: FCR market clearing. RSC: Bilateral communication of each country HVDC constraints, Wide area FCR controller. HVDC operator: FCR offers submission, HVDC controller with adaptive FCR settings. FSP: FCR offers submission, DER controller with adaptive FCR settings. Flow of information and control: - TSO at each country provides Procurement of FCR bids to MO at each country. - MO at each country performs FCR market clearing, which involves bilateral communication with RSC. - TSO at each country provides Calculation of HVDC link constraints to RSC. - RSC performs Wide area FCR controller, which interacts with the HVDC operator. - TSO at each country provides Wide area monitoring to RSC. - Both TSO at each country and MO at each country provide FCR offers submission to the HVDC operator. - The HVDC operator manages the HVDC controller with adaptive FCR settings, which interacts with the FSP's DER controller with adaptive FCR settings.

5.4.4 German Pilot Site UCs

Table 49: German Pilot's – Ge01 UC overview

UC ID	Ge01
UC name	Utilization monitoring on LV-/MV-level
Scope	Visualization of the distribution grid, integrating real-time measurements from Scada-like systems and intelligent meter measurements.
Objective(s)	Have a measurement-based real-time monitoring of grid utilization in order to identify bottlenecks.
Short Description	UC 1 focuses on implementing the Intelligent Grid Platform (IGP) to digitally visualize the distribution grid, integrating real-time measurements from SCADA-like systems and intelligent meter measurements. The platform enables online monitoring, visualization of measurement locations and values, and in-depth analysis of parameters like voltage, utilization, and symmetry, with notifications for threshold violations. The primary objective is to achieve measurement-based real-time monitoring to identify grid bottlenecks, benefiting the distribution system operator by providing comprehensive grid visualization, statistics on utilization rates and voltage levels, and the ability to detect data inconsistencies for continuous improvement.
Level of depth	Generic UC
UC Diagram	<pre> graph LR MDP[MDP] -- "Station Measurements" --> IGP[Intelligent Grid Platform] MPO[MPO] -- "Smart Meter Data" --> IGP subgraph IGP_Box [Intelligent Grid Platform] MV([Measurement Visualisation]) MA([Measurement Analysis]) end IGP_Box -- "use" --> DSO[DSO] </pre>

Table 50: German Pilot's – Ge02 BUC overview

UC ID	Ge02
UC name	State estimation under changing topology on LV-level
Scope	Expansion of utilization monitoring by integrating real-time topology measurements and developing state estimation algorithms
Objective(s)	Extend the observability from the measurement locations to the full grid using digital twin information (asset attributes, topology, load/generation data, etc.) and computational methods, including changes to the topology and resulting changes in the grid state.
Short Description	UC 2 expands upon utilization monitoring by integrating real-time topology measurements and developing state estimation algorithms. These algorithms analyse measurement data and topology changes to continuously update and visualize the grid state in real-time, including warnings for limit violations. The objective is to enhance observability across the entire grid using digital twin information and computational methods, enabling the distribution system operator to identify and respond to critical situations throughout the grid. By automatically considering topology changes, the system ensures accurate grid state estimation even after network reconfigurations, providing comprehensive grid monitoring and management capabilities.
Level of depth	Individual UC

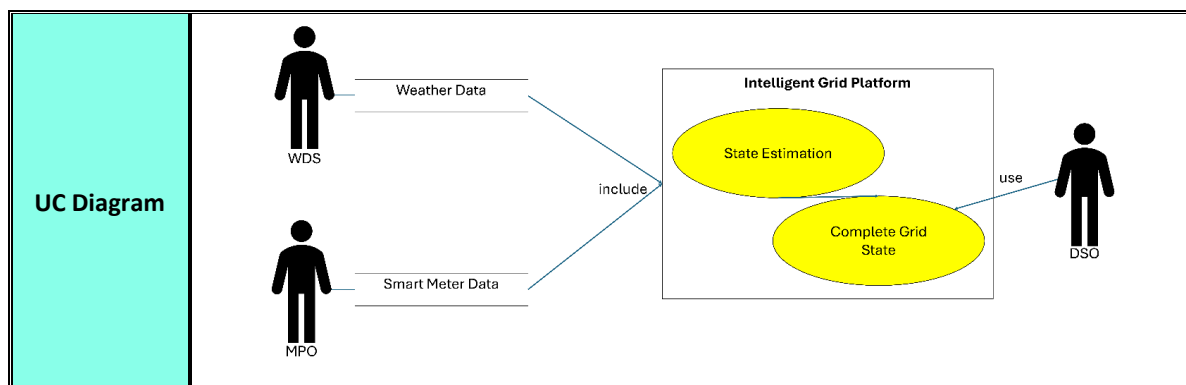


Table 51: German Pilot's – Ge03 BUC overview

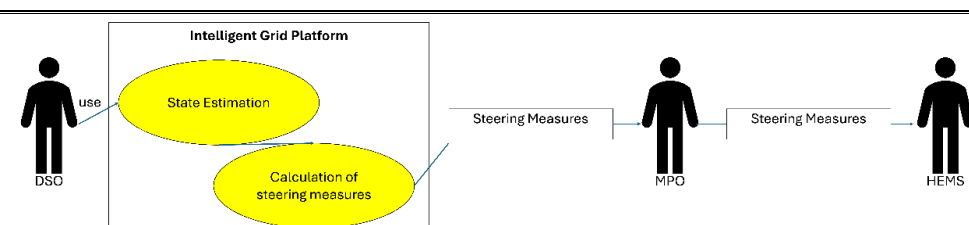
UC ID	Ge03
UC name	Development of advanced monitoring & control tools for congestion management
Scope	Implementation of curative control measures to address bottlenecks in the grid caused by the increasing adoption of electromobility and heat pumps.
Objective(s)	Curative control of congestions based on state estimations.
Short Description	UC 3 utilizes a central network model continuously validated with sensor data integration to perform regular state estimations, identifying critical network states and areas. The objective is to implement curative control measures to address bottlenecks in the grid caused by the increasing adoption of electromobility and heat pumps. By analysing real-time grid status and historical data, the system generates schedules for grid operators to implement ad-hoc adjustments to alleviate congestion. This proactive approach enables the grid operator to manage electricity consumption spikes from electric vehicles and heat pumps, mitigating potential overload scenarios in the low-voltage grid and facilitating the transition to new energy business models.
Level of depth	High-level UC
UC Diagram	 <pre> graph LR DSO[DSO] -- "use" --> SE([State Estimation]) subgraph IGPI [Intelligent Grid Platform] SE CS([Calculation of steering measures]) end CS --> SM1[Steering Measures] SM1 --> MPO[MPO] MPO -- "Steering Measures" --> HEMS[HEMS] </pre>

Table 52: German Pilot's – Ge04 UC overview

UC ID	Ge04
UC name	Development of a concept for a preventive congestion management
Scope	Development of a concept for preventive congestion management, focusing on the conceptual development of a congestion forecast and possible proactive control measures.
Objective(s)	Development of a concept for preventive congestion management.
Short Description	UC 4 aims to develop a concept for preventive congestion management, focusing on the conceptual development of a congestion forecast and possible proactive control measures. The objective is to identify efficient calculation logic for forecasting congestion, with emphasis on critical low-voltage grids. Through the analysis of user data, grid conditions, and various models, the system aims to devise proactive strategies to mitigate congestion. The implementation in the German demonstrator involves testing and evaluating these models to ensure effective preventive congestion management. Additionally, the use case

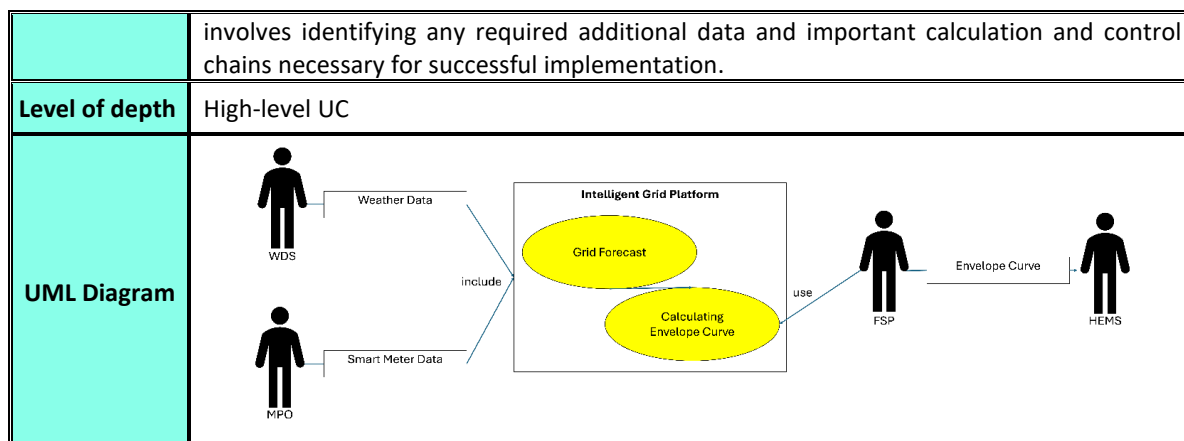
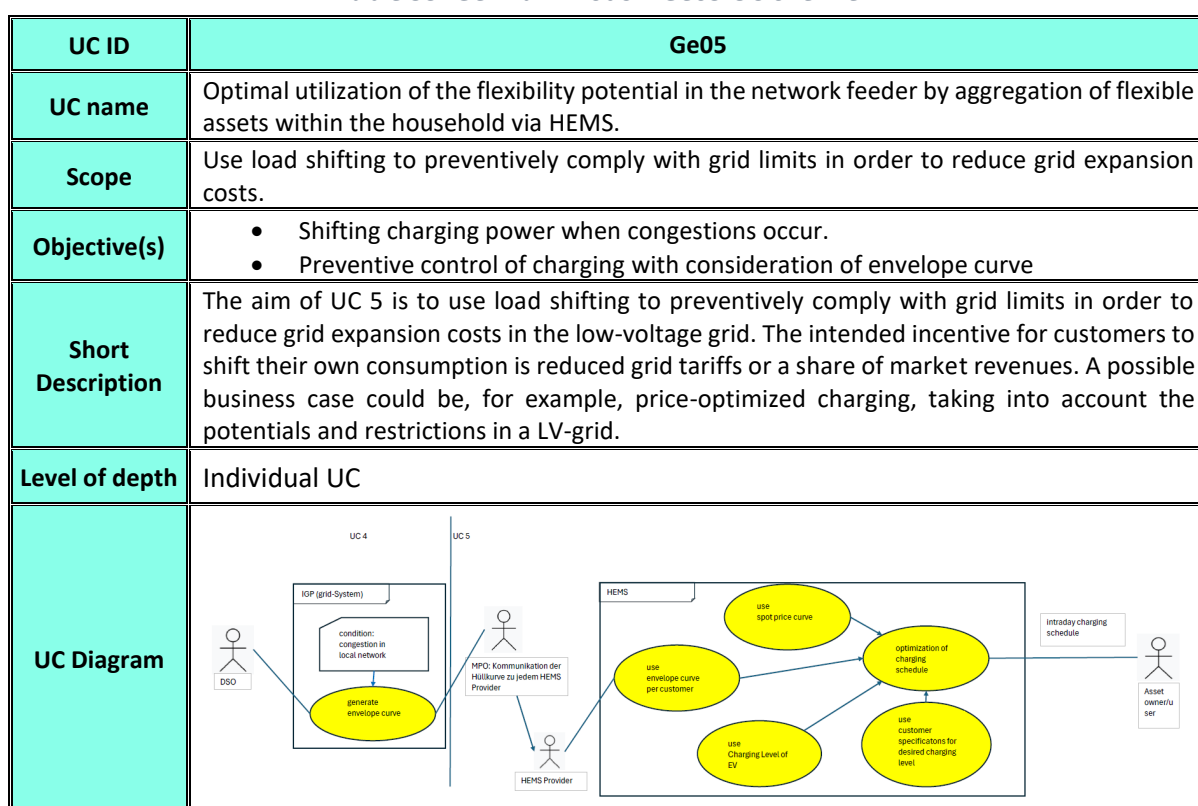


Table 53: German Pilot's – Ge05 UC overview



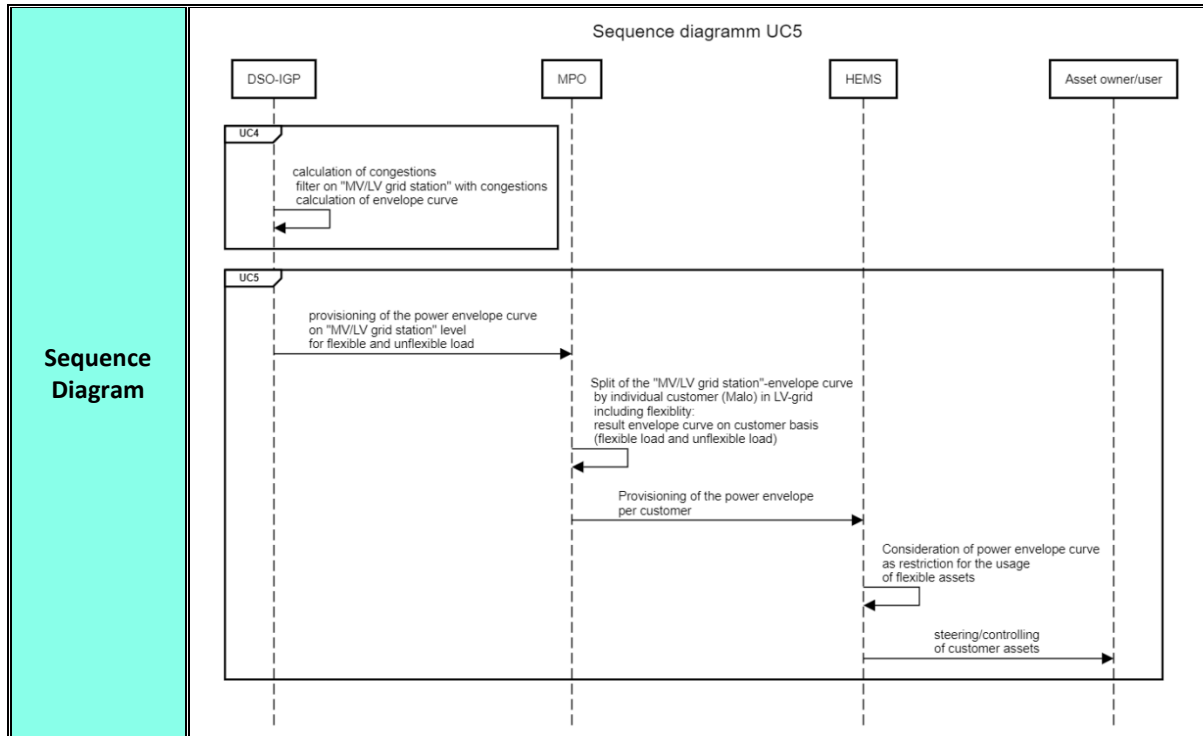


Table 54: German Pilot's – Ge06 UC overview

UC ID	Ge06
UC name	Development of advanced tools for preventive congestion management through regional aggregation of flexible assets
Scope	Further application of aggregated flexibility is considered conceptually in terms of additional use and business cases.
Objective(s)	- Collection of customer data - Forecast flexibility - Aggregation of the customers - Calculation of secured power for Redispatch 3.0 - After the TSO accepts the offer, a signal is sent to initiate disaggregation and deliver the service at the individual customer level - Steering of customers
Short Description	In Use Case 6, the further application of aggregated flexibility, which was already determined and used in the previous use case, is considered conceptually. The entire process chain from data collection to control is considered conceptually in order to be able to provide secure power. This secured power can be offered, for example, by mFRR or redispatch.
Level of depth	High-level UC
UC Diagram	

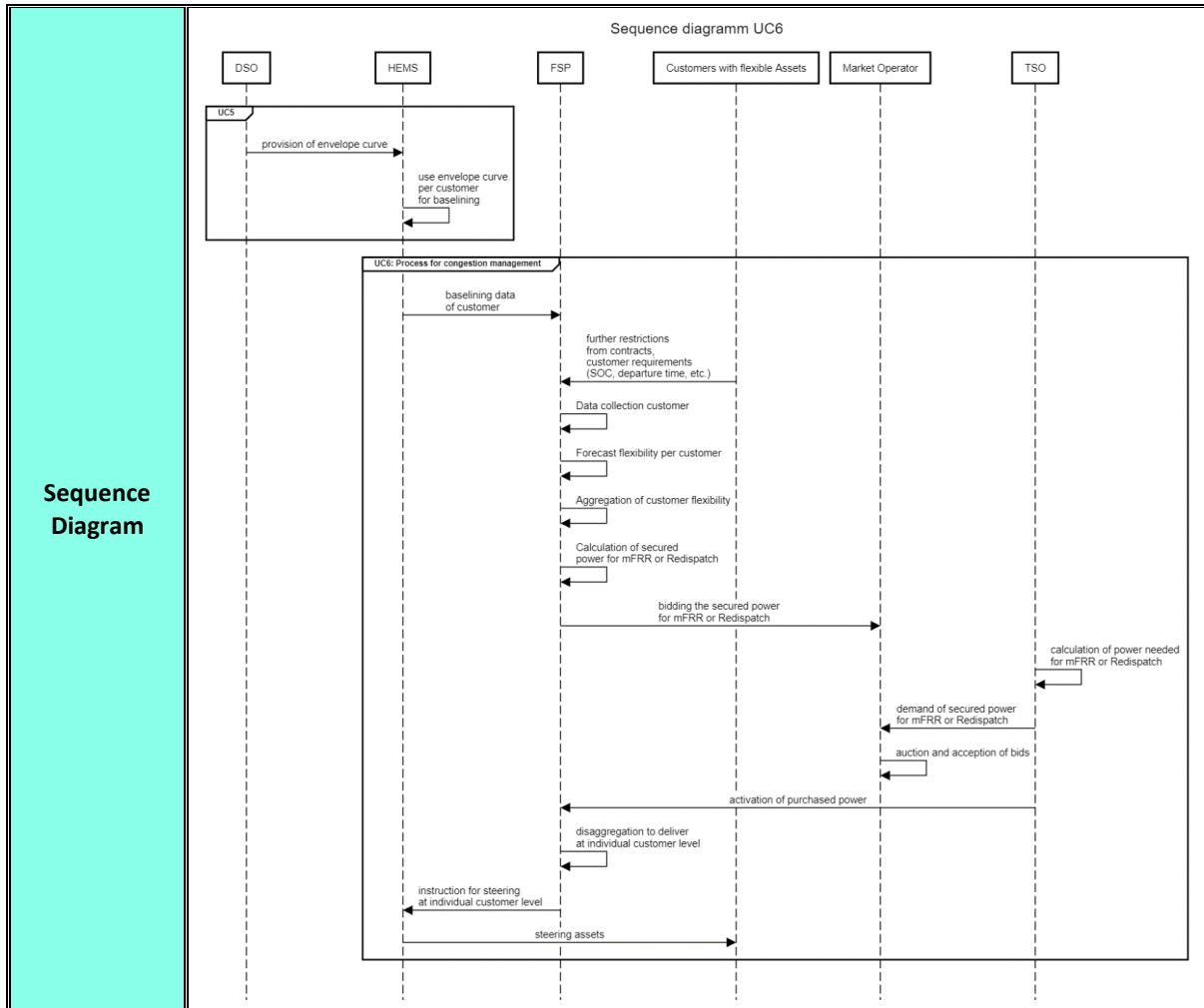


Table 55: German Pilot's – Ge07 UC overview

UC ID	Ge07
UC name	Conceptual description of interoperable solutions that support an efficient TSO-DSO data exchange on the interface level.
Scope	Enhancement of data integration between DSOs and TSOs to improve grid reliability, efficient integration of renewable energy sources and use of flexibilities for the transmission system.
Objective(s)	The European interconnected grid is based on a distribution of tasks according to the voltage levels. Ultimately, this distribution can only function efficiently if the necessary information is available to all parties involved. In particular, the redispatch and ancillary power processes, using micro-flexibilities on LV-level for TSO-purposes, are very important objectives for all parties involved. Existing projects such as PKME and systems such as connect+ could be used for the implementation. Specifically, the following goals are to be achieved: • define a target architecture for a future data exchange. • define requirements to specify the role of market aggregator with regards to TSO-DSO-Connection. • enable the usage of small flexibility sources and test different solutions to initiate and utilize the value chain beginning with the smallest flexibility over to the TSO.
Short Description	UC 7 aims to enhance data integration between DSOs and TSOs to improve grid reliability and the efficient integration of renewable energy sources. It analyses the possibilities of

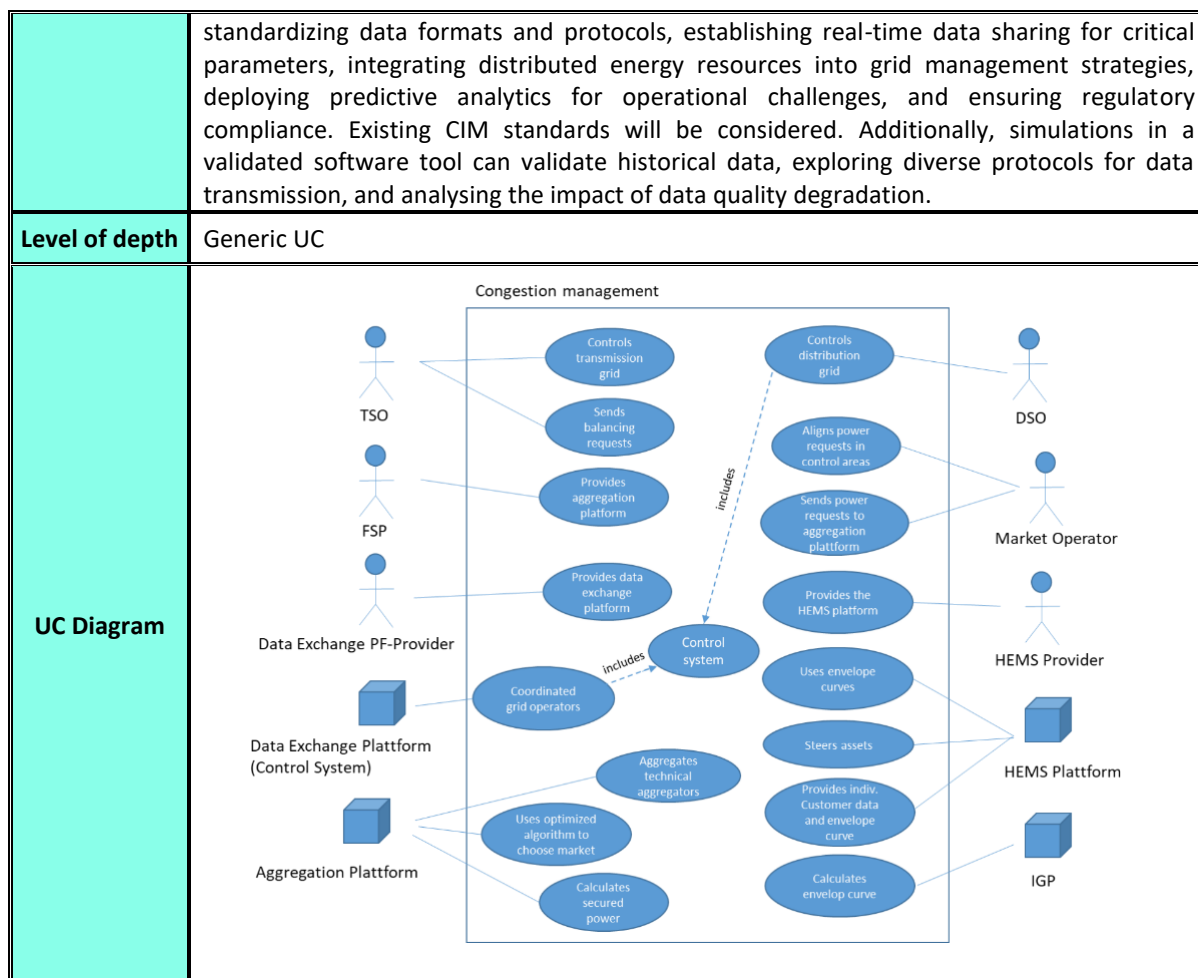
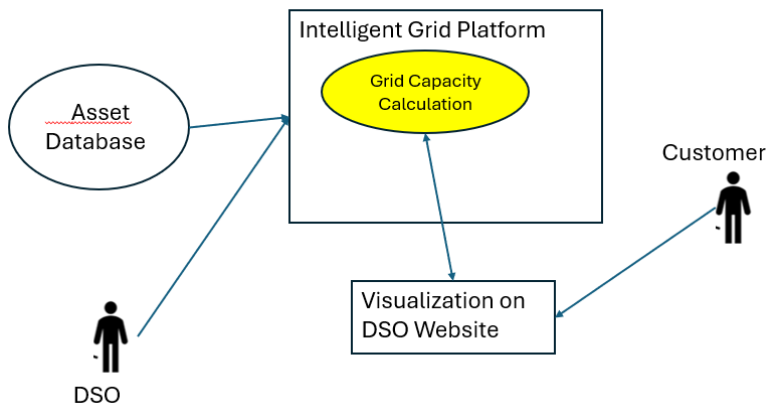


Table 56: German Pilot's – Ge08 UC overview

UC ID	Ge08
UC name	Visualizing hosting capacities within Connection request and online connection check applications.
Scope	Development of a grid hosting map.
Objective(s)	• Allocate grid hosting capacities. • Interconnecting different systems of DSOs and TSOs. • Improve the quality of network planning. • Optimise DSO and TSP network operation.
Short Description	This task provides an integrated mapping of grid hosting capacities (installed and projected), as well as visibility over the connected assets in the Demonstrator. This includes connection request and online connection check applications for the DSO, TSO as well as for third parties (market operators) for e.g., pre-connection check calculations.
Level of depth	Individual UC
UC Diagram	 <pre> graph LR DSO((DSO)) --> AD((Asset Database)) AD --> IGP[Intelligent Grid Platform] subgraph IGP GCA([Grid Capacity Calculation]) end GCA --> V[Visualization on DSO Website] V --> Customer((Customer)) </pre>

5.4.5 Hungarian Pilot Site UCs

Table 57: Hungarian Pilot's – Hu01 UC overview

UC ID	Hu01
UC name	Digital twin for power line monitoring
Scope	Applying dynamic line rating (DLR) is beneficial for revealing the bottlenecks in the aging high-voltage network. DLR systems are based on the conductor's thermal behaviour measured by physical sensors or calculations from weather datasets. The main scope of the Hungarian DT1 (Hu01) is to implement a digital twin for the physical line monitoring system, thus reducing the number of necessary physical devices, improving the performance of conductor temperature calculation, and helping the widespread application of DLR systems.
Objective(s)	The use case's objective is to implement ANN-based digital twins for power line monitoring systems and use the outputs for DLR calculations and the electricity market simulations.
Short Description	Need: In the last few years, increasing the transfer capacity of power lines has become essential due to bottlenecks in the European high-voltage grid. Dynamic systems that adjust the ampacity limit in real time to changes in the environment (DLR) can result in higher transfer capacity a large percentage of the time. However, these systems require real-time measurements. Line monitoring systems that rely only on weather data do not produce sufficiently accurate inputs for the line rating calculation. Systems that include physical sensors monitoring the state of the phase conductor are accurate but, at the same time, require many devices. The high cost of these devices can hinder the DLR system's widespread application in several European regions. Service: The physical sensor-based line monitoring systems (necessary for DLR calculations) can be substituted by ANN-based digital twins (DTs). These kinds of DTs can provide accurate temperature results (inputs for the ampacity calculations) and decrease the sensor numbers in the grid.
Level of depth	Generic UC
UC Diagram	<pre> graph TD Actor1((DSO, TSO and/or market platform)) Actor2((Academic partner)) Actor3((Technology provider)) subgraph UC [Digital twin for power line monitoring] direction TB subgraph Row1 direction LR UC1((<<sub>> Line selection)) UC2((<<sub>> Configuration of the hardware parts)) UC3((<<sub>> Configuration of the software parts)) end UC4((Install and/or reinstall sensors)) UC5((Upgrade softwares and licences)) UC6((<<sub>> Collect & process field data)) UC7((<<sub>> DT development (Short))) UC8((<<sub>> DT development (Long))) UC9((<<sub>> DT evaluation)) UC10((<<main>> Thermal & Ampacity calculation and evaluation)) UC1 --> UC2 UC2 --> UC3 UC4 --> UC2 UC5 --> UC3 UC6 --> UC2 UC6 --> UC7 UC6 --> UC8 UC7 --> UC8 UC8 --> UC9 UC9 --> UC10 end Actor1 -- "provide input" --> UC1 Actor1 -- "supervise" --> UC2 Actor1 -- "supervise" --> UC3 Actor1 -- "supervise" --> UC6 Actor1 -- "supervise" --> UC10 Actor2 -- "provide data" --> UC6 Actor2 -- "supervise" --> UC6 Actor3 -- "development" --> UC7 Actor3 -- "development" --> UC8 Actor3 -- "evaluation" --> UC9 Actor3 -- "calculation" --> UC10 UC2 -- "handling data" --> UC6 UC3 -- "handling data" --> UC6 UC7 -- "handling data" --> UC6 UC8 -- "handling data" --> UC6 UC9 -- "handling data" --> UC6 UC10 -- "handling data" --> UC6 </pre>

Table 58: Hungarian Pilot's – Hu03 UC overview

UC ID	Hu02
UC name	Enhanced flow-based capacity calculation for market co-optimization using DLR data
Scope	Transmission network constraints are handled with flow-based methodology, and dynamic line rating results of additional flow margins are integrated to enable higher volume of energy and balancing capacity exchange. Resulting DLR enhanced market clearing enables the realization of opportunities and upsides of weather-related uncertainties as additional potential for higher price convergence and social welfare for end-users of the market. Additionally, a new, web-based data platform will be developed to serve dual purposes by combining dynamic data visualization functionalities with data queries to support market participants to make better decisions while stepping into market transactions.
Objective(s)	The objective of the use case is to develop and demonstrate an enhanced, multi-product optimization tool to operate daily, spot energy and balancing capacity market auction.
Short Description	This use case demonstrates the use of Dynamic Line Rating (DLR) to improve flow-based capacity calculations for cross-border electricity markets. By integrating line monitoring data, the DLR-enhanced approach enables more accurate and adaptive capacity calculations, which optimizes transmission network utilization, reduces congestion, and supports greater integration of renewable energy sources.
Level of depth	Specialized UC
UC Diagram	<pre> graph TD ENTSE-E[ENTSE-E] -- "TYNDP Study grid" --> C[Collection of flow-based data] TSO((TSO)) -- "F110" --> C AcademicPartner((Academic partner)) -- "SLR, DLR" --> C C --> F[Flow-based Capacity Calculation] F -- "cross-zonal capacity data" --> TSO F -- "cross-zonal capacity data" --> MarketOperator((Market Operator)) TechProvider((Technology provider)) -- "Execution" --> F </pre>

Table 59: Hungarian Pilot's – Hu03 UC overview

UC ID	Hu03
UC name	Co-optimizing the day-ahead and intraday energy and balancing capacity market
Scope	Co-optimization of day-ahead and intraday energy and balancing capacity markets within a unified platform, using flow-based capacity calculations to manage transmission constraints.
Objective(s)	The objective of this use case is to maximize cross-border capacity allocation, increase social welfare, and ensure seamless integration of energy and balancing bids in compliance with SDAC and SIDC.
Short Description	The TwinEU project aims to support EU energy policy goals by enabling solutions for a unified Internal Electricity Market. This demonstration focuses on a co-optimized cross-border capacity auction algorithm (OPTIM-CAP) to optimize cross-zonal network capacity usage across both day-ahead and intraday timeframes. This approach facilitates progress toward the European Power Market Model by unifying current, energy exchange-based market couplings with the procurement of balancing capacity, including aFRR, mFRR, and RR, if applicable, including all standard and local product variants (e.g. HU: mFRR 12.5).
Level of depth	Individual UC
UC Diagram	<pre> graph TD HU02[HU02] -- "cross-zonal capacity data" --> MCO((Market Co-optimization)) TSO[TSO] -- "BC bids" --> MCO MO[Market Operator] -- "Energy bids" --> MCO TP[Technology provider] -- "Execution" --> MCO AP[Academic Partner] -- "Evaluation" --> MCO </pre>

5.4.6 Iberian Pilot Site UCs

Table 60: Iberian Pilot's – Ib01 UC overview

UC ID	Ib01			
UC name	AI Agent for probabilistic grid status forecast and remedial actions identification for the TSO's Control Centre Operator.			
Scope	Power system operation Digital Twin			
Objective(s)	Identify risky grid status for the electrical grid and propose remedial actions.			
Short Description	Develop a digital twin – an AI agent - that support the transmission control centre during real-time operation decisions.			
Level of depth	Specialized UC			
UC Diagram			Generation	Transmission
		Market		
		Enterprise		<pre> graph TD subgraph Operation SCADA[SCADA] end subgraph Enterprise TSO_DT[TSO DT] TOOL_AI_AGENT[TOOL AI-Agent] CC_SIM[Control Center simulator] end subgraph Market end subgraph Generation end subgraph Transmission end SCADA --> TSO_DT TSO_DT --> TOOL_AI_AGENT TOOL_AI_AGENT --> CC_SIM </pre>
		Operation		

Table 61: Iberian Pilot's – Ib02 UC overview

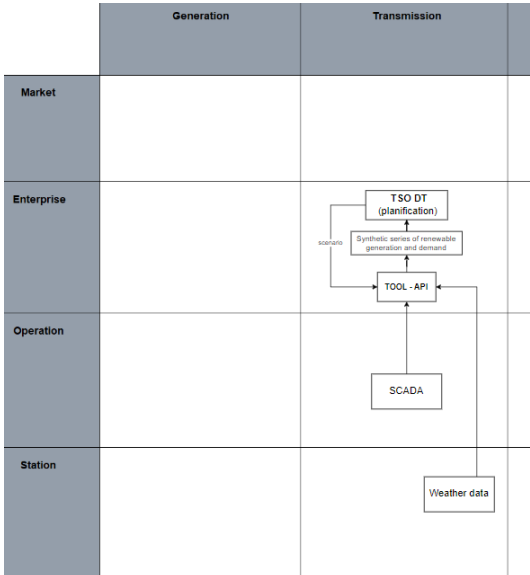
UC ID	Ib02		
UC name	DT for generation of synthetic series of renewable resources		
Scope	Renewable resource forecast		
Objective(s)	Generate synthetic series of renewable resources for power system application		
Short Description	The digital twin will be able to generate series of renewable resources (not generation) like wind, solar and hydro.		
Level of depth	Individual UC		
UC Diagram	 The UC Diagram is a matrix with levels (Market, Enterprise, Operation, Station) on the y-axis and domains (Generation, Transmission) on the x-axis. The diagram illustrates the data flow and components involved in the digital twin for renewable resource forecast. Key components include: Weather data: Located at the Station level in the Transmission domain. SCADA: Located at the Operation level in the Transmission domain, receiving data from Weather data. TOOL-API: Located at the Enterprise level in the Transmission domain, receiving data from SCADA. Synthetic series of renewable generation and demand: Located at the Enterprise level in the Transmission domain, receiving data from TOOL-API. TSO DT (planning): Located at the Enterprise level in the Transmission domain, receiving data from the Synthetic series and providing scenarios back to the TOOL-API.		

Table 62: Iberian Pilot's – Ib03 UC overview

UC ID	Ib03
UC name	DT-enabled multi-area system dynamic behaviour assessment
Scope	The progressive integration of electronic converter based Renewable Energy Sources will lead to a reduction of the system synchronous inertia that can endanger the system frequency stability behaviour, especially in poorly interconnected systems, such as the case of Iberian system. A Digital Twin representing the dynamic behaviour of Iberian system interconnected with the central European system is therefore needed to assess the frequency stability of the Iberian grid when facing large disturbances like a sudden loss a large amount of generation. This DT allows to evaluate the robustness of operation and to tailor new ancillary services to cope with the poorer dynamic behaviour.
Objective(s)	(1) Represent the Dynamic behaviour of the Iberian system and evaluate its dynamic robustness'; (2) Identification and provision of frequency ancillary services, including new ones like FFR and virtual inertia.
Short Description	Exploitation of a properly tuned DT capable to represent the dynamic behaviour of the Iberian system and to enable the identification of required of frequency ancillary services (including innovative ones like FFR, virtual inertia) to improve dynamic behaviour. This involves contributions from conventional generation, RES generation units and dynamic loads within (or not) under a VPP concept, providing both reserves upward and downward without de-loading of the generation units and the loads.
Level of depth	Generic UC
UC Diagram	

Table 63: Iberian Pilot's – Ib04 UC overview

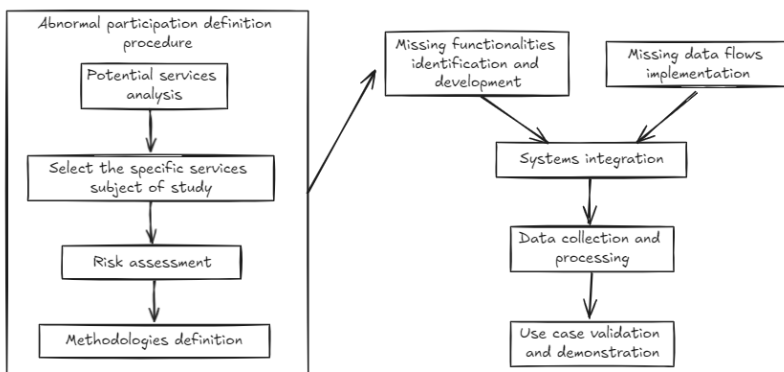
UC ID	Ib04
UC name	Abnormal market participation detection and protocol activation for mitigating the risk and consequences
Scope	Horizontal in the Iberian electricity system. From wholesale markets at transmission level to local flexibility markets at distribution level.
Objective(s)	Selection of abnormal market participation regarding cybersecurity among all stakeholders (specifically MO and TSOs or MO and DSOs) for each market service (wholesale markets or/and local flexibility markets).
Short Description	The DTs already deployed by the market operator (OMIE) and the SOs in the Iberian Peninsula will collaborate to identify abnormal market participation, propagating the threat detection to all stakeholders and implementing the necessary countermeasures to secure the normal operation of the market.
Level of depth	Individual UC
UC Diagram	 <pre> graph TD subgraph "Abnormal participation definition procedure" A[Potential services analysis] --> B[Select the specific services subject of study] B --> C[Risk assessment] C --> D[Methodologies definition] end D --> E[Missing functionalities identification and development] E --> F[Systems integration] G[Missing data flows implementation] --> F F --> H[Data collection and processing] H --> I[Use case validation and demonstration] </pre> The diagram illustrates the workflow for abnormal market participation detection. It begins with a sub-process titled 'Abnormal participation definition procedure' which includes four sequential steps: 'Potential services analysis', 'Select the specific services subject of study', 'Risk assessment', and 'Methodologies definition'. An arrow from the final step of this sub-process points to 'Missing functionalities identification and development'. This step then leads to 'Systems integration', which also receives input from 'Missing data flows implementation'. The process continues sequentially through 'Data collection and processing' and finally 'Use case validation and demonstration'.

Table 64: Iberian Pilot's – Ib05 UC overview

UC ID	Ib05
UC name	DT-based N-1 contingency analysis
Scope	This use case is aimed at resilience assessment by detailed modelling of the distribution network, real-time simulation using sensor data (SCADA) and N-1 contingency analysis by means of power flow optimization.
Objective(s)	The objective of this use case is to analyse the security and stability of the distribution networks under different scenarios and operating conditions, identifying bottlenecks and critical points in the system. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Short Description	ANELL's DT will perform simulation and optimization of power flow under normal conditions and will conduct N-1 contingency analyses. These analyses assess the network's ability to handle the failure of a list of single risk components without compromising the system, thus ensuring the integrity and resilience of the electrical network.
Level of depth	Individual UC
UC Diagram	<pre> graph TD DT[DSO's Digital Twin Operator] -- "Simulation running for the set of identified scenarios" --> SR[Simulation results] SR -.-> DT SR --> ICE[Identification of critical elements] ICE --> DT DT -- "N-1 contingent grid report creation" --> MD[DSO's maintenance department] MD --> DT DT -- "Provision of results for grid planning activities" --> GPD[DSO's Grid planning department] GPD --> DT </pre>

Table 65: Iberian Pilot's – Ib06 UC overview

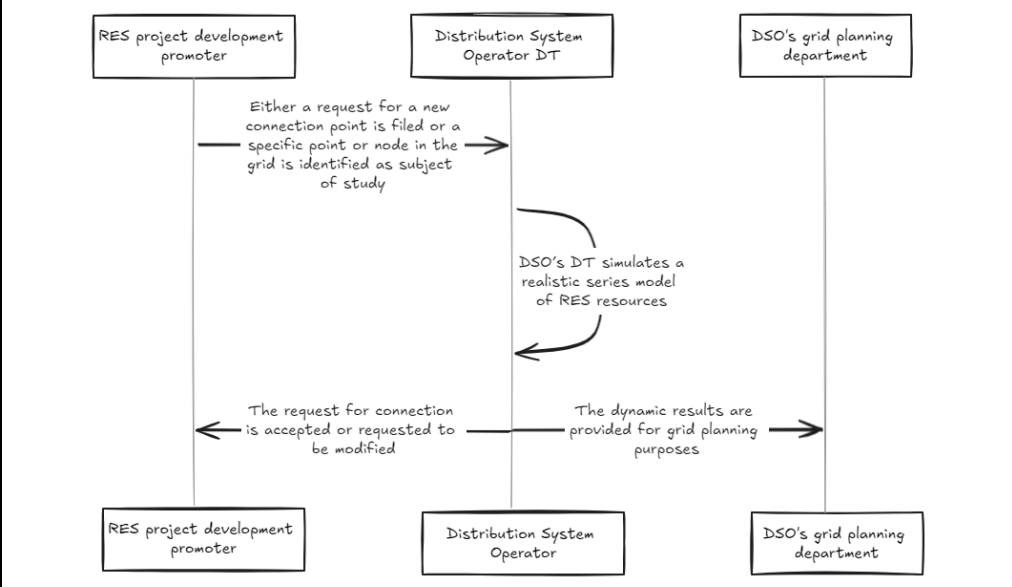
UC ID	Ib06
UC name	DT-enabled new RES integration validated plan in the MV grid
Scope	The scope of this UC is limited to grid planning purposes in the distribution network and, more specifically, in the medium voltage (MV) level, in the context of a large deployment of commercial and utility-scale renewable energy plants.
Objective(s)	The objective of this use case is leveraging the potential of the DT at distribution level to provide a pre-validation stage for connection points for renewable energy plants being requested in different nodes of the grid. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Short Description	Collaboration between the DT of the distribution system and the DTs of the RES power plants for the integration assessment in different nodes of the grid. The result of the Use Case will be a viability assessment for further deployment of RES systems in critical areas of the grid, which will contribute to the grid planning activities.
Level of depth	Individual UC
UC Diagram	 <pre> sequenceDiagram participant P as RES project development promoter participant DT as Distribution System Operator DT participant DSO as DSO's grid planning department P->>DT: Either a request for a new connection point is filed or a specific point or node in the grid is identified as subject of study DT->>DT: DSO's DT simulates a realistic series model of RES resources DT->>DSO: The dynamic results are provided for grid planning purposes DSO->>P: The request for connection is accepted or requested to be modified </pre>

Table 66: Iberian Pilot's – Ib07 UC overview

UC ID	Ib07
UC name	DT-based grid maintenance planning activities
Scope	The scope of this UC is limited to grid planning purposes in the distribution network in the context of planned maintenance works in different critical nodes or lines of the grid.
Objective(s)	The objective of this use case is to improve the maintenance works through the use of the DT for simulation purposes in a dynamic manner throughout the expected duration of the maintenance works. Additionally, the RT monitor system of the DT will ensure that the expected grid behaviour is actually happening during the works. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Short Description	The DT will run simulations for the planned maintenance activities by the DSO, having as an outcome the grid behaviour during these activities. Additionally, the real-time branch of the DT will constantly monitor in the grid and the performance of the execution during the service. The final aim is the validation of the service and/or the reinforced learning of the DT.
Level of depth	Individual UC
UC Diagram	<pre> sequenceDiagram participant DSO as DSO's maintenance department participant DT as Digital Twin operator (within the DSO) DSO->>DT: Input on planned maintenance scenarios DT-->>DSO: Simulation results DSO->>DT: Validate proposed maintenance plan DSO->>DT: Execute maintenance activities DT-->>DSO: Update DT with RT data on the maintenance activities DT-->>DSO: Monitor results and retrofeed DT </pre>

Table 67: Iberian Pilot's – Ib08 UC overview

UC ID	Ib08
UC name	Long term flexibility in MV
Scope	Implement long term flexibility
Objective(s)	Identify the long-term flexibility needs (for planning and operation) to prevent congestion versus the conventional approach, investing in new assets (such as lines).
Short Description	This use case aims to identify long-term flexibility requirements for both planning and operational phases to prevent grid congestions, traditionally addressed by investing in new assets such as lines. The actions focus on increasing consumption or decreasing generation as strategic measures to manage and balance the grid effectively.
Level of depth	Individual UC
UC Diagram	UC NAME: Long term flexibility in MV The diagram illustrates the architecture for long-term flexibility in the medium voltage (MV) grid. It is structured into a grid with columns representing different grid levels (Generation, Transmission, Distribution, DER, Customer Premise) and rows representing different operational levels (Market, Enterprise, Operation, Station, Field, Process). Key components and their interactions include: Market Level: Local Flexibility markets Digital Twin. Enterprise Level: Flexibility system, Action tool. Operation Level: SCADA/RTU, RTU, DER, EVs, Solar, Wind. Station Level: Electrical measurement, Voltage measurement. Field Level: RTU, DER, EVs, Solar, Wind. Process Level: RTU, DER, EVs, Solar, Wind.

Table 68: Iberian Pilot's – Ib09 UC overview

UC ID	Ib09
UC name	Flex Connections
Scope	Determine flexibility requirements (planning and operation) for EV Chargers for ensuring grid voltage quality.
Objective(s)	Determine flexibility requirements (planning and operation) for EV Chargers for ensuring grid voltage quality. Traditional solution: Grid reinforcement and closed-ring operation Actions: increase consumption/decrease generation of the EV Chargers
Short Description	This use case focuses on determining the flexibility requirements for Electric Vehicle (EV) Chargers in both the planning and operational phases to ensure grid voltage quality. Traditionally, maintaining voltage quality amidst the increasing load from EV chargers has been addressed through grid reinforcement and adopting closed-ring operation systems. However, this approach seeks to manage the load more dynamically by either increasing consumption or decreasing generation from EV chargers, as a more cost-effective and efficient alternative to traditional grid upgrades.

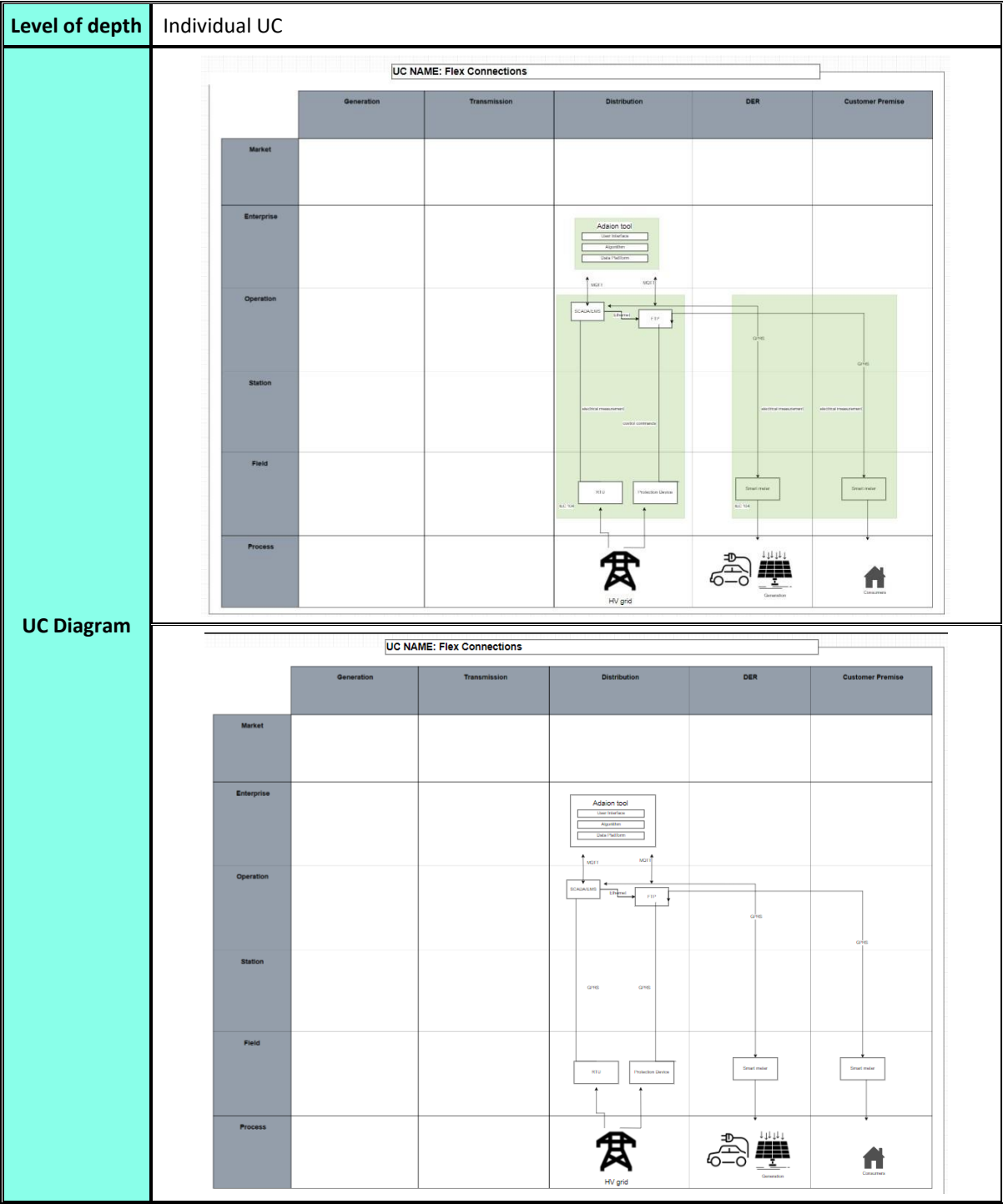


Table 69: Iberian Pilot's – Ib10 UC overview

UC ID	Ib10
UC name	Probabilistic cross-border capacity allocation
Scope	Probabilistic cross-border capacity computation based on Available Transfer Capacity (ATC) methodology, allowing the assessment and definition ex ante of the expected maximum capacity between adjacent bidding zones (in the case of this pilot, between Portugal and Spain)
Objective(s)	• Provide an approach to calculating the amount of electricity that can be safely traded across borders that naturally incorporates uncertainty • Congestion Management to prevent overload on the transmission system. It acts as a safeguard to ensure security of supply. • To contribute to the coordinated transmission capacity allocation with tools better adapted to weather-dependent generation uncertainty to manage risks associated with cross-border trading.
Short Description	Leveraging the integrated Iberian DT continuum, a data-driven robust optimisation approach will be applied to compute the ATC for the day-ahead and intraday market, drawing probabilistic scenarios of Variable Renewable Energy (VRE) generation and grid contingencies to optimize strategies using the DT and compare with business as usual.
Level of depth	Generic UC
UC Diagram	<pre> graph TD subgraph Probabilistic_ATC_Calculation_System [Probabilistic ATC Calculation System] direction TB Main["«Main» Calculate PATC for Cross-Border Capacity"] Sub1["«Sub» Perform Contingency Analysis"] Sub2["«Sub» Update Grid Models"] Sub3["«Sub» Generate Probabilistic Scenarios"] Sub4["«Sub» Incorporate VRE Uncertainty"] Sub5["«Sub» Compute TTC, TRM, CBM"] Main --> Sub1 Main --> Sub2 Main --> Sub3 Main --> Sub4 Main --> Sub5 Sub2 --> Sub4 Sub3 --> Sub4 end CGDT["«system» Common Grid Digital Twin"] MP["«system» Market Platform"] IGDT["«system» Individual Grid Digital Twin"] PFG["«system» Probabilistic Forecast Generator"] CGDT -- "Provides Contingency Data" --> Sub1 MP -- "Receives PATC Data" --> Main MP -- "Receives Capacity Data" --> Main IGDT -- "Initiates PATC Calculation" --> Main PFG --> CGDT Main --> CGDT Main --> MP Main --> IGDT </pre>

Table 70: Iberian Pilot's – Ib11 UC overview

UC ID	Ib11
UC name	Cross-border assessment of flexibility and pre-qualification
Scope	Enabling coordination among System Operators (SOs) and Flexibility Service Providers (FSPs) regarding the capability of cross-border flexibility products, namely fast frequency reserves in the Iberian region.
Objective(s)	• Design and test the prequalification process phase for cross-border products; • Exchange information for the Grid and Product prequalification through the DTs. • Facilitate the entry of FSPs into the various flexibility markets cross-border, namely for a new Iberian Fast Frequency Reserve (FFR) market.
Short Description	Create a demo that test the scenario in which one FSP can be prequalified to provide flexibility to another SO, in which the FSP has no direct connection to, namely for a new FFR product. An FSP connected to one SO can be prequalified to a neighbouring SO. With the digital twin this UC could be tested between PT-ES.
Level of depth	Generic UC

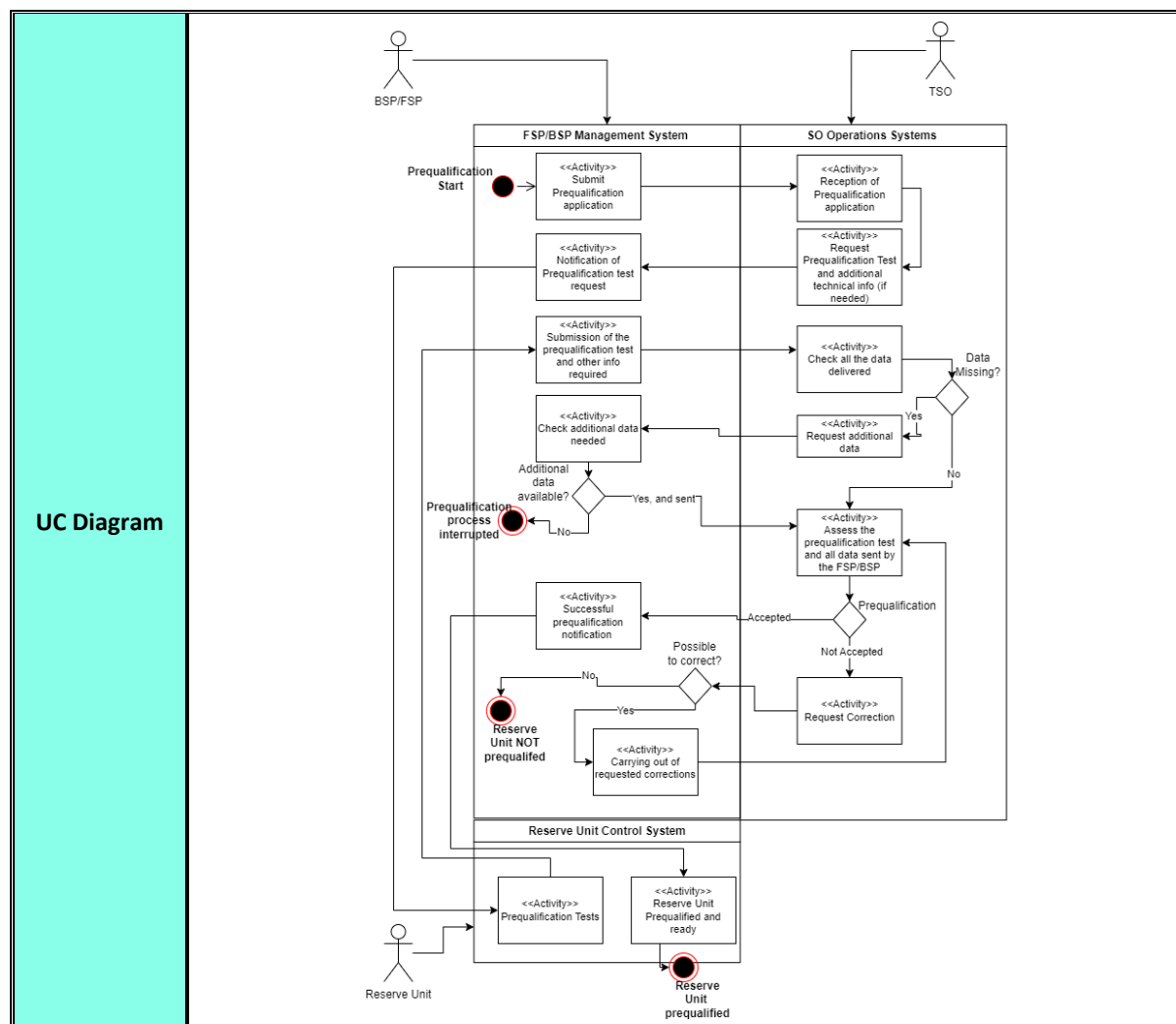


Table 71: Iberian Pilot's – Ib12 UC overview

UC ID	Ib12
UC name	Integration of TSO-DSO-MO-Prosumer market coordination
Scope	Address the challenges and needs for collaboration between different roles of the energy value chain, enhancing coordination and market integration on the Portuguese power system.
Objective(s)	- Improved communication and data exchange between TSOs, DSOs, MOs, and prosumers to enable better grid management and operational planning. - Definition and testing, through the DT, a new market framework integrating local and wholesale markets - Promote prosumers to actively participate in the markets, potentially earning revenues by providing flexibility services to the grid in the Portuguese system - Improving the cost effectiveness of the resolution of the real-time technical constraints, by forwarding the non-used local flexibility market reserves to the resolution of the eventual transmission grid technical constraints.
Short Description	Based on an integration framework for wholesale and local markets (energy/balancing/flexibility), use the federated digital twin to simulate the integration Transmission System Operator -Distribution System Operator – (Local) Market Operator and Prosumer (TSO-DSO-MO-Prosumer) framework, assess it and improve it (and/or draw recommendations for deployment) according to the results, exploiting coordinated grid qualification in operational planning, or near real-time contingency analysis.

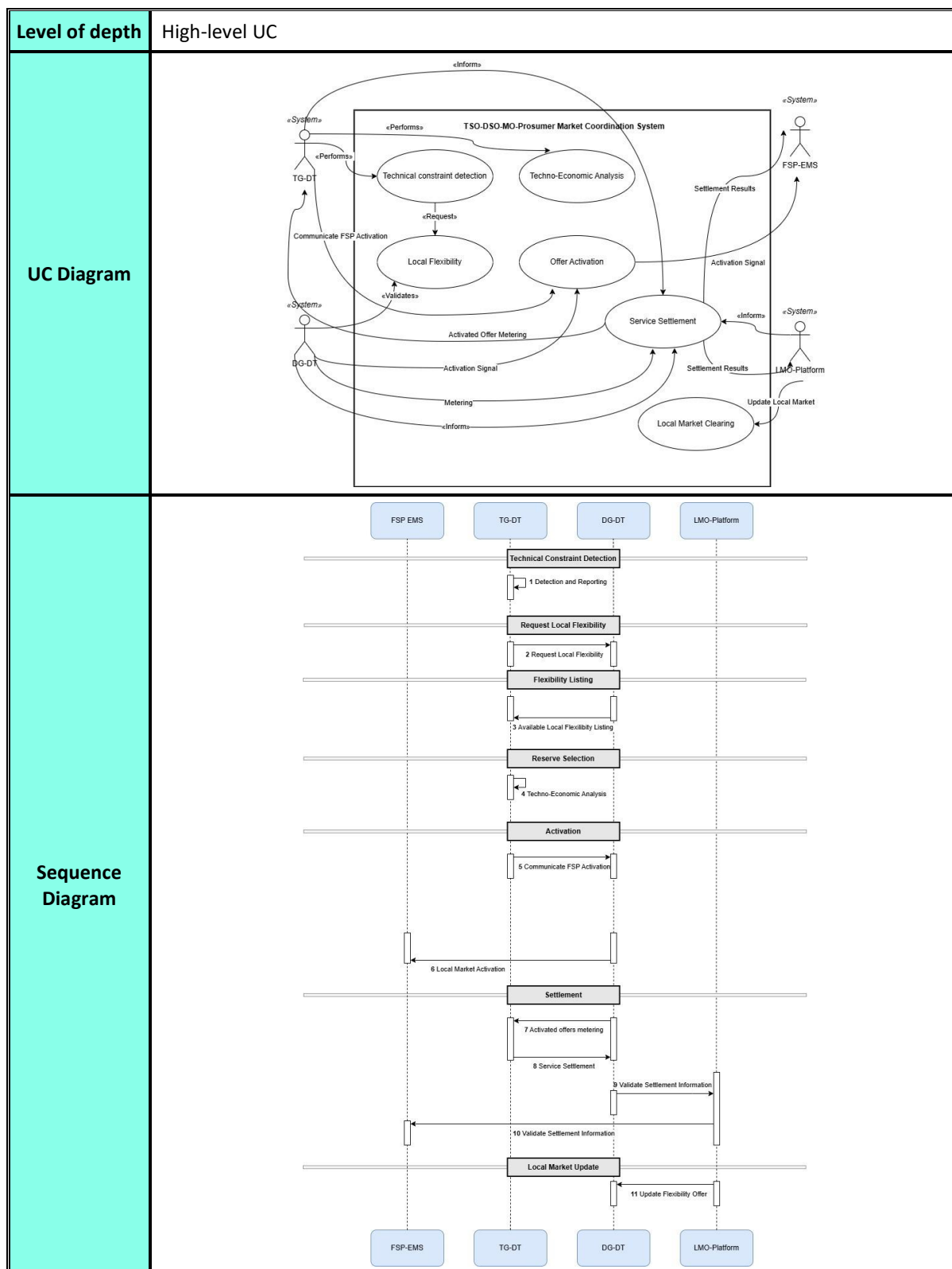


Table 72: Iberian Pilot's – Ib13 UC overview

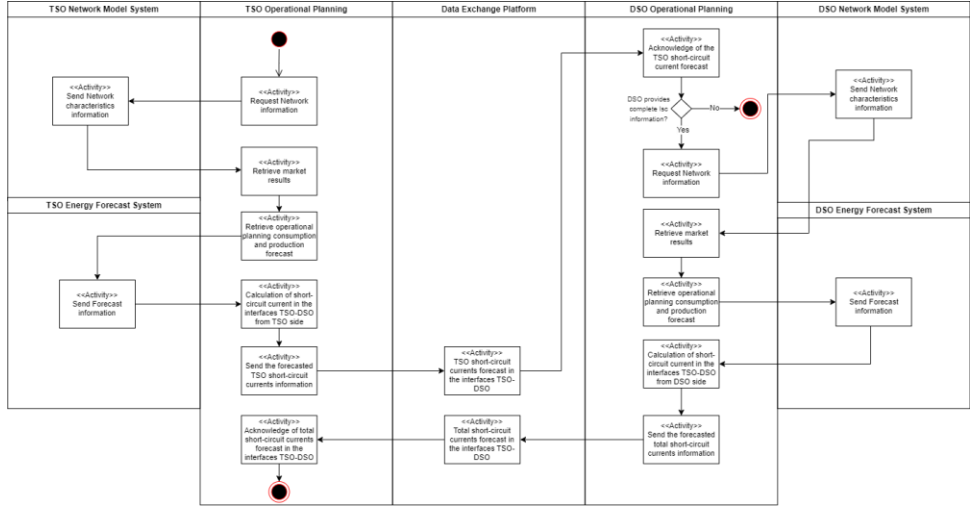
UC ID	Ib13
UC name	Enhancement of short-circuit models and TSO/DSO information exchange for operational planning
Scope	Address the technical validation of the short-circuit currents in the EHV/HV substations and the respective information exchange between TSO and DSO, focusing on the improvement of the short-circuit models for renewable energy sources.
Objective(s)	- Improved communication and data exchange between TSOs and DSOs to enable better grid management and planning. - Enhance TSO short-circuit models of RES generators for more accurate short-circuit currents estimation. - Improve TSO and DSO grid planning by considering each other's short-circuit contributions in the TSO/DSO interface - Improve operation security and quality of service
Short Description	This Use Case presents the processes and information exchanged between TSO and DSO regarding short-circuit currents (three-phase short-circuits) foreseen in the EHV/HV substations in the short-term (day-ahead). Additionally, focus on improving the TSO short-circuit models of the RES generators to obtain estimates closer to reality.
Level of depth	Individual UC
UC Diagram	 <pre> sequenceDiagram participant TSO_NMS as TSO Network Model System participant TSO_OP as TSO Operational Planning participant DEP as Data Exchange Platform participant DSO_OP as DSO Operational Planning participant DSO_NMS as DSO Network Model System participant TSO_EFS as TSO Energy Forecast System participant DSO_EFS as DSO Energy Forecast System TSO_OP->>TSO_NMS: <<activity>> Send Network characteristics information TSO_OP->>TSO_OP: <<activity>> Request Network information TSO_OP->>TSO_OP: <<activity>> Retrieve market results TSO_OP->>TSO_OP: <<activity>> Retrieve operational planning consumption and production forecast TSO_OP->>TSO_OP: <<activity>> Calculation of short-circuit current in the interfaces TSO-DSO from TSO side TSO_OP->>TSO_OP: <<activity>> Send the forecasted TSO short-circuit currents information TSO_OP->>TSO_OP: <<activity>> Acknowledge of total short-circuit currents forecast in the interfaces TSO-DSO TSO_OP->>TSO_EFS: <<activity>> Send Forecast information TSO_EFS->>TSO_OP: <<activity>> Request Network information TSO_EFS->>TSO_OP: <<activity>> Retrieve operational planning consumption and production forecast TSO_EFS->>TSO_OP: <<activity>> Calculation of short-circuit current in the interfaces TSO-DSO from TSO side TSO_EFS->>TSO_OP: <<activity>> Send the forecasted TSO short-circuit currents information TSO_EFS->>TSO_OP: <<activity>> Acknowledge of total short-circuit currents forecast in the interfaces TSO-DSO DSO_OP->>DSO_NMS: <<activity>> Send Network characteristics information DSO_OP->>DSO_OP: <<activity>> Acknowledge of the TSO short-circuit current forecast DSO_OP->>DSO_OP: <<activity>> Request Network information DSO_OP->>DSO_OP: <<activity>> Retrieve market results DSO_OP->>DSO_OP: <<activity>> Retrieve operational planning consumption and production forecast DSO_OP->>DSO_OP: <<activity>> Calculation of short-circuit current in the interfaces TSO-DSO from DSO side DSO_OP->>DSO_OP: <<activity>> Send the forecasted total short-circuit currents information DSO_OP->>DSO_EFS: <<activity>> Send Forecast information DSO_EFS->>DSO_OP: <<activity>> Request Network information DSO_EFS->>DSO_OP: <<activity>> Retrieve operational planning consumption and production forecast DSO_EFS->>DSO_OP: <<activity>> Calculation of short-circuit current in the interfaces TSO-DSO from DSO side DSO_EFS->>DSO_OP: <<activity>> Send the forecasted total short-circuit currents information DEP->>TSO_OP: <<activity>> TSO short-circuit currents forecast in the interfaces TSO-DSO DEP->>DSO_OP: <<activity>> TSO short-circuit currents forecast in the interfaces TSO-DSO DEP->>TSO_OP: <<activity>> Total short-circuit currents forecast in the interfaces TSO-DSO DEP->>DSO_OP: <<activity>> Total short-circuit currents forecast in the interfaces TSO-DSO </pre>

Table 73: Iberian Pilot's – Ib14 UC overview

UC ID	Ib14
UC name	DT-endorsed flexible connection grant through the settlement of a Local Flexibility Market to internally balance the production surplus in congestion-creation hours/scenarios.
Scope	The scope of this UC is limited to grid planning purposes in the distribution network and, more specifically, related to the concession of flexible connection points to RES power plants developers, subject to the results of the simulations undertaken by the DT and the settlement of a LFM able to absorb surplus power without creating congestions.
Objective(s)	The objective of this use case is leveraging the interaction between the DT of the distribution system with the DT of the NEMO's LFM to validate the grid-exported power increase for a specific connection point for renewable energy plants subject to the opening of a LFM than can absorb the surplus power when forecasted. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Short Description	Collaboration between the DT of the distribution system, the dynamic forecasting models of the eventually deployed RES power plants and the DT of the NEMO's LFM to validate the viability of a new installation. The result of the Use Case will be a viability assessment for further deployment of RES systems with increased peak power capacities.
Level of depth	Individual UC
UC Diagram	<pre> sequenceDiagram participant MP as Market player participant DSO as Distribution System Operator participant LFM as Local Flexibility Market participant FSP as Flexibility Service Provider MP->>DSO: A request for connection of a large PV installation is filed to the DSO Note over DSO: DSO's DT makes a series of scenarios simulations to identify bottlenecks where the grid gets congested DSO->>LFM: Identify congestions and flexibility needs in steps, simulating the suitability of the solution among the DTs LFM->>MP: The solution is validated and the connection point request is granted DSO->>LFM: A congestion is forecasted and a request for flexibility is generated to grant a higher power injection FSP->>LFM: Submit flexibility offers LFM->>DSO: Present flexibility offers DSO->>LFM: Select and activate offers LFM->>FSP: Notify activation DSO->>MP: Notify increase in grid power injection LFM->>FSP: Provide flexibility service FSP->>DSO: Verify service delivery DSO->>LFM: Confirm service delivery LFM->>FSP: Calculate settlement FSP->>DSO: Send settlement report DSO->>FSP: Process payment </pre>

5.4.7 Italian Pilot Site UCs

Table 74: Italian Pilot's – IT01 UC overview

UC ID	IT01
UC name	Analysis through DT of the TSO defence system
Scope	Analysis of the performance of the defence system applied to a portion of the Sardinian transmission and distribution grids.
Objective(s)	• Analysis of the power system stability and security. • Testing different scenarios triggering the TSO Defence System. • Testing in real-like conditions the Defence System, performing simulations using a Real Time Simulator (RTS) in Hardware in the Loop (HIL) configuration. • Performing sensitivity analyses by considering the evolution of system parameters according also to future scenarios. • With the aim of simulating even more complex systems, it will be considered the possibility to connect the RTS facilities of Terna and Ensiel (Politecnico di Torino) to simulate the complete grid framework by using a geographical distributed RTS approach.
Short Description	This UC focuses on the developing a DT of a selected portion of the Sardinian high voltage grid to simulate and assess operational aspects specific of the TSO Defence System, devoted to managing power system stability and security and to prevent cascading effects and blackouts. The simulations will be carried out by using HIL techniques. The model, running on an RTS, will be interfaced with specific physical devices, to duly test protections and control logics, as well as operation strategies, in a protected environment and under real-like conditions. The primary objective is to obtain data from the simulation regarding the frequency and voltage behaviour after an event or a series of events. The second objective consists in interfacing real hardware (i.e., EAC relè – Equilibratore Automatico di Carico – “Automatic Load Balancer”) to the RTS in a HIL configuration, with the aim to duly test physical devices in a safe way, also varying the intervention thresholds. The third objective will be covered by a sensitivity analysis that will be carried out to analyse the performance of the defence system taking in to account the planned development of the HV network. To demonstrate the scalability of the experimental setup proposed, it will be considered the possibility to connect the RTS facilities of Terna and Ensiel (Politecnico di Torino).
Level of depth	Individual UC
UC Diagram	<pre> graph TD DSO[DSO • MV feeder data collection (connected to an EAC relay) • Network performance evaluation] TSO[TSO • Industrial interruptible loads • Defence System strategy implementation] DT[Transmission and Defence system Digital Twin • Frequency continuous monitoring] DTI[Digital Twin Interface • Frequencies monitoring • KPI communication] DSTW[Distribution system Digital Twin • MV feeders status • EAC intervention] DSO -- "MV feeders data connected to an EAC relay" --> TSO TSO -- "n° EAC threshold setting" --> DTI DTI -- "n° EAC threshold setting" --> DT DT -- "DTs coupling" --> DSTW DSTW -- "n° EAC activation" --> DT DSTW -- "n° EAC activation communication" --> DSO DTI -- "Monitoring signals" --> DTI subgraph "Distributed Digital Twin" DT DSTW end </pre> The diagram illustrates the architecture of the Digital Twin for the TSO defence system. It shows the interaction between the DSO (Distribution System Operator), TSO (Transmission System Operator), and various Digital Twin components. The DSO provides MV feeder data to the TSO via an EAC relay. The TSO implements the defence system strategy and sets EAC thresholds, which are communicated to the Transmission and Defence system Digital Twin (DT) through the Digital Twin Interface (DTI). The DTI also handles KPI communication and frequency monitoring. The DT is coupled with the Distribution system Digital Twin (DSTW) via DTs coupling. The DSTW provides MV feeder status and EAC intervention data back to the DT and DSO. The entire setup is part of a Distributed Digital Twin.

Table 75: Italian Pilot's – IT02 UC overview

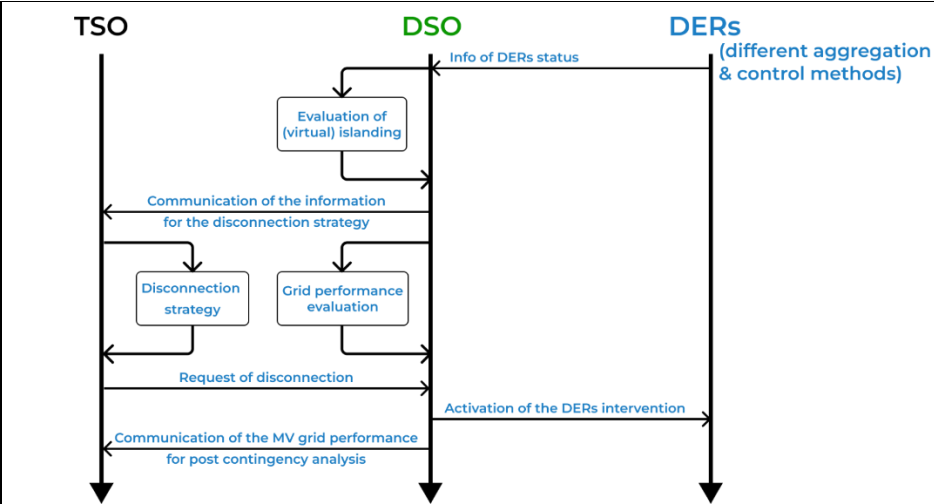
UC ID	IT02
UC name	Analysis through DT of the behaviour of aggregated distributed resources during a grid event in the TSO system
Scope	Analysis of the impact of aggregated distributed resources on the distribution network with the participation of relevant shares of inverter-based resources.
Objective(s)	Studying the impact of inverter-based resource operation on the distribution network after a transmission system grid events.
Short Description	A key focus will be on studying the impact of inverter-based resource operation on the distribution network after a transmission system grid event. The network model will be firstly validated by comparing its outputs with real-world data provided by the Distribution System Operator (DSO). Afterwards, sensitivity analyses will be performed, creating scenarios with varying levels of Distributed Energy Resource (DER) penetration to evaluate the distribution system behaviour.
Level of depth	Individual UC
UC Diagram	 <pre> sequenceDiagram participant TSO participant DSO participant DERs as DERs (different aggregation & control methods) TSO->>DSO: Info of DERs status DSO->>DSO: Evaluation of (virtual) islanding DSO->>TSO: Communication of the information for the disconnection strategy TSO->>TSO: Disconnection strategy DSO->>DSO: Grid performance evaluation DSO->>TSO: Request of disconnection TSO->>TSO: Communication of the MV grid performance for post contingency analysis DSO->>DERs: Activation of the DERs intervention </pre>

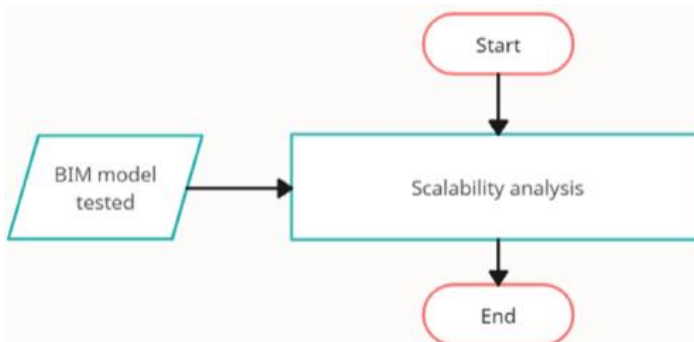
Table 76: Italian Pilot's – EACL-IT-01 UC overview

UC ID	EACL-IT-01
UC name	Digital Twin for definition of data model
Scope	The scope of UC is to develop the Data Model and LOIN for the design of substation deputed to connect a power generator to the grid according to the national and TSO's Regulations and standards.
Objective(s)	- Definition of the Design validation workflow. - Definition of Data Model and LOIN.
Short Description	The UC has the aim of translating design regulations into automated rules and linking these with the information content to be applied to the objects that will make up the digital twin. In this UC will be defined the Design validation workflow and table of Machine-Readable Regulations that can be translated in ruleset of Code Checking. The scope of this UC is to develop the Data Model and LOIN according to the analysed Regulations and standards.
Level of depth	Individual UC
UC Diagram	<pre> graph TD Start([Start]) --> DefWorkflow[Definition of the Design validation workflow and table of Machine-Readable Regulations] Regulations[/Regulations/] --> DefWorkflow DefWorkflow --> TransRuleset[Translation in Ruleset of Code Checking] PropertyLinked[/Property linked to the ruleset/] --> TransRuleset TransRuleset --> DevDataModel[Development of the Data Model and the LOIN of the Connection Substation] LOINStation[/LOIN of a connection station/] --> DevDataModel DevDataModel --> ConfigBIM[Configuration of BIM validation Tool] ConfigBIM --> CodeChecking[/Code checking software configured/] CodeChecking --> End([End]) </pre>

Table 77: Italian Pilot's – EACL-IT-02 UC overview

UC ID	EACL-IT-02
UC name	Digital Twin for design validation
Scope	The scope of UC is to simulate a market operator that proposes a design to TSO and afterwards the TSO has to validate the project.
Objective(s)	• Speed up validation of project. • Minimize exchanges of documents. • Simplify communications, • Minimize errors, • Increase quality of design.
Short Description	The UC is based on the development of the digital twin of an electrical substation that is produced in the process of connection to the network. The market participant proposes a design, and the TSO has to validate it in terms of geometries, information related to each element, compliance with national regulations and TSO standards. In this UC it is planned to simulate a market participant, like is a power generator, that produces a BIM project using standard objects and information. The designer, during the project presentation phase, will have automated feedback from a Code & Model Checking Tool that can identify design mistakes in terms of, for example, right value of the technical properties of the equipment and geometric interferences.
Level of depth	Individual UC
UC Diagram	<pre> graph TD Start([Start]) --> Designing[Designing of the BIM model] LOIN[/Object data model (LOIN)/] --> Designing Observation[/Observation and request of integration/] --> Designing Designing --> Sharing[Model sharing in a platform] Sharing --> Validation{Validation outcome} Validation -- Yes --> End([End]) Validation -- No --> Designing </pre>

Table 78: Italian Pilot's – EACL-IT-03 UC overview

UC ID	EACL-IT-03
UC name	Scalability of Digital Twin for design validation
Scope	The scope of UC is to analyse the scalability of the design validation tool and to define a roadmap for scalability-interoperability of an extended solution
Objective(s)	Evaluation of the possibility to adopt the solution as standard for the design validation of substation design (Scalability of the solution).
Short Description	The UC will analyse the possibility of scaling will be explored in greater detail with Cost-Benefit analysis, roadmap for scalability-interoperability of an extended solution. In this UC it is planned to analyze the process of validation carried out in order to evaluate the scalability of the solution. The scalability hypotheses, explored through cost-benefit analyses, have the aim of understanding how to obtain advantages not only on the individual project but on the entire design validation process for the development of the electricity grid.
Level of depth	Individual UC
UC Diagram	 <pre> graph TD Start([Start]) --> Analysis[Scalability analysis] BIM[BIM model tested] --> Analysis Analysis --> End([End]) </pre>

5.4.8 Slovenian Pilot Site UCs

Table 79: Slovenian Pilot's – SLO-BUC-01 UC overview

UC ID	SLO-BUC-1
UC name	Dynamic RMS Analysis with Upgraded Transmission System Model
Scope	Dynamic power system analysis with inclusion of distributed generation connected to the distribution grid.
Objective(s)	• Enhance the dynamic modelling capabilities of the transmission system by integrating an improved distribution system model. • Improve the accuracy of the dynamic analysis of the power system for operational planning and dynamic security assessments, by inclusion of the impact of generation connected to the distribution network. • Increase system security and the quality of supply. • Enable the exchange of network models between DSOs and TSO in a standardized and interoperable way
Short Description	This UC defines the process of upgrading system dynamic model of the transmission system by the distribution system to increase the accuracy of the dynamic RMS analysis. The distribution system is represented by an equivalent that contains the generation aggregated by different types (synchronous, asynchronous and PV) and an aggregated dynamic consumption model.
Level of depth	Individual UC

UC Diagram

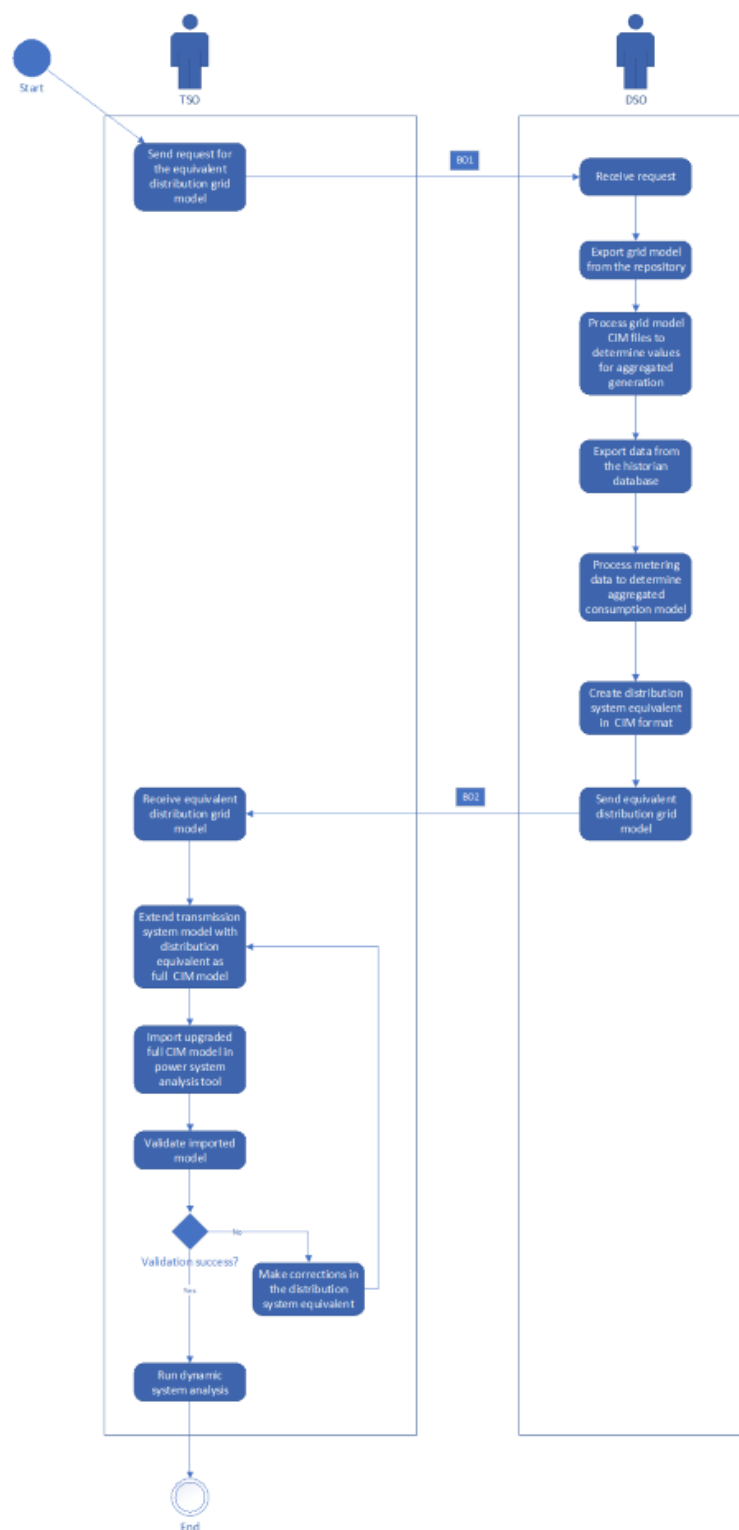


Table 80: Slovenian Pilot's – SLO-BUC-02 UC overview

UC ID	SLO-BUC-2
UC name	Real-time Dynamic RMS Analysis with Transmission System Model improved with the dynamic parameters of generators and control models of the neighbouring TSOs
Scope	Dynamic power system analysis in real-time incorporating detailed dynamic models of neighbouring transmission system operators (TSOs)
Objective(s)	• Enable real-time stability analysis and dynamic state monitoring of power system. • Establish generator dynamic data exchange between TSOs. • Enhance dynamic modelling capabilities of the transmission system by integrating network models from neighbouring TSOs. • Improve the accuracy of dynamic power system analysis for dynamic security assessments by accounting for the impact of interconnections. • Strengthen system security and ensure higher quality of supply. • Facilitate the standardized and interoperable exchange of network models between neighbouring TSOs.
Short Description	This UC defines the process that enables the TSO to perform dynamic security assessments of the power system in real-time. The analysis tool is based on the power system numerical simulation and analysis tool (e.g. DigSILENT PowerFactory) and real-time data exchange with SCADA/EMS. The TSO's dynamic RMS network model is merged with the dynamic RMS network models of neighbouring TSOs (within the TSO's observability area) to enable accurate dynamic RMS analyses. The neighbouring network models include detailed dynamic characteristics of generators connected to the transmission grid. In this use case, neighbouring TSOs exchange dynamic parameters of generators and models of controllers with the set-up parameters via TwinEU federated data exchange.
Level of depth	Individual UC

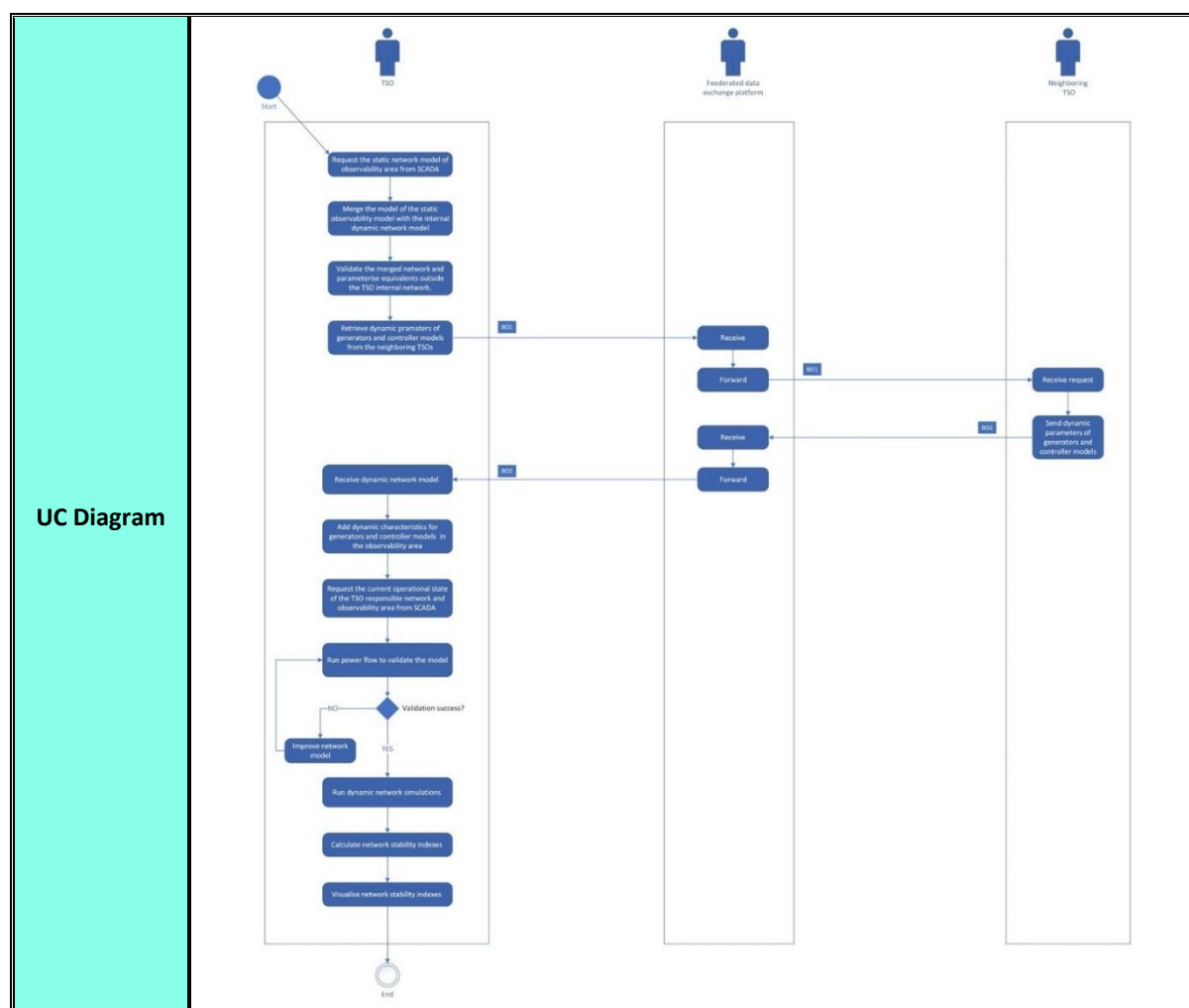
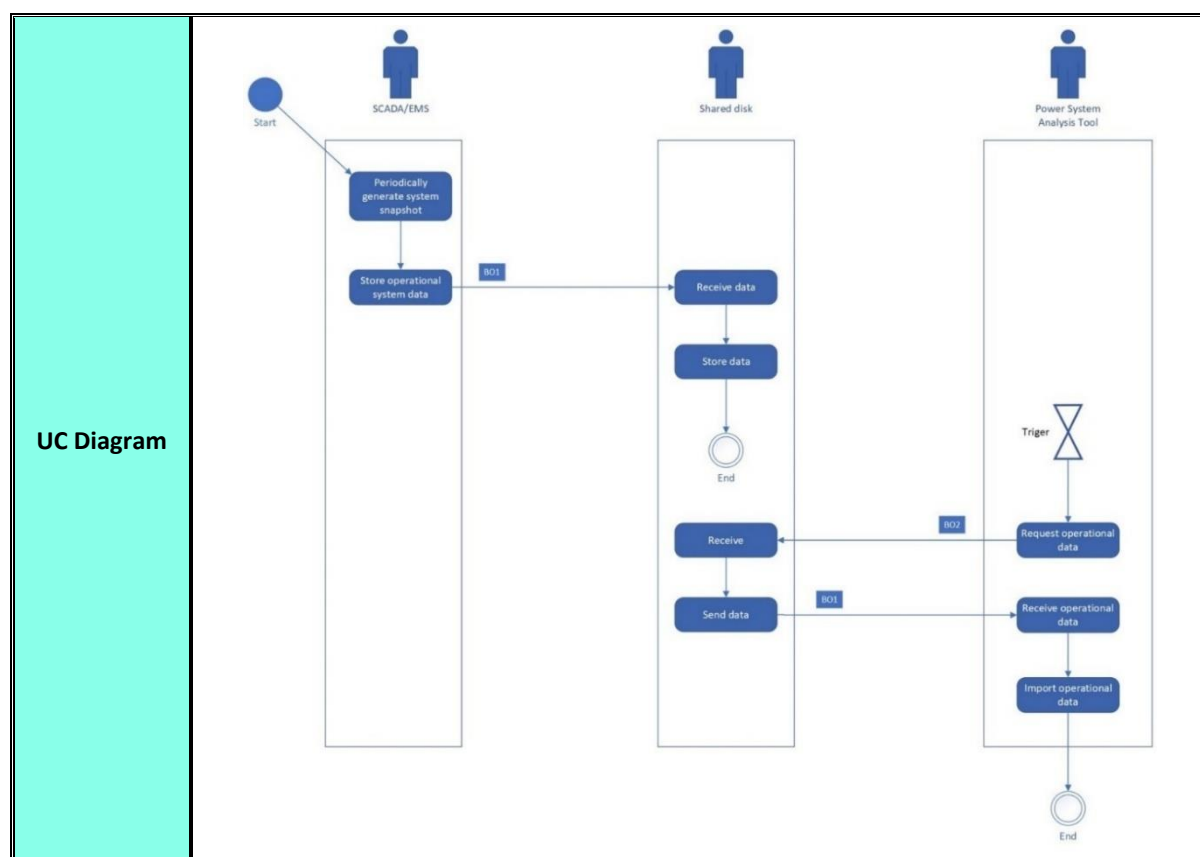


Table 81: Slovenian Pilot's – SLO-SUC-1 UC overview

UC ID	SLO-BUC-3
UC name	Power system analysis tool retrieves operational data from SCADA/EMS
Scope	Power system numerical simulations and analysis
Objective(s)	Provide numerical analysis and simulation tools with operational data from SCADA/EMS for various purposes, such as dynamic security assessment.
Short Description	This UC defines the procedure in which power system analysis and simulation tool (such as DIgSILENT PowerFactory) retrieves operational data from SCADA/EMS. The SCADA/EMS system periodically dumps snapshots of the current operation state of the power system and these data are stored on the shared disk. Power system analytic tool (such as DIgSILENT PowerFactory) accesses these data and imports it for further analysis.
Level of depth	Individual UC



5.4.9 Required KPIs for project performance and validation from the GA

5.4.9.1 KPI Framework for project evaluation: Alignment with GA objectives and UC demonstrations

The GA of the TwinEU project presents a comprehensive framework of KPIs that the project is designed and designated to achieve. These KPIs serve as critical benchmarks in fulfilling the initiative's core objectives [O] and are presented in the following Table 82:

Table 82: Mapping of KPIs linked with TwinEU Objectives (from GA)

[O#]	TwinEU Objectives	Related KPIs	KPI Description	Target	Status
O#1	Define a set of scenarios for the use of digital twin that will benefit from data sharing and exchange among operators (intra and cross-country) and the corresponding requirements for implementation.	KPI#1	No. of UCs based on cross-stakeholder data sharing and exchange	>5	Fulfilled
		KPI#2	No. of formalized requirements for the implementation of the EU DT	>15	Fulfilled
O#2	Define and implement a Reference Architecture for the creation of a European-scale Digital Twin.	KPI#3	No. of new Open APIs and standardizable to support the system of systems vision	>10	Ongoing
O#3	Define & implement a federated DT, consisting of a variety of closed loop adaptive DT instances, to support EU-level wider replication.	KPI#4	No. of adaption requirements for local digital twins	>10	Ongoing
O#4	Enhance data models and semantic interoperability to better support the digital twin use cases.	KPI#5	No. of changes proposed in data model standards	≥5	Ongoing
		KPI#6	No. of changes proposed in data connectors standards	≥5	Ongoing
O#5	Leverage on and adapt the emerging concept of energy data space to break data silos across energy value chain stakeholders, facilitate trusted and sovereignty-preserving data, model and computational resource cross-stakeholder sharing.	KPI#7	No. of UCs using data spaces	>2	Fulfilled
O#6	Leverage advanced technologies such as physics-informed AI and HPC to go beyond classical modelling approaches for digital twin.	KPI#8	No. of DTs making use of big data and AI	≥5	Ongoing
		KPI#9	No. of DTs making use of HPC service	≥2	Ongoing
O#7	Develop and deploy a variety of DTs services which will create the conditions for a more resilient and reliable European power network.	KPI#10	No. of new software tools and services for resilience	>3	Ongoing
		KPI#11	No. of new software solutions and services for cybersecurity	>2	Ongoing
O#8	Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains.	KPI#12	No. of UCs with at least two operators implemented in real grids. Fully operational DTs validated in real-world conditions (TRL 6/7)	>10	Fulfilled
O#9	Large adoption of the TwinEU approach creating the condition for real implementation at EU scale.	KPI#13	No. of operators running DT compatible with TwinEU (All KERs)	>15	Ongoing
O#10	Creating the conditions for the long-term sustainability development of the TwinEU vision and opening new business opportunities based on digital twin.	KPI#14	New business cases enabled by the digital twin	>3	Fulfilled
		KPI#15	No. of companies involved in the future development at the end of the project	>15	Ongoing

5.4.9.2 Status of GA KPIs

The KPIs outlined in Table 82 have been progressively addressed throughout the course of the project. As of the publication of D2.2, four (4) KPIs defined in the GA have been successfully fulfilled. This section provides a detailed overview of how these KPIs have been achieved or exceeded.

Regarding **KPI#1**, thirty-one (31) UCs have been aggregated, that demonstrate cross-stakeholder data sharing and exchange, going beyond the GA's initial expected target of exceeding five. This is highlighted across the various pilot locations that are listed below with each relevant UCs:

- Bulgarian pilot (*Bg02, Bg03, Bg04, Bg05, Bg06, Bg09*): The indicated UCs engage stakeholders such as Weather Forecast Providers, TSOs, DSOs, IT providers, and FSPs to enhance data-driven decision-making.
- Dutch pilot (*NL02*): This UC involves TSO and TU Delft (research institute) demonstrating DT-enabled stability assessments.
- Cypriot pilot (*EMD-CY01, EMD-CY02*): The UCs incorporate TSO, FSP, MO, and HVDC operators communication streams, exploring DT applications in congestion and frequency management.
- Greek pilot (*EMD-GR01, EMD-GR02*): The Greek pilot UCs are focused on TSO, DSO, MO, BMO, DER owners, and FSPs, and investigate TSO-DSO coordination for enhanced grid flexibility.
- German pilot (*Ge01-Ge07*): The UCs leverage MPOs, MDPs, DSOs, Weather Data Suppliers, HEMS, and FSPs data sharing, for optimized asset monitoring and predictive analytics.
- Hungarian pilot (*Hu01*): This UC features collaboration between DSO, TSO, and an academic partner, and highlights research in DT applications.
- Iberian pilot (*Ib01-Ib14*): The UCs from the Iberian pilot encompass TSOs, research centres, DSOs, MOs, DER owners, and FSPs, covering a range of DT-enabled energy market functionalities.
- Italian pilot (*IT01, IT02*): These UCs are focused information sharing among TSO, DSO, and DER owners, exploring DT-driven system analysis.
- Slovenia (*SLO-BUC1, SLO-BUC2*): Demonstrating collaboration between DSOs and TSOs, the UCs validate DT applications in dynamic grid operations.

In accordance with **KPI#7**, the UCs developed under T2.4 also address the integration of DTs within data spaces. Five (5) UCs met this requirement during T2.4, specifically:

- Iberian pilot (*ib07, Ib11, Ib12, Ib13, Ib14*): These UCs facilitate cross-border flexibility markets, market operator platforms, and shared information hubs, ensuring seamless data exchange across entities.

To meet **KPI#12**, the TwinEU project successfully implements thirteen (13) UCs that valorise fully operational DTs in real-world conditions, ensuring that DT technologies move beyond theoretical frameworks, achieving higher TRLs (TRL 6/7), where they are validated under real operational constraints.

The following UCs directly contribute to achieving this KPI demonstrated in the project's GA, proving the practical application of DTs across a variety of power system domains, operators, and geographies:

- Dutch pilot (NL01, NL02): The two Dutch UCs apply TSO-DSO collaboration for real-time cyberattack detection and dynamic stability assessment, valorising the TU Delft's operational DT.
- Cypriot pilot (EMD-CY01, EMD-CY02): These UCs demonstrate DT-driven congestion management in distribution grids and frequency support management for HVDC-interconnected systems. In these UCs, the DTs of the distribution grid that are used are of higher TRL, reflecting demonstration in relevant operational environments.
- Greek pilot (EMD-GR01, EMD-GR02): The two UCs scope in TSO-DSO coordination for congestion management and fast frequency response, valorising the operational DTs of DAM-MO and BM-MO.
- German pilot (Ge01, Ge04, Ge05): The three UCs utilize monitoring at LV-/MV-level, preventive congestion management, and optimal flexibility aggregation within households, valorising the operational IGP Envelio DT.
- Iberian pilot (Ib05, Ib06): DT-enabled RES integration planning, and probabilistic cross-border capacity allocation, valorising the existing DT from ANELL, Individual Grid Digital Twin (IGDT), Market Platform, Common Grid Digital Twin (CGDT).
- Italian pilot (IT01): This Italian UC analyses the TSO defence system through utilizing a HIL simulation DT.
- Slovenian pilot (SLO-BUC2): This UC conducts a real-time dynamic RMS analysis, using the DIgSILENT PowerFactory DT capabilities.

5.4.10 Evaluation plan KPIs for the Use Cases demonstration

As part of the IEC 62559 template, the pilot partners have defined a set of KPIs to test the DTs; these are presented in the following tables, listed per pilot:

Table 83: The Bulgarian pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
BG01	Establishment of the data exchange between the DTs	BG01_KPI1	Percentage of verified DTs [%]	This KPI will be based on verifying the accuracy of the created DTs for the needs of Bulgarian pilot. The target will depend directly on the ratio of the verified DTs developed compared to the total number of the pilot DTs created.
		BG01_KPI2	DT interoperability success rate [%]	This KPI will keep track of the possibility of the DTs to reliably exchange information with one another. Target will be set in such a way to indicate the need for accurate data exchange in the pilot.
BG02	AI-Improved Forecast of WPP Production	BG02_KPI1	Improved Improvement of WPP forecast accuracy [%]	This KPI will be based on comparing the accuracy of the forecast obtained by using ANN techniques with the reference value (either from the literature, or from one of the tools used at the moment, will be decided once the full set of data is available).

BG03	AI-Improved Forecast of SPP Production	BG03_KPI1	Improvement of SPP forecast accuracy [%]	This KPI will be based on comparing the accuracy of the forecast obtained by using ANN techniques with the reference value (either from the literature, or from one of the tools used now, will be decided once the full set of data is available).
BG04	AI-Improved Forecast of OHL Ampacity	BG04_KPI1	Increase of overhead line rating [%]	This KPI will be calculated by comparing line ratings calculated by using the AI-boosted method and the climate parameters to seasonal limits. The indicator will provide a clear view of the effects obtained by applying the suggested innovative technique.
		BG04_KPI2	Better utilization of the existing lines [%]	KPI will be calculated by comparing the loading (percentual) of same lines, under same conditions, for the situations in which seasonal and forecasted ratings are used. This will be the major indicator of potential that these forecasts hold for enhanced utilization of the existing infrastructure in the grid.
BG05	Increase of power flow on cross border transmission lines	BG05_KPI1	Increase of cross-border line rating [%]	This KPI will be calculated by comparing line ratings calculated by using the AI-boosted method and the climate parameters to seasonal limits. It will focus on the selected set of cross-border lines.
		BG05_KPI2	Better utilization of the cross-border lines [%]	This KPI will be calculated by comparing the loading (percentual) of same lines, under same conditions, for the situations in which seasonal and forecasted ratings are used. This will be the major indicator of potential that ampacity forecasts hold for the better utilization of the existing infrastructure in the grid. It will focus on the selected set of cross-border lines.
BG06	Determination of optimal locations for RES connection	BG06_KPI1	Number of optimized connections [#]	This KPI will be based on the number of RES in the region of interest for which the optimization of the connection points will be performed. It will depend both on the interest of the investors in this area and on the capabilities of the created optimization tool.
BG07	N-1 assessment on the DT level	BG07_KPI1	Number of detected critical outages [#]	This KPI will be centred around the detection of the outages in the transmission system of Bulgaria for which there are issues in the TSO grid. KPI will be verified in tight cooperation with the TSO.
		BG07_KPI2	Percentage of considered congestions [%]	As stated before, one of the main goals of this UC will also be examination of the possible mitigation measures based on different operational actions. This KPI will be the measurement of success of this process. Those issues that remain after the chosen measures are implemented will be highlighted as the ones that need to be resolved by new projects.
BG08	DT-based Maintenance plan of TSO grid	BG08_KPI1	Percentage of addressed issues in the system [%]	This KPI will be calculated based on the share of the spotted problems in the grid while some of the elements are undergoing maintenance. The ways in which these issues will be addressed may include some operational measures (new or taken from

				BG07) or recommendations for maintenance planning.
BG09	Flexibility Requirements to Avoid Congestions	BG09_KPI1	Percentage of the mitigated congestions in DSO grid via FSP services [%]	This KPI will be determined by comparing the total number of congestions considered in DSO grid with the number of congestions that were mitigated (or, in some cases, removed) by using the services that are offered by the FSPs in the distribution grid.
BG10	Inter-SO Flexibility Exchange	BG10_KPI1	Percentage of the mitigated congestions in TSO grid via FSP services [%]	This KPI will be determined by comparing the total number of congestions considered in TSO grid with the number of congestions that were mitigated (or, in some cases, removed) by using the serviced that are offered by the FSPs in the distribution grid.

Table 84: The Dutch/French pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
FR01	Power system training simulator for complex and critical situations	FR01-KPI1	Real-time physical simulation [#]	Physical simulation should take less than simulated time considering a 1s time step.
		FR01-KPI2	Increased events successfully processed per sec [#].	The cyber-physical simulator manages pre-scenarized events and events sent by other modules (the trainees through SCADA emulator, game master, smart assistants), at the rate of 1 event per second while keeping real-time synchronization. Complex events can be queued and sent to the simulator over multiple time steps.
		FR01-KPI3	Decreased event failure rate [%]	The event success rate when played by the trainees should be more than 95%.
		FR01-KPI4	Data update of SCADA emulator in less than 1 sec. [#]	SCADA emulator displays real-time update of points and measurements within 1 second. and sends command to the simulator.
		FR01-KPI5	Real-time performance [#]	Training simulator should be able to handle 1 non-critical event per second, with a time step of 1s for the French network (6000 voltage levels).
NL01	DT-enabled real-time cyberattack detection and impact analysis on the operation of integrated power grid	NL01-KPI1	Number of Simulated Cyberattacks [#]	Number of cyberattack to be simulated will be 3 types of attacks
		NL01-KPI2	Impact Index of Cyberattacks [#]	Will measure and evaluate the overall impact of cyberattacks, considering loss of load, frequency deviations, voltage deviations, survived islands, and affected components.
		NL01-KPI3	Time to cascading Failures [#]	Will measure the time taken from the initiation of a cyberattack to the point where cascading failures begin.
		NL01-KPI4	Machine Learning Anomaly Detection Accuracy [%]	The accuracy of machine learning algorithms in correctly identifying anomalies within the power grid will be over 85%.
NL02	DT-based dynamic stability assessment under active power flow changing events.	NL02-KPI1	Frequency Deviation Index [#]	Maximum frequency deviation (in Hz) recorded during active power flow disturbances.
		NL02-KPI2	Voltage Deviation Index [#]	Maximum voltage deviation (in per unit, p.u.) during different disturbance events.

		NL02-KPI3	Scenario Analysis Coverage Index [#]	Number of different disturbance scenarios successfully simulated and analyzed.
		NL02-KPI4	Stability Restoration Time [#]	Average time (in seconds) taken to restore system stability after a disturbance event.
		NL02-KPI5	Predictive Maintenance Accuracy Index [%]	Percentage of correctly predicted stability issues that were proactively addressed.

Table 85: The EAST-MED pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
EM-CY-01	Congestion management in distribution grids through ancillary services	CY01-KPI1	Volume of available active and reactive power deviation, procured by DSO, offered by FSPs, and cleared by the Market operator [#]	This indicator contains the procured, offered and cleared ΔP and ΔQ availability service (in kW and kVar) for the time period under examination.
		CY01-KPI2	Reduction of overloading condition [#]	This indicator will provide information for the duration and the intensity of the overloading conditions occurs at the distribution grid as a percentage of the nominal thermal capacity of the distribution lines/substations. This will be compared with the base case where no ancillary services for congestion management are provided by the flexibility resources of the distribution grid.
EM-CY-02	Frequency support management of HVDC-interconnected systems at a regional level	CY02-KPI1	Volume of available power, procured by TSO, offered by FSPs, and cleared by the Market operator, for FCR services. [#]	This indicator contains the procured, offered and cleared FCR availability service (in MW/Hz) for the time period under examination.
		CY02-KPI2	Volume of power provided by HVDC link during frequency events. [#]	This indicator will provide the amount of power provided by the HVDC link to the interconnected systems during a frequency event.
		CY02-KPI3	Rate of Change of Frequency (ROCOF). [#]	This indicator considers the maximum rate of change of frequency (in Hz/s) after an intense disturbance on system balancing.
		CY02-KPI4	Frequency Nadir [#]	This indicator considers the minimum frequency (in Hz) observed after an intense disturbance on system balancing.
EM-GR-01	Congestion management in transmission and distribution grids through TSO-DSO coordination	GR01-KPI1	Thermal Limit Violation (Both TSO+DSO) [#]	This KPI measures the number or percentage of transmission and distribution lines that exceed their thermal capacity limits.
		GR01-KPI2	Transformers' overloading [%]	The present KPI aims to quantify the percentage of transformer's' overloading due to the selection of the residential assets by the balancing market.

		GR01-KPI3	Activation of assets from the side of the distribution network [#]	The present KPI quantifies the contribution of the distribution network assets in terms of their participation in the market scheme
		GR01-KPI4	Facilitating DERs Transactions in the DAM [#]	This KPI quantifies the volume of MWh successfully transacted using new trading products for renewable energy sources (RES) and energy storage systems within DAM.
		GR01-KPI5	Social Welfare Increase from DERs Participation in DAM [%]	This KPI measures the impact of integrating new energy sources into DAM on overall social welfare by comparing current metrics against a baseline established prior to their integration.
		GR01-KPI6	Participation rate of Industrial facilities in the DR program [%]	This KPI measures the percentage of eligible industrial facilities participating in DR programmes.
		GR01-KPI7	Frequency of industrial DR events (events/year) [#]	This KPI measures the number of DR events called within a specific period, typically a year.
		GR01-KPI8	Increase in mFRR activation signals from industrial DR (both up and down) [#]	This KPI measures the mFRR volume, offered in the balancing market, from industrial DR
		GR01-KPI9	Redispatch Volumes [#]	This KPI measures the volume of generation that must be adjusted (redispatch) to manage grid congestion at both the transmission and distribution levels.
		GR01-KPI10	Utilization Rate of Flexibility Resources [%]	This KPI measures the percentage of available flexibility resources (like distributed energy resources, storage, demand response) utilized to manage congestion.
		GR02-KPI1	Number of FFR activations [#]	This KPI measures the number of DR events called within a specific time period, typically a year.
		GR02-KPI2	Resource Utilization rate [#]	This KPI measures how effectively the available FFR resources are being utilized, to the total FCR and FFR available capacity.
EM-GR-02	Fast Frequency Response for Effective Frequency Control through TSO-DSO coordination	GR02-KPI3	Renewable Energy Curtailment [#]	This KPI measures the reduction in renewable energy curtailment due to FFR actions.
		GR02-KPI4	DER Activation Rate [%]	This KPI measures the percentage of DERs successfully activated to provide Fast Frequency Response within the required time frame.

Table 86: The German pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
Ge01	Utilization monitoring on LV-/MV-level	Ge01-KPI1	Increase in Grid Observability accuracy [%]	Relevant variables for observability of the grid are valid: - voltage at (all) nodes of the grid, - utilization of lines, - utilization of transformers etc. - count of measurements, - quality of measurements.
Ge02	State estimation under changing topology on LV-level	Ge02-KPI1	Decrease in the deviation error [%]	The higher the standard deviation, the higher the inaccuracy and the greater its influence on the result of the state estimation → target: small deviation.
		Ge02-KPI2	Increase in number of monitored switches [%]	Number of monitored switches (most of the switches are not monitored from remote yet).
		Ge02-KPI3	Increase in number of monitored switches	Number of monitored switches (most of the switches are not monitored from remote yet).
		Ge02-KPI4	Percentage of State Estimation (SE) runs that did not converge [%]	The current solver for the SE optimization problem is not intrinsically guaranteeing a feasible solution - The calculation may be interrupted by a crash - → Key is a continuous monitoring of the grids with as few interruptions as possible.
		Ge02-KPI5	Relative deviations between SE input and output [#]	High deviations (relative, normalized to e.g. the nominal power of the asset) are often an indicator for data quality problems, faulty measurement inputs, → Disproportionately high deviations are not a strict metric, much rather a hint towards one of a selection of potential problems.
Ge03	Development of advanced monitoring & control tools for congestion management	Ge03-KPI1	Increase in Response Time [%]	Time taken to identify and respond to potential congestion events.
		Ge03-KPI2	Increase of congestion events that are avoided. [%]	Number solved congestions.
		Ge03-KPI3	Decrease of SE runs that did not converge [%]	Just as in UC2, Online Monitoring, CM relies on a SE run every minute to observe the repercussions of the sent control commands. If these SEs cannot be carried out, the transparency of congestion resolution processes gets lost.
		Ge03-KPI4	Quota of failed regulator interventions [#]	Regulator interventions are initiated with a fixed timeline in order to solve a congestion detected earlier, using parameters fitting to the given situation. Still, a regulator intervention may not resolve the congestion: A second (third, fourth, ...) intervention would be chained in this case. Reaching a 100% quota should not be the goal here (the volatility of the inputs would not allow for that), but a good steering algorithm takes eventualities into account and mitigates as many congestions as possible.

Ge04	Development of a concept for a preventive congestion management	Ge04-KPI1	Increase in envelope curves implemented [%]	Dependent on criticality, a certain number of envelope curves have been implemented.
		Ge04-KPI2	Prediction Accuracy in %	The percentage accuracy of the congestion forecasts compared to actual congestion events.
		Ge04-KPI3	False Positive Rate in %	The percentage of times a congestion event is forecasted but does not occur.
		Ge04-KPI4	False Negative Rate in %	The percentage of times a congestion event occurs but is not forecasted.
Ge05	Optimal utilization of the flexibility potential in the network feeder by aggregation of flexible assets within the household via HEMS	Ge05-KPI1	Increased successfully steered charging events	How often a charging event is steered.
		Ge05-KPI2	Reduction of charging costs [%]	The charging schedules uses the cheapest hours within the envelope curve in comparison without congestions/envelope curve.
Ge06	Development of advanced tools for preventive congestion management through regional aggregation of flexible assets	Ge06-KPI1	Increase in forecasting accuracy [%]	
		Ge06-KPI2	Achieved aggregation of EVs in the algorithm. [#]	EV charging point check-up if goal has been achieved
Ge07	Conceptual description of interoperable solutions that support an efficient TSO-DSO data exchange on the interface level.	Ge07-KPI1	Number Master Data points [#]	Number of data points about units and topology exchanged
		Ge07-KPI2	Number Data Streams [#]	Number of units where a successful data stream was exchanged
		Ge07-KPI3	Response Time for Power Requests [#]	Tracks the time taken from when a TSO requests additional power to when the aggregator responds with the available power resources.
		Ge07-KPI4	Increase of RES data integration [#]	Measures the increase in the integration of data from renewable energy sources (RES) into the system.
Ge08	Visualizing hosting capacities within Connection request and online connection check applications	Ge08-KPI1	Decrease in time needed to establish network capacities. [#]	The effort that is needed to find a suitable location for an asset (i.e. in minutes per asset)
		Ge08-KPI2	Increase in visibility of connected assets [%]	Transparency about connected assets in terms of share of in the map included assets to total assets

Table 87: The Hungarian pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
DT1	Digital twin for power line monitoring	DT1-KP1	Over 3 physical sensors used	How many physical sensors were used for the data collection of the ANN-based DT training?
		DT1-KP2	Number of trained virtual sensors	How many ANN-based DT models have been implemented?
		DT1-KP3	Over 1 of successfully trained models	How many ANN-based DT models have been made where the average achieved accuracy is within plus or minus 2 degrees Celsius?
		DT1-KP4	Virtual sensor accuracy (max & mean)	What is the maximum and average DT accuracy achievable (one-month exam period)?
		DT1-KP5	Virtual sensor accuracy (outliers)	What is the outlier percentage of the DT model (one-month exam period)?
		DT1-KP6	Number of power lines covered with virtual sensor	How many power transmission lines are covered with virtual sensors (DT)?
		DT1-KP7	Number of potential substitution	How many physical sensors can be potentially substituted by ANN-based DT models?
HU02	Co-optimizing the day-ahead and intraday energy and balancing capacity market	HU02-KPI1	Depth of the market	The quantity of orders is near the equilibrium price. Hour, rate, zone, quantity, and price parameters => Orders are grouped by type, rate, zone, and hour. For each group, the number and total quantity of orders within $\pm 15\%$ of the equilibrium price need to be determined. The equilibrium prices need to be processed by averaging over hours.
		HU02-KPI2	Price Sensitivity	Change of upward and downward balancing capacity prices relative to the base case. For each product, zone, and hour, a single value needs to be extracted from price results
		HU02-KPI3	Zonal spreads	Upward and downward balancing capacity prices differences along borders. The 4 zones have 4 borders between them: HU-AT, AT-CZ, SK-CZ, HU-SK. Constraints on the power flow across these borders can result in price differences. For each product and hour, the differences in price values across borders need to be calculated.
		HU02-KPI4	Reserve Costs	Upward and downward balancing cost. One value is needed per zone, product, and hour.
HU03	Enhanced flow-based capacity calculation for market co-optimization using DLR data	HU03-KPI1	Transmission Capacity Utilization	Measures the increase in transmission capacity available for cross-border flows as a result of using DLR compared to static ratings. This can be tracked as a percentage increase in capacity over time.
		HU03-KPI2	Congestion Management	Quantifies the reduction in grid congestion on cross-border lines by comparing congestion hours or events with and without DLR implementation.

		HU03-KPI3	Capacity Adjustment Frequency	Measures how often DLR adjustments are applied to update capacity ratings based on real-time conditions. This KPI reflects the responsiveness of the system to dynamic changes in grid conditions.

Table 88: The Iberian pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
Ib01	AI Agent for probabilistic grid status forecast and remedial actions identification for the TSO's Control Centre Operator	Ib01-KPI1	Increased Accuracy [%]	Precision of the algorithm to determine the grid action
Ib02	DT for generation of synthetic series of renewable resources	Ib02-KPI1	AP	Series correlation
Ib03	DT-enabled multi-area system dynamic behaviour assessment	Ib03-KPI1	Frequency Nadir	The Frequency Nadir corresponds to the minimum value of frequency excursion, and it is an indicator of the dynamic robustness of the system. The system is considered in a dynamic safe region if the frequency nadir does not cross the boundary defined for dynamic safe operation (49.2 Hz)
		Ib03-KPI2	Frequency Zenith	The Frequency Zenith corresponds to the maximum value of frequency excursion, and it is an indicator of the dynamic robustness of the system. The system is considered in a dynamic safe region if the frequency nadir does not cross the boundary defined for dynamic safe operation (50.8 Hz).
		Ib03-KPI3	RoCoF	The RoCoF corresponds to the maximum value of the time derivative of frequency excursion regarding time (for a time window to be defined), and it is an indicator of the dynamic robustness of the system. The system is considered in a dynamic safe region if the RoCoF does not cross the boundary defined for dynamic safe operation (1 Hz/s).
		Ib03-KPI4	ACE	Area Control Error should be 0 after 300s
Ib04	Abnormal market participation detection and protocol activation for mitigating the risk and consequences	Ib04-KPI1	New methodologies/ protocols defined for mitigating the risk and consequences	Depending on the defined scenarios and services included in the study during the development of the prepared methodology, there will be a number of protocol of methodologies defined to mitigate the consequences of a cyber threat toward the market participation both at distribution and transmission levels.
Ib05	DT-based N-1 contingency analysis	Ib05-KPI1	Critical elements identified	Number of identified elements that make the grid not to be N-1 contingent.

Ib06	DT-enabled new RES integration validated plan in the MV grid	Ib06-KPI1	Available RES power hosting capacity	This KPI measures the increased RES available power capacity that could be deployed along the grid thanks to the simulations implemented by the DSO's DT.
Ib07	DT-based grid maintenance planning activities	Ib07-KPI1	Accuracy in recalculated power flows	Divergence between the expected behaviour of the grid forecasted by the DT for the period of time in which the maintenance activities will take place.
Ib08	Long term flexibility in MV	Ib08-KPI1	Overload reduction	Measure the number of times overloads are prevented in the outgoing lines of the substation or secondary-substation. .
		Ib08-KPI2	Utilization of flexible resources	Evaluate the amount of flexible resources used compared to those available.
		Ib08-KPI3	Implementation of cost vs savings	Compare the implementation cost of the flexibility solution with the savings in CAPEX and OPEX compared to the traditional solution.
		Ib08-KPI4	Availability and Reliability of Flexibility Service	Measure the number of hours flexibility services were available and reliable.
Ib09	Flex Connections	Ib09-KPI1	Voltage Quality Improvement	Measure the improvement in grid voltage quality due to the implementation of flexibility measures.
		Ib09-KPI2	Flexibility Utilization Rate	Assess the extent to which the flexibility of EV chargers is utilized to manage grid load.
		Ib09-KPI3	Load Balancing Efficiency	Measure the efficiency of load balancing achieved through the flexibility of EV chargers.
		Ib09-KPI4	Grid Stability	Assess the overall stability of the grid as a result of implementing flexibility measures.
Ib10	Probabilistic cross-border capacity allocation	Ib10-KPI1	Cross-border capacity utilization rate	This KPI measures the percentage of total available transmission capacity that is actually used. Helps to evaluate whether the allocated capacity is being effectively utilized by market participants.
		Ib10-KPI2	Capacity Reliability Index	This KPI measures the reliability of the calculated cross-border capacity under various probabilistic scenarios. It indicates that the available capacity will meet or exceed the required capacity when dealing with uncertainties in demand, generation and network conditions.
		Ib10-KPI3	Grid Stability Index	This KPI evaluates the overall stability of the grid by integrating multiple critical parameters such as voltage levels, phase angles and loading of critical network elements (CNEs). It provides a holistic view of the grid's operational health and ensures cross-border electricity flows do not compromise the overall stability of the interconnected grid.

Ib11	Cross-border assessment of flexibility and pre-qualification	Ib11-KPI1	Available Flexibility	This indicator measures the flexible power that can be used for FFR at a specific grid segment, i.e., the available power flexibility in a defined period (e.g., per day) that can be allocated by the SO at a specific grid area. It relates to the total amount of power in the specific grid area in the same period.
		Ib11-KPI2	Percentage of successfully prequalified FSPs	This indicator calculates the percentage of FSPs in the demo that are successfully prequalified, against the number of FSPs available in the grid area under analysis.
		Ib11-KPI3	Volume by prequalified units	This indicator measures the volume of prequalified flexibility.
		Ib11-KPI4	Number of implemented cross border products	This indicator measures the number of implemented products that can be traded in more than one country (cross border products). This KPI is valid for UCs that aim to harmonize the definition and process of flexibility products among SOs in different countries.
		Ib11-KPI5	Curtailed avoidance	This indicator measures the amount of power that is not curtailed by the usage of cross-border flexibility.
Ib12	Integration of TSO-DSO-MO-Prosumer market coordination	Ib12-KPI1	Number of qualified Local FSPs	This KPI measures the number of pre-qualified FSPs that provide reserves to the DSO and are also qualified to provide grid support in real-time to the transmission grid. The target is greater than zero.
		Ib12-KPI2	FSP revenues	This KPI measures the revenues of FSPs, particularly local FSPs, obtained by providing grid support to solve technical constraints in real-time. The target is greater than zero.
		Ib12-KPI3	Service cost difference	This KPI assesses the cost reductions in real-time technical constraint management. The target is greater than zero.
Ib13	Enhancement of short-circuit models and TSO/DSO information exchange for operational planning	Ib13-KPI1	% deviation to the maximum planning short-circuit current forecasted	Computation of the deviation between the maximum planning estimated value of the short-circuit current in a certain EHV/MV substation and the maximum short-circuit current forecasted through the model.
		Ib13-KPI2	% deviation between the short-circuit forecast with the rated short-circuit current of the circuit breaker in EHV/HV substations	Computation of the deviation between the rated short-circuit value of the circuit breaker in a certain EHV/MV substation and the maximum short-circuit current forecasted through the model.
Ib14	DT-endorsed flexible connection grant through the settlement of a Local Flexibility	Ib14-KPI1	Number of LFM sessions cleared	This KPI states the amount of sessions for local flexibility markets that are successfully cleared, generating an increased RES power export to the distribution grid.

	Market to internally balance the production surplus in congestion-creation hours/scenarios.	Ib14-KPI2	Increased RES power	This KPI measures the increased RES generated power that could be exported to the grid thanks to the collaboration between the DSO's and the MO's digital twins.

Table 89: The Italian pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
IT01	Analysis through DT of the TSO defence system	IT01-KPI1	Voltage profile comparison by evaluating the maximum error	Comparison of the simulated voltage profile with available historical data voltage profile.
		IT01-KPI2	Current profile comparison by evaluating the maximum error	Comparison of the current profile of the simulated systems with available historical data.
		IT01-KPI3	Frequency profile comparison by evaluating the maximum error	Comparison of the frequency of the simulated system with available historical data in case of relatively small unbalances.
		IT01-KPI4	Defence system performance with different intervention thresholds and scenarios - Voltage	The voltage profile of a node during an event that triggered the Sardinian defence system is take as reference curve. The new simulated condition (scenario and/or intervention thresholds) will be compared in terms of duration of the voltage transient and the magnitude of the voltage variation.
		IT01-KPI5	Defence system performance with different intervention thresholds and scenarios – Frequency	The frequency profile of the simulated system during an event that triggered the Sardinian defence system is take as reference curve. The new simulated condition (scenario and/or intervention thresholds) will be compared in terms of duration of the frequency transient and the magnitude of the frequency variation.
		IT01-KPI6	Defence system performance with different intervention thresholds and scenarios – Net load at HV/MV substation	The net load at HV/MV substation during an event that triggered the Sardinian defence system will be compared with the simulated HV/MV substation using different simulation conditions.
IT02	Analysis through DT of the behaviour of aggregated distributed resources during a grid event in the TSO system	IT02-KPI1	Grid losses (Wh)	Grid losses result from difference between energy feed-in and withdrawal.
		IT02-KPI2	Percentage grid losses (%)	Grid losses result from difference between energy feed-in and withdrawal.
		IT02-KPI3	Reverse power flow (Wh), (min)	The reverse power flow represents the injection of energy to the transmission system through the HV/MV transformer
		IT02-KPI4	Max power injected to/withdrawn from	Peak power

			HV/MV substation (W)	
		IT02-KPI5	Grid self-sufficiency (%)	Grid self-sufficiency represents the percentage of RES production that is used for supplying the loads and the energy of the loads.
		IT02-KPI6	Grid self-consumption (%)	Grid self-consumption represents the ratio between the RES production used for supplying the loads and the total RES production
		IT02-KPI7	Voltage profiles (pu)	Voltage profiles can be used to evaluate voltage stability of the power system.
		IT02-KPI8	Lines loading factor (pu)	Lines loading factor (pu)
		IT02-KPI9	Max nadir	Maximum nadir reached during an extreme event (to be defined extreme event)
EACL-IT-01	Digital Twin for definition of data model	EACL-IT01-KPI1	Rule's analysis	Evaluate the number of the rules to analyse how is automatable.
		EACL-IT01-KPI2	Translation of the standard	Percentage of the number of rules translated into automatable actions
		EACL-IT01-KPI3	Data model development	Number of Ioin needed, per object, completed
EACL-IT-02	Digital Twin for design validation	EACL-IT02-KPI1	Objects in model production	Progress of design in terms of objects
		EACL-IT02-KPI2	Reduction of documents	Fewer documents exchanged compared to the traditional process
		EACL-IT02-KPI3	Efficiency of design validation	Evaluation of the checks carried out automatically, and errors detected, compared to the total number of detectable errors and checks
EACL-IT-03	Scalability of Digital Twin for design validation	EACL-IT03-KPI1	Extension of the data model	Number of objects that should still be evaluated to extend the solution to all types of connection stations.

Table 90: The Slovenian pilot UC KPIs

UC ID	UC Title	KPI ID	KPI Name	KPI Description
BUC1	Dynamic RMS Analysis with Upgraded Transmission System Model	SLO-UC1-KPI1	Equivalent dynamic network model is merged with dynamic transmission network model.	Equivalent dynamic network model is merged with dynamic transmission network model.
		SLO-UC1-KPI2	Successful run of dynamic RMS analysis with included equivalent distribution model.	Successful run of dynamic RMS analysis with included equivalent distribution model.
BUC2	Real-time Dynamic RMS Analysis with Transmission System Model improved with the dynamic parameters of generators and control models of the neighbouring TSOs	SLO-UC2-KPI1	Dynamic network models exchange	Dynamic network models exchange
		SLO-UC2-KPI2	Dynamic network model of the transmission grid with observability area is developed.	Dynamic network model of the transmission grid with observability area is developed.
		SLO-UC2-KPI2	Run dynamic network analysis on the extended network model with operational data retrieved from SCADA.	Run dynamic network analysis on the extended network model with operational data retrieved from SCADA.
SUC1	Power system analysis tool retrieves operational data from SCADA/EMS	SLO-SUC1-KPI3	Operational data are successfully retrieved and imported in the simulation tool.	Operational data are successfully retrieved and imported in the simulation tool.

The comprehensive set of KPIs defined for each pilot under the IEC 62559 framework reflects the diverse objectives and technical scopes of the TwinEU UCs. These KPIs guide the assessment of DT implementation and performance while ensuring the comparability of results across heterogeneous pilots and UCs, while they are tailored to address unique grid challenges, such as congestion management, cyber-physical resilience, forecasting accuracy, market coordination, and interoperability. TwinEU UC KPIs support the evaluation of the project's real-world impact and contribute to the evidence base required for scaling and replication, reinforcing the robustness of methodology.

6 The pan-EU impact of the TwinEU federated DT solutions to the electricity grid and market challenges

Following the analysis of pilots' DTs and the technology requirements, the definition of the resulting pilot use cases and related KPIs, we will be presenting the correlation of these achievements with the key priorities in the EU energy policy, as this is expressed through the EU policy guidelines and regulation updates. A short presentation of these most important topics mapped with the pilot DTs functionalities as these will be demonstrated in the use cases will follow, to showcase how the project may support innovative practices for system operation and planning with data-driven approaches.

This Chapter 6 notably reviews selected key EU policy initiatives, including the EU Action Plan for Grids [41], the Demand Response Network Code, the Digitalization Action Plan and the recent reform on Market Design, to identify 18 priority topics – ranging from anticipatory grid investments and local flexibility services to cybersecurity exercises and digital twin integration - and assess their relevance to each TwinEU pilot.

This mapping allows a better understanding of how the TwinEU project contributes to EU goals for decarbonisation, system flexibility, and digitalization. Furthermore, Chapter 6 defines detailed propositions for pan-EU scenarios that will be addressing the previously identified challenges and will highlight the federated capabilities of TwinEU architecture for data and model sharing for cross-pilot partners.

In Chapter 6.1, we present a selection of the key current challenges for the European power system that are related to the technologies and functionalities of the DTs in the TwinEU project, based on recent evolutions of the regulatory framework. Then, we will establish a list of topics that we can examine considering the questions addressed by the different TwinEU pilot technologies. In Chapter 6.2 we analyze these topics separately and we showcase how TwinEU technologies can specifically support the implementation of these mandates. In Chapter 6.3, we present a set of propositions (pan-EU scenarios) for addressing key priorities set in the EU energy strategy using the federated TwinEU architecture connecting DT technologies developed in the pilots and validating this federation with cross-pilot participation, showcasing the wider applicability of the TwinEU innovations across Europe.

6.1 Key challenges for the European power system related to the TwinEU DT technologies

In this chapter, a review of the key current challenges for the European power system is established. The review is based on recent evolutions of the regulatory framework. This review will therefore help us establish a list of topics that we can examine considering the questions addressed by the different TwinEU demos.

6.1.1 Grids, the missing link – An EU Action Plan for Grids

The European Commission's document COM/2023/757 final "Grids, the missing link – An EU Action Plan for Grids" [41] , introduces an extensive strategy to modernize and expand Europe's electricity grids in response in compliance with latest energy and climate targets.

With energy demand expected to grow significantly due to electrification in sectors such as transport, heating, and industry, and the integration of renewable energy sources like wind and solar, the plan presents 14 key actions to strengthen the grid infrastructure.

A central challenge identified by this action plan is aligning the pace of grid development with the deployment of renewables. It is emphasized that both transmission and distribution networks are getting increasingly constrained by the changing configurations of generation and demand, which creates a need for decentralization, digitalisation, and flexibility. The document identifies bottlenecks such as long permitting timelines, ageing infrastructure, connection backlogs, and insufficient financing as critical issues.

Regarding the applicability of the DT innovations produced, we can notably focus on the following key actions of the plan:

Action 2: Supporting top-down planning towards 2050 by integrating the identification of offshore and onshore system needs

This action put forward the priority of bringing together offshore and onshore network planning under a common framework through the next TYNDP process, integrating also expectations of hydrogen infrastructure needs in cooperation with hydrogen stakeholders. Additionally, system operators are further encouraged to assess the flexibility needs of their energy systems when planning transmission networks

Action 3: Supporting DSO Grid Planning

The plan tasks the EU DSO Entity with improving grid planning at the distribution level, through introducing best practices to the existing process of Distribution Network Development Plans (NDPs). These plans should anticipate future demand and integration of renewables, EV charging infrastructure, heat pumps, and local energy communities. Reliable and transparent NDPs are expected to help reduce connection delays and optimize grid reinforcement. National Regulatory Authorities (NRAs) are also encouraged to provide guidance and promote EU-wide consistency.

Action 6: Pan-EU Grid Hosting Capacity harmonized definitions to establish a pan-EU overview for system operators

This action seeks to enhance transparency around grid connection capacities. ENTSOe and the EU DSO Entity are instructed to agree on harmonized definitions for available grid hosting capacity and develop a pan-European overview, with the objective of avoiding connection backlogs and providing transparency to project promoters. This initiative is also meant to help support regulators to identify locations where flexible connection agreements are necessary and promote the digitalisation and streamlining of connection procedures.

Action 7: Promoting the uptake of Smart Grid Technologies and network efficiency

This action addresses the limited use of currently available smart grid technologies, which can significantly improve grid efficiency and reduce energy losses. Smart solutions such as automation, real-time monitoring, and demand-side flexibility are identified as key enablers for optimizing existing assets while mitigating infrastructure investment needs. ENTSOe and the EU DSO Entity are therefore in charge of promoting the adoption of these innovations, and regulators are encouraged to adjust tariff structures to better incentivize operational

expenditures (OPEX) that support digitalization and flexibility, moving away from traditional capital expenditure (CAPEX)-focused models.

6.1.2 ACER proposition for Demand Response Network Code and respective updates in Electricity Balancing, Demand Connection and System Operation Network Codes

In May 2024, EU DSO Entity and ENTSOe published a proposition for the Demand Response Network Code (NCDR) [42], outlining regulations for integrating demand response, distributed generation, energy storage, and demand curtailment into electricity markets. In March 2025, ACER evaluated these propositions and public consultation and published the final ACER Recommendation 01/2025 for NCDR [43]. The aim of the NCDR is to foster market integration and remove barriers to fair competition and the efficient monitoring of grid stability. The code introduces rules for aggregation, data management, prequalification, and coordination between TSOs and DSOs. It promotes digitalisation, interoperability, and transparent stakeholder engagement, while addressing technical, regulatory, and operational aspects to support energy transition goals and efficient system operation across the EU.

In this review, we focus on the following articles of the NCDR:

- **Article 29-39 addresses the topic of market-based procurement of local services.** It notably specifies requirements for the procurement of local services, roles for flexible connection agreements and market-based procurement of local services, coordination and interoperability issues of local services with system operators and DAM, IDM, BM, data exchange, product attributes, settlement and definition of local products.
- **Article 43-44 specifies the Distribution Network Development Plans (DNDP).** It specifies the content and requirements for the DNDPs, mainly focusing on the description of the distribution system planning framework, the scenario(s) used to identify network development needs, planned and ongoing investments, assessment of needs for local services to time horizons.
- **Articles 47 to 52 address TSO-DSO and DSO-DSO Coordination.** Article 47 provides guidelines for TSOs and DSOs to forecast and detect physical congestion and voltage issues while article 48 prescribes the respective solution process for these issues. Articles 49-52 prescribe the procedures for grid prequalification for service providing units or groups (SPUs/SPGs) and the temporary limits, as well as the data exchange characteristics.

6.1.3 Commission Delegated Regulation (EU) 2024/1366 on sector-specific rules for cybersecurity aspects of cross-border electricity flows

The Commission Delegated Regulation (EU) 2024/1366, adopted on 11 March 2024 and published on 24 May 2024 [44], supplements Regulation (EU) 2019/943 by establishing a network code for sector-specific cybersecurity rules for cross-border electricity flows. It aims to strengthen cybersecurity practices in the operation of the electricity grid, outlining responsibilities for the different entities, including national and EU actors that are required to

assess, mitigate, and respond to cybersecurity risks, ensuring the continuity and the resilience of electricity operations across borders.

In this review, we focus on the following articles:

Article 18 – Cybersecurity Risk Assessment Methodologies

Article 18 requires TSOs, supported by ENTSOe and in cooperation with the EU DSO entity, to develop and submit by 13 March 2025 their proposals for cybersecurity risk assessment methodologies at Union, regional, and national levels. These methodologies must include an identification of supply chain threats, proposed criteria for assessing high or critical cybersecurity risks based on likelihood and consequences, a review of legacy systems, and an analysis of cascading cyber effects and dependencies on single ICT suppliers. The regulation mandates the use of a uniform risk impact matrix to standardize assessments across Member States, focusing on impacts like load loss and generation reduction.

Article 39 – Detection of Cyber-Attacks and Handling of Related Information

Article 39 defines how the entities must manage and respond to detected cyber-attacks. They are expected to build internal capabilities, with support from national authorities, ENTSO-e, EU DSO entity, and CSIRTs. Attacks that affect cross-border electricity flows are specifically targeted and the emphasis is put on proactive detection, classification and mitigation. Key mentioned duties include sharing information among affected parties through designated points of contact, testing cyber-attack procedures annually, and ensuring real-time coordination during incidents. The general objective is therefore to minimize the impact of cyber threats by enhancing operational resilience.

Chapter VI (Articles 43 and 44) – Electricity Cybersecurity Exercise Framework

Chapter VI introduces a structured framework for conducting cybersecurity exercises. Article 43 requires that each critical-impact entity must carry out a cybersecurity exercise every three years, simulating cross-border electricity cyber incidents based on identified risks. ENTSOe and the EU DSO entity are responsible for developing standard exercise scenarios and associated success criteria, providing first templates by 31 December 2026. Article 44 addresses regional and cross-regional levels, encouraging collaborative simulations between Member States. The goal of these exercises is to test the robustness of response plans, improving cross-entity coordination and consistency with national crisis management frameworks.

6.1.4 Digitalising the energy system – EU Action Plan

The *EU Action Plan on Digitalising the Energy System*, adopted by the European Commission on 18 October 2022 [45], lays out a comprehensive strategy to integrate digital technologies into the EU's energy infrastructure to enhance efficiency, resilience, and sustainability. This initiative aligns with the European Green Deal and the Digital Decade Policy Programme, forming the basis of the EU's "twin transition" toward a greener and more digital economy.

The key focuses of this review are as follows:

The DT Initiative

A key feature of the action plan is the creation of a digital twin of the EU electricity grid, which aims to significantly improve the efficiency and intelligence of the grid. The digital twin is presented as a dynamic, real-time virtual model of the European electricity network. Its development is meant to make the energy system more intelligent and responsive to the demands of decarbonisation and decentralisation.

The plan outlines five coordinated investment areas:

1. Observability and Controllability – Enhancing visibility and management of grid conditions in real time.
2. Efficient Infrastructure and Network Planning – Supporting better, data-driven planning of electricity infrastructure to anticipate future needs.
3. Operations and Simulations for a More Resilient Grid – Using simulations to improve grid robustness and manage unexpected challenges.
4. Active System Management and Forecasting – Enabling demand response and flexibility through improved forecasting and system control.
5. Data Exchange Between TSOs and DSOs – Ensuring interoperability and real-time communication between Transmission System Operators and Distribution System Operators for coordinated operations.

The digital twin is not a one-time deployment but a long-term innovation effort, leveraging advanced digital technologies such as cloud computing, AI, and Internet of Things (IoT) devices to enable precise grid operations and new energy services.

Cross-Border Digital Infrastructure and TEN-E Regulation

To support the digital twin and broader grid digitalisation goals, the revised TEN-E Regulation (Trans-European Networks for Energy) plays an essential enabling role [46]. The regulation now includes provisions for cross-border smart electricity grids, to improve the EU's ability to implement cross-border digital infrastructure projects.

Under this framework, digital technologies and secure connectivity will be used to retrofit existing energy and transport infrastructure with cross-border digital infrastructure necessary for the functioning of a connected European grid. This includes the deployment of Operational Digital Platforms and new categories of Projects of Common Interest (PCIs) for smart grid innovations.

Moreover, funding mechanisms such as the Connecting Europe Facility (CEF) Digital, Horizon Europe, and other EU programmes will support feasibility studies, implementation projects, and strategic partnerships for building this cyber-secure, digitally integrated energy system.

6.1.5 Regulation (EU) 2024/1747 on the Union's electricity market design

Regulation (EU) 2024/1747 represents a significant legislative update aimed at reinforcing the EU's internal electricity market design [47]. The main objectives are to enhance energy security, improve market efficiency, increase consumer protection, and integrate greater shares of renewable energy by enabling flexibility and long-term investments in grid infrastructure and technologies.

This reform emerges as a response to volatile energy prices and supply uncertainties exacerbated by the geopolitical crisis following the Russian invasion of Ukraine, addressing key structural challenges in the electricity system, placing a new emphasis on grid flexibility, capacity transparency, and consumer empowerment in the energy transition.

In this review, the main focuses are as follows:

Article 19e – Flexibility Needs Assessment and Reporting

Article 19e introduces an updated process for assessing and reporting flexibility needs across the EU electricity system. TSOs and DSOs of each Member State are required to provide relevant data and analysis to their National Regulatory Authorities (NRAs).

In this context, ENTSOe and the EU DSO Entity must jointly develop a common methodology for flexibility analysis, considering available cost-effective sources of flexibility, investment plans for interconnectors and flexibility-related infrastructure as well as EU decarbonisation objectives.

ACER is set to play a supervisory role by reviewing these national reports and preparing an EU-wide assessment of future flexibility needs and potential. This assessment should cover a 5 to 10-year horizon and focus on identifying cross-border opportunities and challenges for flexibility, such as demand-side response and energy storage.

Capacity Transparency for Grid Connections

Another key aspect of this regulation is the requirement for TSOs and DSOs to collaborate on publishing updated data on the capacity available for new grid connections. This is described as essential for project developers and investors to evaluate where and how new energy projects, and in particular renewable installations, can be integrated into the grid.

By offering a more granular visibility into regional grid capacity, the regulation is therefore meant to enhance transparency and accelerate grid connection procedures, as well as helping derisk investment decisions. The general purpose is therefore to facilitate quicker decision-making by developers and support the faster deployment of renewable energy sources, thereby aligning EU climate and energy goals.

6.1.6 Other relevant documents

Even though the list of studied topics that is used in the remainder of this chapter is primarily extracted from the regulatory sources above, we observe that other policy documents and stakeholder contributions tend to reinforce this thematic overview:

Directive (EU) 2019/944 Article 24 “Interoperability requirements and procedures for access to data”

In this electricity market design directive [47], it is explicitly mentioned that “*The Commission shall adopt, by means of implementing acts, interoperability requirements and non-discriminatory and transparent procedures for access to data referred to in Article 23(1). Those implementing acts shall be adopted in accordance with the advisory procedure referred to in Article 68(2).*” This paragraph is highly relevant to the TwinEU developments, especially with the main federated DT architecture that can serve as a connecting backbone of DTs across Europe enabling new technologies to foster an advanced concept of DT while determining the conditions for interoperability, data and model exchanges through standard interfaces and open APIs to external actors.

JRC study on Transmission System Regional Coordination in Europe (2024)

The 2024 JRC report “*Transmission System Regional Coordination in Europe*” explores the role of Regional Coordination Centres (RCCs) in enhancing the security and efficiency of electricity transmission across Europe [48]. The Regional Coordination Centres (RCCs) are currently regulated entities having to progressively meet several requirements which are depicted in Table 91.

Table 91: List of RCC tasks (source JRC analysis 2023)

No.	Task of Regional Coordination Centres (RCCs)	Cat. by operational activity	Timeframe	Methodology development status	Degree of implement. in an RCC process
1-a	Coordinated capacity calculation (CCC)	CA	DA and ID	Developed	High
2-b	Coordinated security analysis (CSA)	OS	DA and ID	Developed	High
3-c	Creation of common grid models (CGM)	OP	YA to ID	Developed	High
4-d	Supporting the TSOs in defence and restoration plans' consistency assessment	OP	Upon submission from TSOs	Developed	Medium
5-h	Supporting the TSOs in the coordination	OS	C2RT. Upon request from TSOs	In development	Unknown
6-i	Post-operation and post-disturbances analysis and reporting	Other	Conditional. Upon request from TSOs	Developed	Medium
7-j	Regional sizing of reserve capacity	CA	DA and/or ID	In development	Unknown
8-k	Facilitating the regional procurement of balancing capacity	CA	DA and/or ID	In development	Unknown
9-e	Short-term adequacy (STA) assessment	SA	WA to DA	Developed	High
10-f	Regional outage planning coordination (OPC)	OP	YA, (MA), WA	Developed	High

11-l	Supporting the TSOs in the inter Transmission System Operators' settlements	Other	Upon request from TSOs	Developed	Unknown
12-g	Training and certification of RCC staff	Other	When needed	Developed	Medium
13-m	Tasks related to identification of regional electricity crisis scenarios	OP	Upon request from ENTSOe. Every 4 years	Developed	Unknown
14-p	Identification of needs for new transmission capacity and supporting the ten-year network development plan (TYNDP)	OP	Upon request from TSOs. Every 2 years	In development	Unknown
15-o	Calculation of maximum entry capacity for foreign capacity	CA	Upon request from TSOs	Developed	Unknown
16-n	Tasks related to the seasonal adequacy assessments	SA	Upon request from ENTSOe. Two times per year	Developed	Unknown

The conclusions of the report align closely with the EU Action Plan for Grids [41], as it emphasises the need for integrated grid planning, transparency, and cross-border coordination that are key to addressing congestion and enabling renewable integration. There are also significant connections to the EU Digitalisation Action Plan, with RCCs depending on high-quality data exchange, simulations, and real-time grid modeling, aligning with the vision of a digital twin. More specifically, as it is also indicated in the above table, the report states that “*few points of improvements for RCCs tasks with forward looking vision, in relation to the regional electricity crisis scenarios, critical grid situation coordination, flexibility and data learning, were pointed out*”, as these are depicted in the above table.

The TwinEU federated DT architecture and the pilot technologies of DTs are serving the seamless integration of local digital twins for system operation and can support several tasks allocated for regional coordination purposes i.e. Training and certification, regional sizing of reserve capacity, facilitating the regional procurement of balancing capacity.

ACER & CEER review of Challenges of the Future Electricity System (2024)

The ACER & CEER report “*Challenges of the Future Electricity System – Recommendations and Commitments*” provides an outlook on the regulatory and policy needs to support the EU’s evolving electricity system [49]. It is strongly connected to the Demand-Response Network Code, as it explicitly calls for the removal of barriers and the development of a clear legal framework to enable demand response, distributed flexibility, and active consumer participation. It also presents converging views with the EU Action Plan for Grids [41], advocating for improved grid planning, transparency, and integration of flexible and digital solutions at both transmission and distribution levels. It also links to the digital twin concept of the EU Digitalisation Action Plan by calling for DSOs to digitalise operations, offer real-time data to users, and activate automated consumer flexibility.

ENTSOe's RDI Roadmap 2024-2034 (2024)

The *ENTSOe RDI Roadmap 2024–2034* is a strategic innovation roadmap that highlights the research, development, and innovation priorities for Europe's electricity transmission system operators over the next decade [50]. The main objective is to support the transition toward a carbon-neutral, secure, efficient, and digitalised energy system by defining six innovation missions: enhancing grid use and sustainability, developing onshore and offshore HVDC infrastructure, improving the management of hybrid AC/DC grids, boosting digitalisation for system control, strengthening market flexibility, and enabling cross-sector energy integration.

This roadmap is tightly aligned with the **EU Action Plan for Grids** [41], as it supports grid reinforcement, cross-border integration, and system flexibility enhancement through HVDC and offshore networks. It also presents strong connections to the **EU Digitalisation Action Plan**, emphasizing real-time data, interoperability, and digital twins for better grid monitoring and control. The roadmap directly supports the **EU Market Reform** by promoting new flexibility assessment tools, innovative market mechanisms, and end-user participation, facilitating demand-side flexibility.

DSO Entity and ENTSOe report “TSO-DSO Challenges & Opportunities for the Digital EU Electricity System”, March 2025.

The report underscores the critical need for digitalisation to enhance grid operation, planning, and customer integration, which is essential for achieving global and European carbon emission reduction targets [51]. It provides a comprehensive compilation of anticipated priority challenges in the transition toward a fully digitalised electricity system. Furthermore, it also compiles insights and expectations regarding digital twin solutions, gathered through various representatives from the energy sector (via workshops, surveys, and focus groups). Lastly, it highlights existing gaps, improvement opportunities, and necessary measures to advance digital solutions across Europe's power systems. In the conclusion section, the key barriers to overcome are identified as five main topics, i.e. data integration, scaling and interoperability, forecasting accuracy, stable and supportive regulatory framework, resource scarcity.

6.2 Supporting the key priorities of the European energy strategy with the TwinEU DT technologies

6.2.1 List of studied topics-priorities

Based on the previously reviewed sources, the following list of 19 topics was short-listed based on their representativity and presumed connection to TwinEU efforts.

Topics related to EU ACTION FOR GRIDS - Incentivising a better usage of the grids

GRIDS TOPIC #1: Grid hosting capacity (TSOs & DSOs)

Based on ARTICLE 6: ENTSOe and EU DSO Entity to agree on harmonised definitions for available grid hosting capacity for system operators and establish a pan-EU overview.

GRIDS TOPIC #2: Smart grid networks (TSOs & DSOs)

Based on ARTICLE 7: ENTSOe and EU DSO Entity to promote uptake of smart grid network efficiency and innovative technologies.

GRIDS TOPIC #3: 2050 Top-down planning (TSOs)

Based on ARTICLE 2: ENTSOe to enhance top-down planning towards 2050 by integrating the identification of offshore and onshore system needs and further considering hydrogen.

GRIDS TOPIC #4: Grid planning (DSOs)

Based on ARTICLE 3: EU DSO Entity to support DSO grid planning by mapping the existence and characteristics of distribution development plans.

GRIDS TOPIC #5: Anticipatory investments (TSOs & DSOs)

Based on the position on anticipatory investments by ACER and CEER: Anticipatory investments reinforce the grid based on anticipated potential future needs, which go beyond confirmed generation and demand needs. On one hand, this will help ensure that the power grids are fit for the rapid uptake of renewable energy sources (RES), avoiding connection delays of RES caused by a slower grid capacity expansion. On the other hand, investing into anticipatory investments carries a risk that they may turn out be underused, at least until there are developments on the generation side.

Topics related to the DEMAND RESPONSE NETWORK CODE (proposal of EU DSO ENTITY and ENTSOe)

DR TOPIC #1: Congestion and voltage issues (TSOs & DSOs)

Based on ARTICLE 47-48: TSO-DSO COORDINATION AND DSO-DSO COORDINATION: Forecasting and identifying congestion and voltage issues, and solutions (48-49).

DR TOPIC #2: Grid prequalification & temporary limits (TSOs & DSOs)

Based on ARTICLE 49-51: TSO-DSO COORDINATION AND DSO-DSO COORDINATION: Grid prequalification and temporary limits, consistency of trade positions (49-51).

DR TOPIC #3: Data exchange (DSO-DSO & DSO-TSO)

Based on ARTICLE 52: TSO-DSO COORDINATION AND DSO-DSO COORDINATION: Data exchange DSO-DSO and DSO-TSO.

DR TOPIC #4: Local services in the DNDP

Based on Article 29-37 - Local services in the DNDP (Distribution Network Development Plan).

DR TOPIC #5: Process and Content of the DNDP

Based on Article 43-44, dealing with the content and requirements of the Distribution Network Development Plan (DNDP) and local services in the DNDP.

DR TOPIC #6: Congestion and voltage management products

Based on Article 38-39: Requirements for the definition of congestion management products and voltage control products based on active power.

Topics related to the CYBERSECURITY NETWORK CODE

CYBER TOPIC #1: Cybersecurity exercise

Based on CHAPTER VI (Article 43-44): Electricity Cybersecurity Exercise Framework.

CYBER TOPIC #2: Detection of cyber-attacks

Based on Article 39 - Detection of cyber-attacks and handling of related information.

CYBER TOPIC #3: Cybersecurity risk assessments

Based on Article 18 -Cybersecurity risk assessment methodologies.

Topics related to DIGITALISING THE ENERGY SYSTEM - EU ACTION PLAN**DIGITAL TOPIC #1: Digital twin investments**

“The aim of the digital twin is to enhance the efficiency and smartness of the grid as a way to make the energy system as a whole more intelligent. The creation of a digital twin will be achieved through coordinated investments in five areas: (i) observability and controllability; (ii) efficient infrastructure and network planning; (iii) operations and simulations for a more resilient grid; (iv) active system management and forecasting to support flexibility and demand response; and (v) data exchange between TSOs and DSOs.”

DIGITAL TOPIC #2: Cross-border digital infrastructure

“The revised TEN-E Regulation provides for greater opportunities to support cross-border smart electricity grid [...] Supporting the European cyber-secure digital twin of the electricity grid, these shall provide digital technologies and connectivity for retrofitting the existing energy and transport infrastructures with the required cross-border digital infrastructure.”

Topics related to the Electricity Market Reform (REGULATION (EU) 2024/1747)

MARKET TOPIC #1: Flexibility Needs (DSOs, TSOs & ACER)

Article 19e: *“TSOs and DSOs of each MS shall provide the data and analyses needed for the preparation of the report referred on flexibility needs to the relevant NRA [...] ENTSOe and the EU DSO entity shall [...] develop a methodology for the analysis of flexibility needs, taking into account available sources of flexibility in a cost-efficient manner, planned investment in interconnection and flexibility and decarbonisation targets.*

Among the issues of cross-border relevance, ACER shall assess [...] the estimated flexibility needs in the electricity system at Union level and its projected economically available potential for a period of the next 5 to 10 years taking into account the national reports.”

MARKET TOPIC #2: Available capacity for new connections (TSOs & DSOs)

“DSOs and TSOs shall cooperate with each other in publishing, in a consistent manner, consistent information on the capacity available for new connections in their respective areas of operation that provides sufficient granular visibility to developers of new energy projects and other potential network users.”

6.2.2 Connection to TwinEU demos

Based on the list above, TwinEU pilot leaders were asked to rank the relevance of the different tasks of their demos to each key EU topic (**3: HIGH relevance; 2: MEDIUM relevance, 1: LOW relevance**).

The ranking has been conducted at the level of tasks, where the activities of DT developments have been the most relevant topics are therefore identified for each pilot with 3 tasks:

- **Priority topics:** at least one task with a HIGH relevance.
- **Significant topics:** at least two tasks with MEDIUM relevance.

6.2.2.1 Iberian Pilot (Tasks 5.4, 8.3 & 8.4)

Priority topics:

- Grid hosting capacity (TSOs & DSOs) - GRIDS
- Grid planning (DSOs) - GRIDS
- Grid prequalification & temporary limits (TSOs & DSOs) - DR
- Local market operators - DR
- Cybersecurity exercise - CYBER
- Detection of cyber-attacks - CYBER
- Cybersecurity risk assessment – CYBER

Significant topics:

- 2050 Top-down planning (TSOs) – GRIDS
- Digital twin investments-DIGITAL
- Flexibility Needs (DSOs, TSOs & ACER) - MARKET

6.2.2.2 Eastern Mediterranean Pilot (Tasks 5.3, 7.2 & 7.6)

Priority topics:

- Smart grid networks (TSOs & DSOs) - GRIDS
- Local services in the DNDP – DR
- Congestion and voltage management products – DR
- Cybersecurity risk assessments - DR
- Digital twin investments – DIGITAL

Significant topics:

- Grid hosting capacity (TSOs & DSOs) – GRIDS
- Congestion and voltage issues (TSOs & DSOs) – DR
- Cybersecurity exercise – CYBER
- Flexibility Needs (DSOs, TSOs & ACER) - MARKET
- Available capacity for new connections (TSOs & DSOs) - MARKET

6.2.2.3 Hungarian Pilot (Tasks 6.8 & 7.3)

Priority topics:

- Smart grid networks (TSOs & DSOs) - GRIDS
- Cross-border digital infrastructure-DIGITAL
- Digital twin investments-DIGITAL
- Available capacity for new connections (TSOs & DSOs)-MARKET

Significant topics:

- Grid hosting capacity (TSOs & DSOs) – GRIDS

- Congestion and voltage issues (TSOs & DSOs) – DR
- Digital twin investments-DIGITAL
- Flexibility Needs (DSOs, TSOs & ACER) - MARKET

6.2.2.4 Bulgarian Pilot (Tasks 7.5 & 7.5)

Priority topics

- Grid hosting capacity (TSOs & DSOs) - GRIDS
- Smart grid networks (TSOs & DSOs) - GRIDS
- Anticipatory investments (TSOs & DSOs) - GRIDS
- Congestion and voltage issues (TSOs & DSOs) - DR
- Data exchange (DSO-DSO & DSO-TSO) - DR
- Congestion and voltage management products - DR
- Digital twin investments - DIGITAL
- Cross-border digital infrastructure - DIGITAL
- Available capacity for new connections (TSOs & DSOs) – MARKET

Significant topics:

- Grid planning (DSOs) - GRIDS
- Flexibility Needs (DSOs, TSOs & ACER) - MARKET

6.2.2.5 German Pilot (Tasks 6.4, 6.5 & 6.6)

Priority Topics:

- Grid hosting capacity (TSOs & DSOs) – GRIDS
- Data exchange (DSO-DSO & DSO-TSO) – DR
- Digital twin investments – DIGITAL
- Available capacity for new connections (TSOs & DSOs) - MARKET

Significant Topics:

- Smart grid networks (TSOs & DSOs) – GRIDS
- Congestion and voltage issues (TSOs & DSOs) – DR
- Cybersecurity exercise - CYBER

6.2.2.6 Italian Pilot (Tasks 6.2 & 6.3)

Priority Topics:

- Smart grid networks (TSOs & DSOs) – GRIDS
- Digital twin investments – DIGITAL

Significant Topics:

- Data exchange (DSO-DSO & DSO-TSO)– GRIDS

6.2.2.7 Slovenian Pilot (Tasks 6.7 & 7.7)

Priority topics:

- Digital twin investments – DIGITAL

Significant Topics:

- Smart grid networks (TSOs & DSOs) – GRIDS
- Available capacity for new connections (TSOs & DSOs)-MARKET

6.2.2.8 French/Dutch Pilot (Tasks 5.2, 5.5 & 8.2)

Priority Topics:

- Smart grid networks (TSOs & DSOs) – GRIDS
- Cybersecurity exercise - CYBER
- Detection of cyber-attacks - CYBER
- Cybersecurity risk assessments - CYBER
- Digital twin investments – DIGITAL
- Cross-border digital infrastructure-DIGITAL

6.2.2.9 Summary Table

The table below summarizes the topics identified as “priority” or “significant” to each of the TwinEU demo, using a “coloured map” approach with different colors. In this way, it is easy to identify the strong relevance of various pilots with specific EU energy priorities and guide the reader where he can find relevant DT technologies.

Table 92: Summary of topics identified as “priority” or “significant” to each of the TwinEU pilots, using a “coloured map” approach with different colours.

	IBERIAN PILOT			EAST=MED PILOT			HUNGARIAN PILOT		BULGARIAN PILOT		GERMAN PILOT			ITALIAN PILOT		SLOVENIAN PILOT		FRENCH/DUTCH PILOT		
tasks:	5.4	8.3	8.4	5.3	7.2	7.6	6.8	7.3	7.4	7.5	6.4	6.5	6.6	6.2	6.3	6.7	7.7	5.2	5.5	8.2
GRIDS TOPIC #1: Grid hosting capacity (TSOs & DSOs)																				
GRIDS TOPIC #2: Smart grid networks (TSOs & DSOs)																				
GRIDS TOPIC #3: 2050 Top-down planning (TSOs)																				
GRIDS TOPIC #4: Grid planning (DSOs)																				
GRIDS TOPIC #5: Anticipatory investments (TSOs & DSOs)																				
DR TOPIC #1: Congestion and voltage issues (TSOs & DSOs)																				
DR TOPIC #2: Grid prequalification & temporary limits (TSOs & DSOs)																				
DR TOPIC #3: Data exchange (DSO-DSO & DSO-TSO)																				
DR TOPIC #4: Local services in the DNDP																				
DR TOPIC #5: Process and Content of the DNDP																				
DR TOPIC #6: Congestion and voltage management products																				
CYBER TOPIC #1: Cybersecurity exercise (Article 43-44)																				
CYBER TOPIC #2: Detection of cyber-attacks (Article 39)																				
CYBER TOPIC #3: Cybersecurity risk assessments (Article 18)																				
DIGITAL TOPIC #1 Digital twin investments																				
DIGITAL TOPIC #2: Cross-border digital infrastructure																				
MARKET TOPIC #1: Flexibility Needs (DSOs, TSOs & ACER)																				
MARKET TOPIC #2: Available capacity for new connections (TSOs & DSOs)																				

6.3 Main avenues for the definition of pan-European scenarios in TwinEU.

6.3.1 Definition of pan-EU scenarios in the context of TwinEU

The TwinEU project is developing the federated DT twin architecture described in Sections 3.6 - 3.7 which is connecting the DT technologies developed and demonstrated in 8 pilots across Europe, deploying several use cases that test the DT models and data exchanges and solving several critical issues.

In order to validate the federated TwinEU architecture and showcase the wide applicability, specific DT models and data structures, that originate from different pilots, will be shared among partners. This validation process of cross-pilot collaboration to address specific challenges using the federated TwinEU architecture is considered as pan-EU scenario in the scope of TwinEU.

Based on the analysis previously elaborated in this document, several topics of pan-EU scenarios have been identified as potential candidates and are elaborated in the following sections. These pan-EU scenarios will be specified in more details during T4.3 and result into validation cases in T4.6.

6.3.2 The grid hosting capacity map

As renewables thrive and consumers shift toward electrification and away from fossil gas, pressure on the grid is mounting. Since the power grid equipment, i.e. transformers, lines, cables, have technically finite capacity, the lack of grid capacity can be a key barrier to deploying new renewables and connecting new consumers.

The TwinEU DT technologies developed in the German pilot, that will implement in the demonstration activities the respective use cases described in UC01, UC02, UC03, UC04 and UC08, can provide a significant proposition for a conceptual version of an advanced grid hosting capacity map. This pan-European map is currently being developed as a concept and is not yet fully operational. It will aim to provide a harmonized, real-time digital interface for visualizing grid hosting capacity across Europe and appears to echo several of the previously identified challenges for the European power system. This work combines advanced grid data simulations and APIs that enable DSOs to deliver automated feedback on connection requests for both load and generation.

This initiative strongly supports the goals of the EU Action Plan for Grids (COM/2023/757) [41], particularly Action 6, which calls for transparent and harmonised data on available capacity at both transmission and distribution levels. TwinEU's Hosting Capacity Maps addresses this by proposing a standard for the publication of capacity data and reducing connection delays, which is a key bottleneck in renewable energy deployment. It also connects to Action 2 by supporting better long-term planning. Furthermore, the task aligns with the EU Digitalisation Action Plan for Energy Markets (COM/2022/552) [45] as it supports the development of digital twin solutions for the operation and planning of the electricity grid. The project also sets the basis for a common European energy data space, as also mentioned in the Digitalisation Action Plan. Overall, the Pan-EU Hosting Capacity Map is being explored as a conceptual framework to enhance transparency and efficiency in grid operations and provides an operational application to key EU policy objectives.

One of the major use cases of the Intelligent Grid Platform is supporting the grid connection process for new distributed energy resources. In line with this, the IGP automatically performs regular hosting capacity assessments. These calculations can be presented in various formats to offer direct feedback to DSO customers regarding their connection applications.

While the full pan-European map is under conceptual development, hosting capacity maps are already technically feasible within the IGP software. However, their current implementations are limited to individual DSOs and do not yet support a unified or cross-DSO view. This makes them a strong starting point for further evolution toward a harmonised, integrated European-wide solution.

In this pan-European context, the automated self-service use case for potential grid connections introduces a new level of interaction between DSOs and their customers. This fully automated process allows connection applicants to instantly receive feedback on potential connection points based on live grid calculations accessible directly via the DSO's website. Additionally, the results of hosting capacity calculations for both loads and generation can be shared as indicative information with end-customers. This supports their decision-making process when implementing new generation units, such as solar PV systems, or large loads like data centres. An example of this can be seen in Westnetz's self-service connection check platform in the next Figure 17.

The screenshot displays the 'westnetz Online Connection Check' web application. On the left, there's a form titled 'Anlagentyp auswählen' (Select plant type) with four buttons: 'Kraft-Wärme-Kopplung', 'Photovoltaik', 'Windenergieanlage', and 'Andere Einspeiser'. Below this is a section 'Ihre Angaben' (Your data) with a 'STANDORT' (Location) field showing coordinates: 'Breite: 51.65892665 °' and 'Länge: 6.6027832 °'. On the right, a map shows the region around Düsseldorf, with a blue pin indicating the selected location near 'Wesel'.

Figure 17: Westnetz Self-service connection check platform

This initiative strongly supports the goals of the EU Action Plan for Grids (COM/2023/757) [41], particularly Action 6, which calls for transparent and harmonised data on available capacity at both transmission and distribution levels. TwinEU's Hosting Capacity Maps addresses this by proposing a standard for the publication of capacity data and reducing connection delays, which is a key bottleneck in renewable energy deployment. It also connects to Action 2 by supporting better long-term planning.

Furthermore, the task aligns with the EU Digitalisation Action Plan for Energy Markets (COM/2022/552) [45] as it supports the development of digital twin solutions for the operation and planning of the electricity grid. The project also sets the basis for a common European energy data space, as also mentioned in the Digitalisation Action Plan. Overall, the Hosting Capacity Map enhances transparency and efficiency in grid operations and provides an operational application to key EU policy objectives.

Traditional Hosting Capacity Maps	Advanced Hosting Capacity Maps
• Not always up-to-date (mostly updated annually) • Just a rough overview of the capacity • Not / partially integrated to customer portal • Only “as-recorded” version • Only current capacity • Only offer capacity data • Need intervention of grid planners	• Each inquiry is calculated based on the latest grid state • Tailored feedback to specific location, capacity, and project type • Fully integrated to customer portal • Consider grid reservations, supports queue management • Project future planned capacity increases • Enhanced data provision: obtainable capacity, cost estimation, real-life routing, alternative connection options • Self-service check without involvement of grid engineers

Figure 18: Benefits of advanced hosting capacity maps provided during TwinEU project

One of the major use cases of the Intelligent Grid Platform is supporting the grid connection process for new distributed energy resources. Contributing to this idea, the IGP performs regular assessments of the hosting capacity (both for new loads and generators) automatically. These calculations can be presented in various formats to offer feedback to DSO customers regarding their connection applications.

In the context of this pan-EU scenario, the automated self-service for potential grid connection use case is designed to create a completely new level of interaction between the DSO and its customers. This fully automated process allows connection applicants to instantly receive feedback on potential connection points based on live grid calculations directly through the grid operator's website. Additionally, the results of hosting capacity calculations for both loads and generation can be shared as indicative information with end-customers. This supports their decision-making process when implementing new generation units, such as solar PV systems, or large loads like data centres.

In the following Figure 19, a proposition for the implementation process of a pan-EU scenario involving cross pilot contributions is presented.

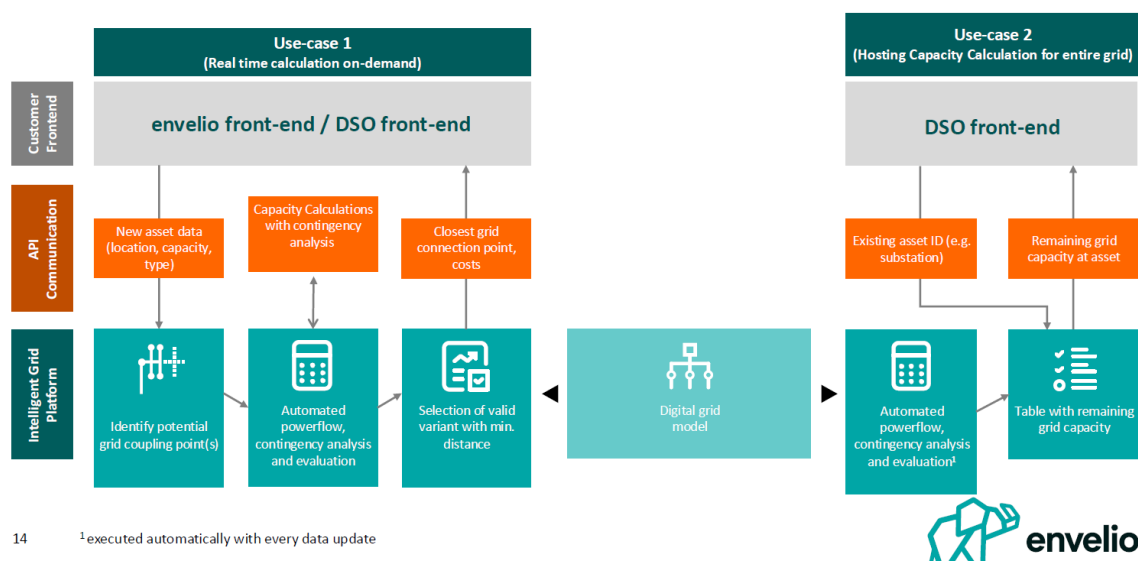


Figure 19: Calculation modes for different use cases

6.3.3 Co-optimization of the energy and balancing capacity market coupling with dynamic flow-based auction

The DT technologies developed and demonstrated in the Hungarian pilot (HU03) also appear as an excellent candidate to address the above-mentioned challenges for the EU energy system.

Use case HU03 focuses on co-optimizing energy and balancing capacity markets in Hungary using a unified auction platform enhanced by dynamic, flow-based capacity calculation. It demonstrates an innovative approach to market integration by linking day-ahead and intraday energy markets with balancing services, increasing system efficiency and enabling better use of cross-border transmission capacity.

This pan-EU scenario for cross-pilot participation aligns strongly with the EU Action Plan for Grids (COM/2023/757) [41], especially regarding Action 4, which promotes the smarter use of existing grids through digital tools and real-time system observability. The integration of Dynamic Line Rating (DLR), real-time data, and the integration of system simulations contribute directly to this purpose and supports the efficient use of the infrastructure to reduce grid congestion. From a digitalisation perspective, the task illustrates the priorities described in the EU Digitalisation Action Plan for Energy Markets (COM/2022/552) [45]. It supports the development of a digital twin for the electricity grid through real-time data exchange, optimization algorithms, and platform interoperability between different supports – notably connecting ENTSOe's Transparency Platform and the HUPX Labs platform. The task notably includes the creation of a data space that integrates diverse data formats (bids, capacity, line ratings) into a shared digital framework.

As identified in the following two figures, the Input data – balancing capacity bids and energy bids – from TSOs and NEMOs participating in the pan-EU scenarios can be routed either through the HUPX Labs data platform (similarly to the Hungarian partners' data, as option 1), or input directly for bid generation in the TwinEU framework (option 2). The following figures show these two possible solutions through the example of Romanian partners

D2.2 - TwinEU use cases, pan-European scenarios and KPIs

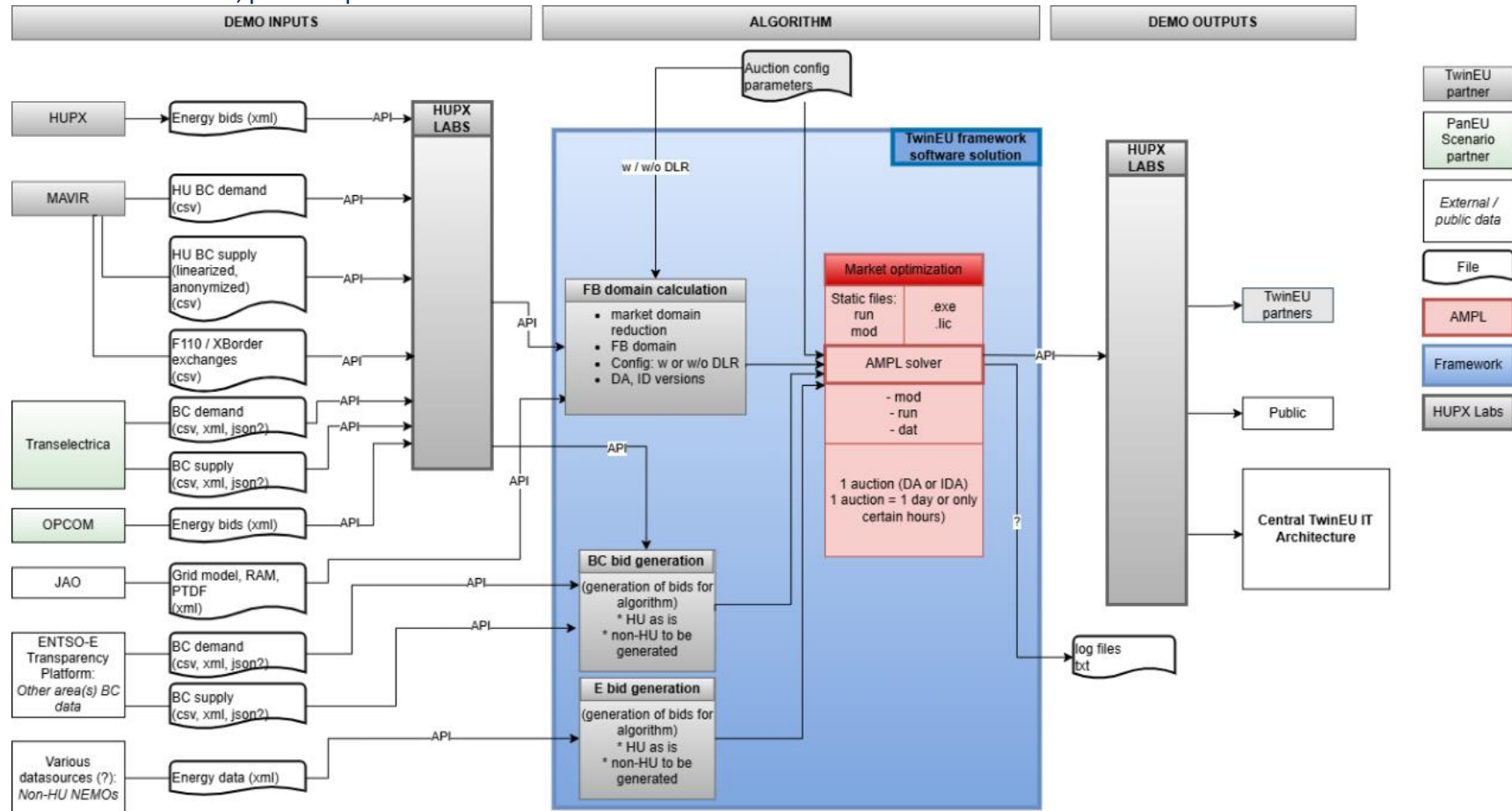


Figure 20: Implementation graph for the pan-EU scenario for the co-optimization of energy and balancing capacity market coupling with dynamic flow-based auction (option 1)

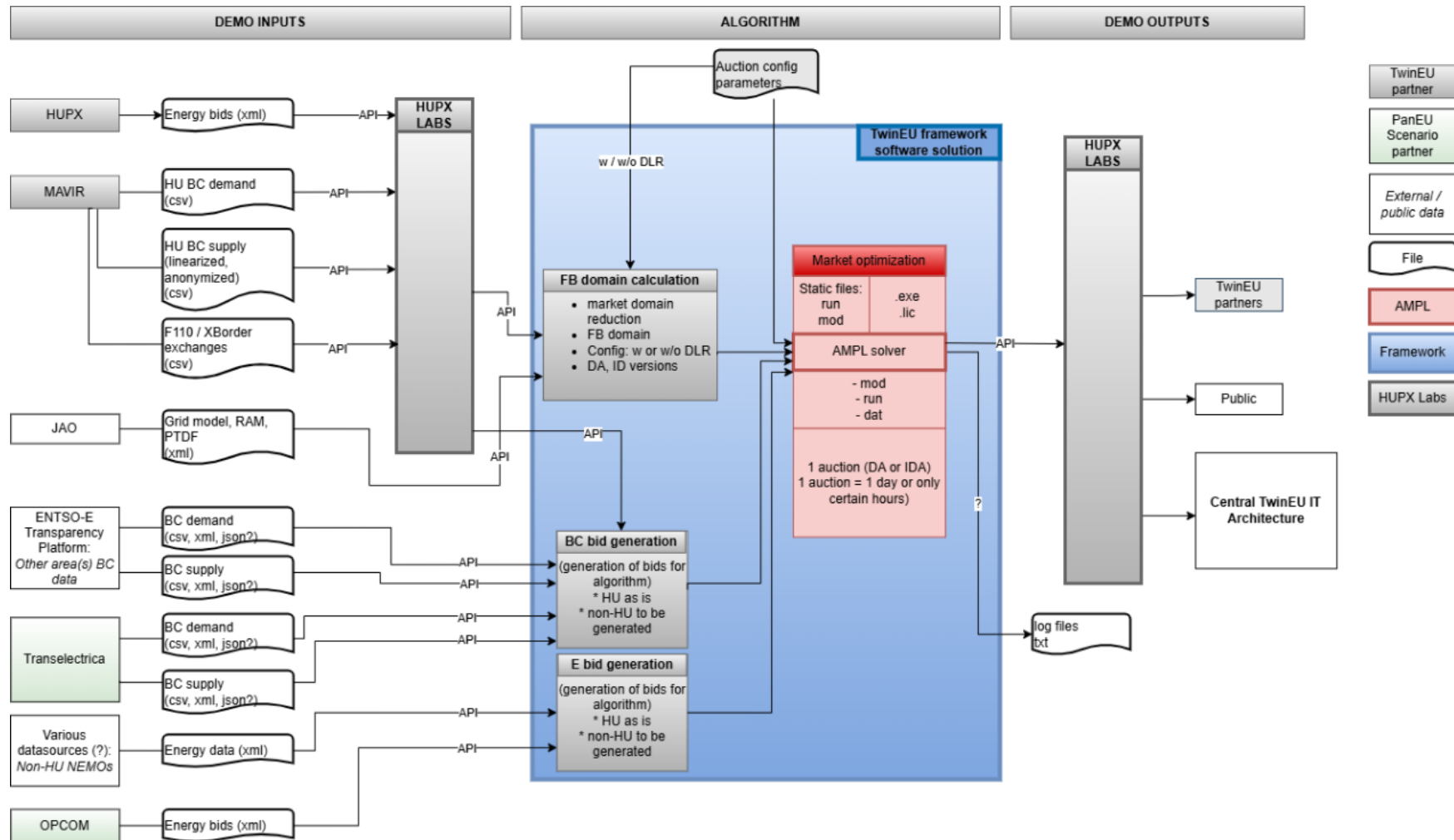


Figure 21. Implementation graph for the pan-EU scenario for the co-optimization of energy and balancing capacity market coupling with dynamic flow-based auction (option 2)

6.3.4 High accuracy forecasting

As identified in the conclusions of the report “TSO-DSO Challenges & Opportunities for the Digital EU Electricity System” by ENTSOe and EU DSO Entity [51], forecasting accuracy is one of the five main topics that emerge as a barrier for DT adoption to succeed, ensuring seamless data exchange across diverse platforms and devices. Reducing errors in forecasting of demand, production and grid capacity (i.e. DLR) can improve the grid utilization and security of supply. Additionally, it can reduce the need for activation of short-term flexibility resources in the balancing time frame. Proposed actions for enhancing the forecasting accuracy are increased data sharing from balancing service providers (BSPs)/BRPs or other relevant entities, as well as consolidation of increasing number of data sources and development of efficient AI models.

The TwinEU DT architecture can support the improvement of forecasting accuracy with the technologies that are developed and demonstrated in the pilots. Possible options can be:

- 1) The DT technologies developed in the Bulgarian pilot, that will implement in the demonstration activities the respective use cases described in UC02, UC03, UC04. The Bulgarian pilot scenarios practically valorise the DT technologies to achieve generation high accuracy forecasts on Wind, Solar and OHL ampacity. These DT models can be connected through the federated TwinEU architecture with data provided by a partner in another pilot cluster to run a pan-EU scenario in the scope that this is described in the above Chapter 6.3.1.
- 2) The DT technologies developed in the Iberian pilot, that will implement in the demonstration activities of the respective use case described in UC01. This concerns the probabilistic grid status forecast and remedial actions identification for the TSO’s Control Centre Operator, mainly dealing with risky grid status and unbalances in load and demand.

6.3.5 Flexibility management and frequency support

Flexibility is the ideal resource that can enable the cost-efficient massive deployment of distributed technologies in the electricity grids, without incurring unbearable investment costs in transmission and distribution infrastructure that would otherwise disincentive the end user from the adoption of these technologies. This is also explicitly highlighted, as mentioned previously, in the electricity market reform where in article 19e, there is a mandate for ENTSOe and EU DSO Entity to propose a methodology that analyses the flexibility needs, resources, planned investments and decarbonisation targets. The operational reserves will be called upon to balance the mismatch of generation and demand

- 1) The DT technologies developed in the Eastern Mediterranean pilot, that will implement in the demonstration activities of the respective use cases EM-GR-02, EM-CY-02. These technologies will achieve optimized fast frequency response services through TSO-DSO coordination integrating several flexible assets and storages, while achieving data exchanges between system operators at various voltage levels. Additionally, DT technologies will provide frequency support management with HVDC interconnection in low inertia system.
- 2) The DT technologies in the Iberian demo that will implement in the demonstration activities the use cases Ib08 and Ib09. These technologies aim to identify flexibility requirements for planning and operational phases to prevent grid congestion, deferring investments in new assets such as lines or transformers. Additionally. These DT technologies focus on optimal

connections EV chargers in order to maintain voltage quality, phase balancing, congestion mitigation.

- 3) The Italian UC (IT02) focuses on developing a DT of selected portions of the medium distribution grids, with a particular focus on integrating DERs, such as photovoltaic (PV) systems and electric vehicle (EV) charging stations. The objective is to evaluate operational challenges related to load and generation variability, ensuring secure grid operations, especially in high-density urban areas and rural zones. The use case will also examine the potential contribution that DERs can provide to the transmission network, if needed.

6.3.6 System security and stability

System security can be considered as the capability to withstand disturbances i.e. events or incidents producing abnormal system conditions, or contingencies that result from failures/outages of system components, malicious cyber-attacks on digital-driven equipment, achieving the minimum acceptable service disruption. Maintaining operational security and regaining acceptable state of operational condition, after covering dynamic issues and real-time network management issues.

For the purposes of safeguarding operational security, preventing the propagation or deterioration of an incident to avoid a widespread disturbance and the blackout state as well to allow for the efficient and rapid restoration of the electricity system from the emergency or blackout states, the Network Code for Emergency and Restoration (NCER) has been established, which lays down the requirements of managing the relevant situations, the coordination of system operation at European level, the simulation, tests, tools and facilities for preventing emergencies/blackouts and ensuring restoration process.

The NCER mentions that each TSO should “establish a system defence plan and a restoration plan, through a three steps approach: a design phase, consisting of defining the detailed content of the plan; an implementation phase, consisting in the development and installation of all necessary means and services for the activation of the plan; and an activation phase, consisting of operational use of one or more measure(s) from the plan”.

Furthermore, in 2024 the Network Code on Cybersecurity (NCCS) has been established aiming to set a European standard for the cybersecurity of cross-border electricity flows. It includes rules on cyber risk assessment, common minimum requirements, cybersecurity certification of products and services, monitoring, reporting and crisis management.

The TwinEU project includes digital twin technologies and tools that can support these requirements for operational security and cyber resilience highly prioritized at European level for the European grids. Several options can improve the current practices adopted at EU and be tested as pan-EU scenarios at cross-pilot level:

- 1) The DT technologies developed in the Italian pilot, demonstrated in the use cases IT01 and IT02, will be able to evaluate the impact of the defence system on the network, highlighting the discrepancy, if any, between the model results in terms of power/load switched off. They will be capable of evaluating accurately the operational challenges related to load and generation variability, ensuring secure grid operations, especially in high-density urban areas and rural zones.

- 2) The DT technologies developed in the Slovenian pilot, demonstrated in the use cases SLO-UC-01 and SLO-UC-02, will enable a more accurate representation and analysis of the grid's dynamics, facilitating better interoperability across the network. They will involve the integration of frequency and voltage-dependent consumption models, which are vital for reflecting real-time operational conditions more accurately. These improvements can support the development of a distribution network dynamic model and the upgrade of the transmission network dynamic model.
- 3) The DT technologies developed in the Dutch/French pilot, demonstrated in the NL01 and FR01 UCs, will provide game master that supervise all the SCADA modules and can run training scenarios for managing contingencies and cyberattacks impact on stability and cascading failures in real-time on the operation of interconnected power grids. This will enable the development of highly skilled personnel for operating the highly digitalized grids for the clean transition era.

7 Conclusion

This document D2.2 presents the work that has been carried out to define the DTs, pilot use cases, KPIs and propositions for pan-EU scenarios that will use the federated TwinEU architecture for cross-pilot collaboration in data and model sharing. This work has been facilitated greatly by the detailed analysis of challenges and stakeholders' requirements presented in [D2.1](#).

The basic elements that can be considered as conclusions during our activities in Tasks 2.3, 2.4 and 2.5 are the following:

- As a continuation of T2.2 activities, interviews were conducted with selected energy stakeholders and policy makers to collect their expert feedback and wider market requirements for DTs in the electricity grids.
- As a common direction stemming from the interviews, a Pan-European use cases database that addresses a wide range of stakeholder priorities would be valuable, with a strong emphasis on predictive maintenance, grid resilience, interoperability, and the digital transformation of electricity networks.
- Smart grid KPIs is also a market expectation, reflecting interoperability metrics, real-time monitoring performance, cybersecurity resilience, and decarbonization progress.
- DTs standardization should proceed with a fast pace, leveraging AI, edge computing, and real-time data analytics to ensure operational efficiency, predictive accuracy, and rapid responsiveness.
- The respective DT development initiatives should be favoured by incentives-driven EU regulatory frameworks, promoting incentives for digital development and providing clear policy guidelines to stimulate innovation, enhance collaboration, and ensure robust cybersecurity practices.
- Several professional and scientific organizations, industry and market stakeholders across the energy and digital sectors are developing propositions and implementations of Digital Twins. A comprehensive presentation of selected developments has been included and related to the TwinEU practices.
- The common elements identified are the physical layers of assets, the virtual layer of their representations, the data measurements of both, the services/functionalities that the DTs deliver, and lastly the connections/interactions that these previous elements establish to function properly.
- The wide variability and approaches for DTs dictate the need for further collaboration among the involved parties, to identify ways to interact, complement and valorise existing expertise and developments, while at the same time working on common terms and methodologies that will facilitate their interaction. The standardization for system operators and utilities organizations, scientific task forces and others are good opportunities to raise discussions on common grounds and future steps in DTs for the electricity grids.
- The TwinEU project is proposing the federated DT architecture, a facilitator of connection and interoperability of DTs across Europe. It will be based on open standards, advanced data

connectors and Data Spaces to achieve the seamless and secure integration of functionalities and services.

- The TwinEU IT reference architecture consists of 3 core concepts: (i) The digital twin federation, integrating the Onenet4DT connector, IoT, edge computing and edge nodes to exploit data sources and devices securely, (ii) the data space structure, a middleware that ensures secure communications among distributed resources, improving the OneNet framework, (iii) the service workbench and AI tools, developing data-driven services for the energy ecosystem.
- The overall architecture of the TwinEU federation will be based on the foundational building blocks of data sovereignty, decentralization, interoperability, trust and security.
- During the preparation phase of the pilots, a systematic cross-pilot activity was carried out to analyze on a common template the developed DT technologies, gaps and communication flows in the various pilots. This process revealed a wide network of model and data interactions among pilot DTs instances that will be connected through the federated TwinEU architecture, that prove the dense cyber-physical nature of system operation pilot challenges that TwinEU architecture will tackle. It is a product of great value for further work in WP3 and WP4.
- Additionally, this preparation of DTs in the Task 2.3 activity revealed that TwinEU pilots are providing significant insights into all of the business processes that System Operators and market entities, i.e. grid development, operation and market mechanisms across many European countries. These insights are accompanied with detailed communication flows with the main business systems of TSOs, DSOs and market operators, showcasing the direct interaction of TwinEU with their day-to-day operations.
- In T2.4 and T2.5, a set of 50 pilot Use Cases (UCs) and a set 145 related KPIs have been produced as results, following a very well standardized way based on the IEC62559 template. These UCs and KPIs reveal that TwinEU has a wide scope of applicability and a significant validation process.
- By analysing specific policy guidelines i.e. Network Codes, European Directives, JRC studies for the European Commission, policy recommendations of European Associations, we saw a correlation between the specific priorities included in these and the TwinEU DT technologies. As a result, these topics have been evaluated for their relevance to the DT developments in the TwinEU pilot tasks, with a characterization of low, medium, high relevance. This resulted in the conclusion that TwinEU DT technologies affect many different aspects, targets and priorities set in the various European strategies, addressing them to medium or great extent.
- As a follow up of this analysis, we arrived at 5 pan-EU scenarios and implementation propositions, that reflect important challenges that the European system will be facing and for which several pilot DT technologies can provide solutions, mainly addressing the hosting capacity, optimization of reserves, forecasting accuracy, flexibility services, stability and cyber resilience. These selected pan-EU scenarios can deliver a cross-pilot validation of the federated TwinEU architecture, enabling the data and model sharing across European pilot partners.

References

- [1] Gelernter, D. H., "Mirror worlds, or, The day software puts the universe in a shoebox-- : how it will happen and what it will mean", New York: Oxford University Press, 1991. Retrieved from <https://archive.org/details/mirrorworldsorda0000gele>
- [2] Liu, Mangnan; Fang, Shuiliang; Dong, Huiyue; Xu, Cunzhi. "Review of digital twin about concepts, technologies, and industrial applications". Journal of Manufacturing Systems, Vol. 58, Part B, pp 346–361, <https://doi.org/10.1016/j.jmsy.2020.06.017>.
- [3] Hernández, L.A.; Hernández, S., "Application of digital 3D models on urban planning and highway design". WIT Transactions on the Built Environment, Vol. 30, pp. 391–402, doi 10.2495/UT970361, <https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/33/8418>.
- [4] Technological advancements relevant to TSOs during the energy transition. <https://www.entsoe.eu/Technopedia/>
- [5] E.DSO Technology Radar: Second Edition: <https://www.edsoforsmartgrids.eu/edso-publications/discover-the-second-edition-of-the-e-dso-technology-radar/>.
- [6] ENTSO-E, <https://www.entsoe.eu/news/2022/12/20/entso-e-and-dso-entity-signed-today-the-declaration-of-intent-for-developing-a-digital-twin-of-the-european-electricity-grid/>
- [7] International Energy Agency (IEA), "Electricity Grids and Secure Energy Transitions", October 2023, <https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions>.
- [8] Ovaere, Marten et al., "The effect of flow-based market coupling on cross-border exchange volumes and price convergence in Central Western European electricity markets", Energy Economics, Volume 118, 2023, <https://doi.org/10.1016/j.eneco.2023.106519>.
- [9] ACER -CEER, "Position on anticipatory investments", March 2024, <https://www.ceer.eu/publication/acer-ceer-paper-on-anticipatory-investments/>.
- [10] OECD, "Electricity Grids and Secure Energy Transitions Enhancing the foundations of resilient, sustainable and affordable power systems", 2023, page 32, https://www.oecd.org/en/publications/electricity-grids-and-secure-energy-transitions_455dd4fb-en.html.
- [11] European Cyber Security Organisation, "ECSO Technical Paper on Cybersecurity scenarios and Digital Twins", May 2023, v1.0, <https://ecs-org.eu/?publications=ecso-technical-paper-on-cybersecurity-scenarios-and-digital-twins>.
- [12] Cioara, Tudor et al., "An Overview of Digital Twins Application Domains in Smart Energy Grid", 2021, <https://doi.org/10.48550/arXiv.2104.07904>
- [13] Botín-Sanabria, Diego, et al., "Digital Twin Technology Challenges and Applications: A Comprehensive Review". Remote Sensing. 2022; 14(6):1335, <https://doi.org/10.3390/rs14061335>
- [14] Higgins, J.P.T.; Thomas, J., "Cochrane Handbook for Systematic Reviews of Interventions"; John Wiley & Sons: Chichester, UK, 2021; Chapter Part 2: Core Methods.
- [15] Song, Zhao et al., "Digital Twins for the Future Power System: An Overview and a Future Perspective". Sustainability 2023, 15(6), 5259. <https://doi.org/10.3390/su15065259>
- [16] Værbak, M. et al., "A Digital Twin Framework for Simulating Distributed Energy Resources in Distribution Grids", Energies 2024, 17, 2503. <https://doi.org/10.3390/en17112503>

- [17] Usländer, T. et al., “Symbiotic Evolution of Digital Twin Systems and Dataspaces”, Automation 2022, 3(3), 378–399. <https://doi.org/10.3390/automation3030020>
- [18] ISO 23247-1:2021: “Automation systems and integration — Digital twin framework for manufacturing”, <https://www.iso.org/standard/75066.html>.
- [19] AIOTI WG Energy, “Edge driven Digital Twins in distributed energy systems: Role and opportunities for hybrid data driven solutions”, January 2024, <https://aioti.eu/edge-driven-digital-twins-in-distributed-energy-systems-paper/>.
- [20] VDE ETG, “Der Digitale Zwilling in der Netz- und Elektrizitätswirtschaft”, VDE Study, Offenbach am Main, Germany, May 2023, <https://www.vde.com/resource/blob/2257516/cce234dea484fc0b1943774391752d8a/vde-studie-digitaler-zwilling-data.pdf>.
- [21] German Federal Ministry for Economic Affairs and Climate Action, “Overview of the Easter Package” , Berlin, April 2022, https://www.bmwk.de/Redaktion/EN/Downloads/Energy/0406_ueberblickspapier_osterpaket_en.pdf?_blob=publicationFile&v=5.
- [22] IEC, “Find out more about IEC 61850”, <https://iec61850.dvl.iec.ch/>.
- [23] IEC, “IEC 61970 series, Energy management system application program interface (EMS-API) - ALL PARTS”, <https://webstore.iec.ch/en/publication/61167>”.
- [24] T&D Europe, “Digital Twins: Crucial for the Energy Transition”, October 2024, https://tdeurope.eu/position_paper/digital-twins-crucial-for-the-energy-transition/.
- [25] GridOS Orchestration Software: <https://www.gevernova.com/software/products/gridos>.
- [26] IdentiQ: <https://www.hitachienergy.com/services-and-consulting/identiq>.
- [27] Electrical Digital Twin: <https://www.siemens.com/global/en/products/energy/grids-software/planning/electrical-digital-twin.html>.
- [28] envelio • Power grid digitalization with smart grid solutions, <https://envelio.com/>.
- [29] EcoStruxure Grid: A value-driven grid data management: <https://www.se.com/ww/en/work/campaign/grid-digital-twins-guide/#9usecasesalignedtodistributionutilityfunctions>
- [30] Rede Eléctrica Nacional, S.A. (REN), “Capacidades Indicativas de Interligação para Fins Comerciais para o Ano de 2024”, November 2023, <https://mercado.ren.pt/PT/Electr/Explora%C3%A7%C3%A3odosistema/Interlig/Previsao/BibRelAno/Cap2024.pdf>.
- [31] Rede Eléctrica Nacional, S.A. (REN), “Caracterização das Interligações em 31 de dezembro de 2023”, March 2024, <https://mercado.ren.pt/PT/Electr/AcessoRedes/AcessoRNT/CaractRNT/BibRelAnoInter/CIRel2023.pdf>.
- [32] Red Eléctrica de España (REE), “Plan de Desarrollo de la Red de Transporte de Energía Eléctrica: Periodo 2021-2026”, https://www.planificacionelectrica.es/sites/default/files/2022-02/REE_PLAN_DESARROLLO_v3.pdf
- [33] European Union, “Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management”, <https://eur-lex.europa.eu/eli/reg/2015/1222/oj/eng>.
- [34] Rede Eléctrica Nacional, S.A. (REN), “Caracterização das Interligações em 31 de dezembro de 2023”, March 2024,

- <https://mercado.ren.pt/PT/Electr/AcessoRedes/AcessoRNT/CaractRNT/BibRelAnoInter/CIRel2023.pdf>.
- [35] Red Eléctrica de España (REE), Rede Eléctrica Nacional, S.A. (REN), “South West Europe TSOs common capacity calculation methodology for the day-ahead and intraday market timeframe in accordance with Article 21 of Commission Regulation (EU) 2015/1222 of 24 July 2015”, June 2021, <https://eepublicdownloads.entsoe.eu/clean-documents/nc-tasks/SWE%20CCM%20TSOs%20Amendment.pdf>.
 - [36] Coreso, Yearly Operational Review, <https://www.coreso.eu/media/documents/>.
 - [37] CO2-free generation, <https://www.esios.ree.es/en>
 - [38] A. Cockburn, “Writing Effective Use Cases”, ISBN 0-201-70225-8, Boston: Addison-Wesley, 2001.
 - [39] Gottschalk, M., Uslar, M., Delfs, C., “Use Cases – The IEC 62559 Methodology”, in: “The Use Case and Smart Grid Architecture Model Approach”, SpringerBriefs in Energy. Springer, 2017, https://doi.org/10.1007/978-3-319-49229-2_2.
 - [40] IEC 62559-2 “Use case methodology - Part 2: Definition of the templates for use cases, actor list and requirements list” <https://webstore.iec.ch/en/publication/22349>.
 - [41] European Union, “Grids, the missing link - An EU Action Plan for Grids”, November 2023, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A757%3AFIN&qid=1701167355682>.
 - [42] “DSO Entity and ENTSO-E submit Joint Network Code on Demand Response”, May 2024, <https://www.entsoe.eu/news/2024/05/08/dso-entity-and-entso-e-submit-joint-network-code-on-demand-response/>.
 - [43] “New network code on demand response will further advance the energy transition”, March 2025, <https://www.acer.europa.eu/news/new-network-code-demand-response-will-further-advance-energy-transition>.
 - [44] European Union, “Commission Delegated Regulation (EU) 2024/1366 of 11 March 2024 supplementing Regulation (EU) 2019/943 of the European Parliament and of the Council by establishing a network code on sector-specific rules for cybersecurity aspects of cross-border electricity flows”, May 2024, https://eur-lex.europa.eu/eli/reg_del/2024/1366/oj/eng.
 - [45] European Union, “Digitalising the energy system - EU action plan” , October 2022, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560>.
 - [46] European Union, “Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure, amending Regulations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and repealing Regulation (EU) No 347/2013”, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32022R0869>.
 - [47] European Union, “Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943 as regards improving the Union’s electricity market design”, <https://eur-lex.europa.eu/eli/reg/2024/1747/oj/eng>.
 - [48] JRC, “State of the art of Regional Coordination Centres (RCCs) and their impact on security of electricity supply in Europe” May 2024, <https://publications.jrc.ec.europa.eu/repository/handle/JRC137433>.

- [49] ACER, "Challenges of the future electricity system: Recommendations and commitments", July 2024, https://www.ceer.eu/wp-content/uploads/2024/07/Future_electricity_system_challenges_2024.pdf.
- [50] ENTSO-E, "ENTSO-E Research, Development & Innovation Roadmap 2024 – 2034", July 2024, <https://www.entsoe.eu/news/2024/07/10/entso-e-research-development-innovation-roadmap-2024-2034/>.
- [51] ENTSO-E, "Report TSO-DSO Challenges & Opportunities for Digital Electricity System", March 2025, <https://www.entsoe.eu/news/2025/03/06/report-tso-dso-challenges-opportunities-for-digital-electricity-system/>.

Annex A Full description of the technologies implemented per Pilot

A.1 Digital Twins involved in the Iberian Pilot Site Ecosystem

A.1.1 REE's Transmission Grid DT

Two different use cases of the digital twin are going to be developed and tested for the power transmission system using information and expertise for Spanish TSO Red Eléctrica. The first use case focuses on simulation of synthetic renewable resources profiles for power system studies application and the second use case is to develop AI based algorithms to support the control centre decision for power system operation.

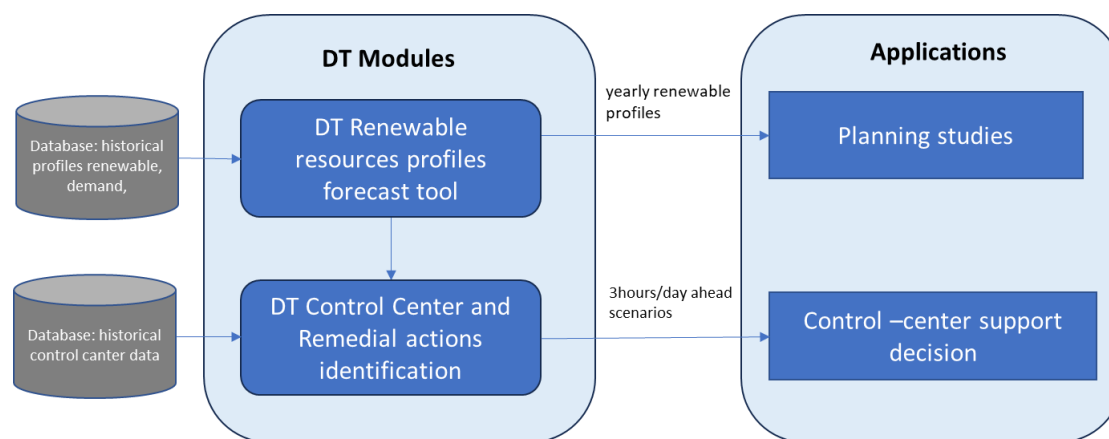


Figure A-1 - DT module: Renewable resources profiles tool

This digital twin module aims to emulate and generate different profiles of renewable resources relevant for power system planning and operation. Based on historical data of the power system, the digital twin will be able to generate different synthetic profiles of renewable power such as wind, solar radiation and hydropower.

Planning application:

The planning proposal is formulated to ensure the future development of the transmission grid within the Spanish electricity system, which is responsible for providing electricity in the upcoming years. In pursuit of this objective, a comprehensive process is undertaken which involves conducting detailed technical and economic studies, as well as simulations, with the aim of identifying the most optimal investment solutions for the entire system. During these studies, various sets of data, such as meteorological data and the potential for renewable generation production, are utilized as initial hypotheses.

Currently, the acquisition of these time series data is derived from the historical data of various climatic years, with the purpose of guaranteeing their correlation. The consideration is now being given to enhancing and fortifying future electricity planning studies, by potentially revising the identification of pertinent variables that impact these studies and incorporating supplementary data sources, which can be artificially generated, into the historical data, to analyze different scenarios in relation to the electricity system planning.

In the context of this project, the aim is to construct a systematic approach for creating diverse climate series that can be employed in the electricity planning analyses conducted by TSOs, ensuring the correlation between the series. The key specifications that this instrument ought to possess are delineated as follows:

- The meteorological data set ought to furnish the meteorological data set to ascertain the indicated potential for renewable production. Moreover, an examination must be conducted to choose the pertinent factors to be considered to ensure the temporal and geographical correlation.
- Duration of the time series of at least 1 year, with hourly granularity.
- Possibility of choosing different climatological approaches for each specific type of meteorological series that is generated.

Operation application:

The scenarios generation digital twin module will be able also to create probabilistic generation scenarios and profiles for power system operation from in day-ahead timeframe. These profiles generated will be used as input data historical records from the control centre, creating different probabilistic scenarios of the power system and generation. The probabilistic scenarios obtained will be used as one input in the DT Control centre and remedial actions identification described below.

DT Control Centre and remedial actions identification

This DT module faces challenges in power system operation from control centre and identification of effective remedial actions (if required) typically proposed by control centre operators to preserve power system security. For that purpose, an advanced tool is proposed that combines AI-based algorithms with optimization systems.

The key component of the methodology is the integration of an optimization system that uses the forecasting grid scenarios and the historical data for real-time to find optimal actions for the system operation in different hours-ahead scenarios. This will enable the Control Centre to make quick and effective decisions, considering the changing conditions of the electricity system, as is the case of high penetration of variable renewable power. The expected benefits of this approach include improved operational efficiency, efficient management of renewable energy, reduced operating costs, and increased resilience of the power system to unforeseen variations.

Ultimately, this approach aims not only to optimise the operation of the Spanish electricity system, but also to establish a framework for adaptive and sustainable decision-making in the electricity sector, promoting the transition towards a smarter and more efficient grid.

A.1.2 REN's Transmission Grid DT

The DT of REN's Transmission Grid encompasses several key features and capabilities to effectively model, simulate and optimize the operation of the Portuguese transmission grid and interface with neighbour TSO and internal DSO. The DT can be divided into 2 different frameworks: one stationary and another dynamic.

The stationary DT transmission grid model details comprehensively a representation of the entire Portuguese transmission network, including substations, transformers, transmission lines, and other

grid components. It accurately captures the physical and operational characteristics of each asset regarding steady-state. The DT involved in the Pilot Site Ecosystem supports scenario analysis capabilities, allowing grid operators to simulate and evaluate different operating scenarios, such as changes in demand, renewable energy integration, or network contingencies. This helps in assessing the impact of various factors on grid stability and reliability. The DT will incorporate predictive analytics capabilities that enables the digital twin to forecast grid behaviour, identify potential congestion, and optimize grid performance. The DT can feature different functionalities and in the specific case of the pilot site environment will be relevant for doing a probabilistic cross-border capacity allocation analysis, cross-border flexibility assessment and short-circuit calculations. Related to the cross-border capacity analysis, the horizontal network identifications method will be applied to guarantee that the relevant grid assets are in the DT model.

Regarding the dynamic DT, the main objective is to create a model that represents in a reliable way the distribution grid behaviour to disturbances seen from the TSO perspective. The role that distributed generation units connected to these parts of the network have in the overall system performance must be taken into account with respect to different phenomena and planning/operation strategies, once it may represent an important percentage of the total generated power in a given region. Therefore, in order to achieve relevant results within the scope of networks' stability studies, the distribution networks modelling strategies should be revised – from a classical passive lumped loads approach to a dynamic model able to capture the whole active behaviour of the grid. However, an even assuming the availability of data to fully characterize distribution grids and generation assets connected to it – traditionally difficult since transmission and distribution systems are operated and managed by different companies – a detailed modelling approach would raise increased computational burdens with respect to overall system studies. To maintain data discretion and simulation computational burden within reasonable limits, this DT intends to derive an equivalent, reduced dynamic model able to capture the transient response of the distribution network when facing large disturbances occurring at the transmission side.

It's also planned that the REN's Transmission Grid DT involved in the Pilot Site Ecosystem will have a communication layer to integrate with existing grid management systems, market platforms, operational tools used by grid operators and other DTs from the project, enabling interoperability, data exchange and coordination across different systems, facilitating more efficient grid operation and management.

A.1.3 OMIE's Electricity Market DT

The Digital Twin of the Iberian Electricity Market is based on the architecture of the trading platforms owned by OMIE, which are fully integrated with the information exchange systems necessary for compliance with the European regulation of the internal energy market, and specifically, the market rules of the Spanish and Portuguese systems.

SIOM: Market Operator Information System

For the negotiation of daily and intraday auctions, **SIOM** incorporates access to the Market Web through "Web Service" technology that complements access through browser, providing an application interface.

LTS (Local Trading Solution) for continuous trading developed by OMIE.

On the other hand, for continuous intraday trading, the connection to OMIE's systems is carried out through the **LTS**. Each NEMO has their own LTS platform to integrate energy transactions among different Members States in the common XBID system.

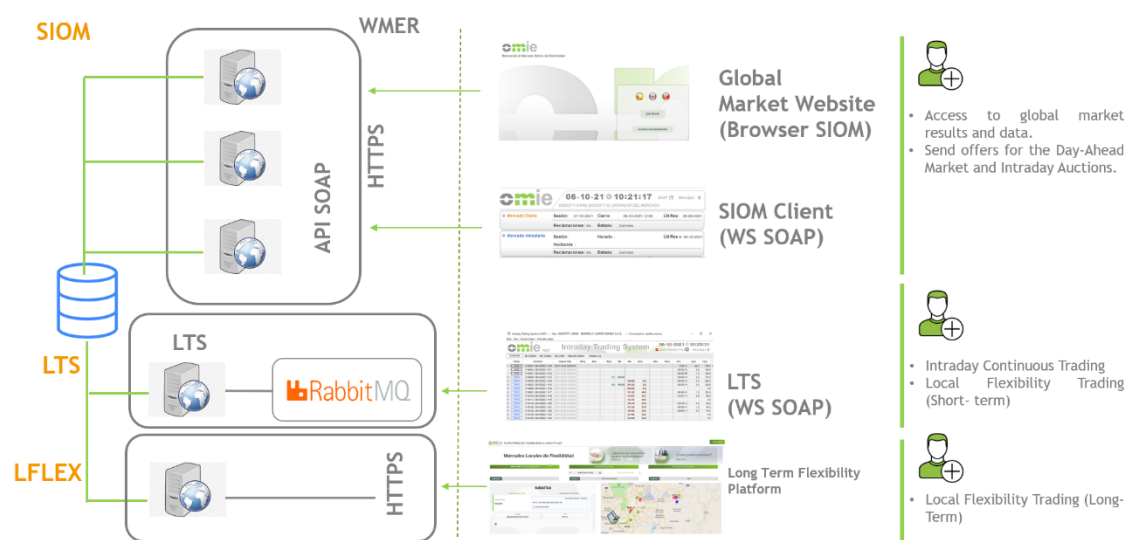


Figure A-2 - OMIE's Market Operator Information System (SIOM) architecture

AMQP messages to communicate with the intraday continuous market through LTS (Local Trade System).

AMQP messages are based on message queues to carry out its communications. A LTS module is made available to market participants as a tool owned by OMIE that facilitates their access without having to carry out any type of external development or integration.

These **types of messages allow to communicate with the trading platform** of the continuous intraday market, being able to perform the following functionalities:

- Presentation of the contracts that are negotiated.
- Sending, cancellation, modification, and activation orders to contracts under negotiation.
- Consult information related to offers, transactions, and units.
- Other information query and update operations

Digital Twins of the last prototypes for the negotiation of local flexibility needs.

OMIE is developing two market **platforms for procuring local flexibility markets**. There is one for the local short-term negotiations, with the same technology as the LTS system to provide grouping functionalities in the same market tool.

On the other hand, for the long-term flexibility negotiation, a new market platform has been developed seeking the objective of achieving a more attractive and easier-to-use tool, focused on new roles such as aggregators, DSOs or active consumers with renewable energy resources that have manageable capacity. This long-term flexibility platform has been designed to cover all the processes related to local flexibility procurement to demonstrate this type of negotiation.

This market platform is based on a web application where users, both flexibility-providing markets participants and DSOs, can register their selves using a username and password. Once registered, users will be able to participate in long-term flexibility auctions through the GUI to integrate their energy flexibility into the markets.

A.1.4 ANELL's Distribution Grid DT

ETER is the product within ETRA's portfolio targeting distribution system operators, aiming at facilitating the monitoring, control and planning activities of modern distribution grids efficiently. The application can be categorized as a DMS (Distribution Management System), and as such, it features several specialized functionalities. The most relevant could be:

- Geographic information system (GIS).
- Topology processor.
- Intelligent alarm processing.
- On-line power flow.
- Short-circuit analysis.
- State estimation.
- Fault location, isolation, and service restoration.
- Volt/VAR optimization.
- Optimal Network Reconfiguration.
- Switch order management.
- Emergency load shedding.
- Short-term load forecasting.

The functionalities are designed in ETER as independent software modules and subsystems that communicate and coordinate with each other to build the complete platform and fulfil its requirements. This approach is commonly known as micro-service-based architecture and, in comparison to traditional monolithic architectures, it facilitates maintenance of the software modules, minimizes the impact of failures avoids vendor lock-in or increases reusability of the developments from the design phase. Additionally, ETER is equipped with an additional module to be referenced as Digital Twin, the Simulation Profiling module.

The next figure depicts the main components or services of ETER.

The ESTEBANELL network topology will be included in ETER network topology repository following a pre-defined structure. In this way, all the functionalities previously described will be used to obtain a distribution network digital twin.

ANELL's Digital Twin will be completed with the integration of ETRA's ETER with the local systems currently running in ANELL's premises, with a special focus on the network model in Digsilent. Estabanell (Anell) is working with several control hardware (PLCs and RTUs) and software to monitor their network with different monitorization, simulation and control capabilities. The system in use right now is TedisNet, a SCADA software developed by SITEL, a software provider that implements SCADA systems. This system runs locally and uninterruptedly at Estabanell's control centre within its headquarters in Granollers. The features of this embedded Multiprotocol (IEC 870-5-101/104 , Modbus TCP, Prosa, ICCP) platform are listed below:

- Real time information on the status of all the elements and devices of the system both on High Voltage and Medium Voltage.

- Historical data analysis and graphic representation.
- Generation of tailored feedback.
- Alarm management.
- Technical calculations and limited simulations.
- Automatizations
- Real time power flow calculations
- Distribution quality ratings

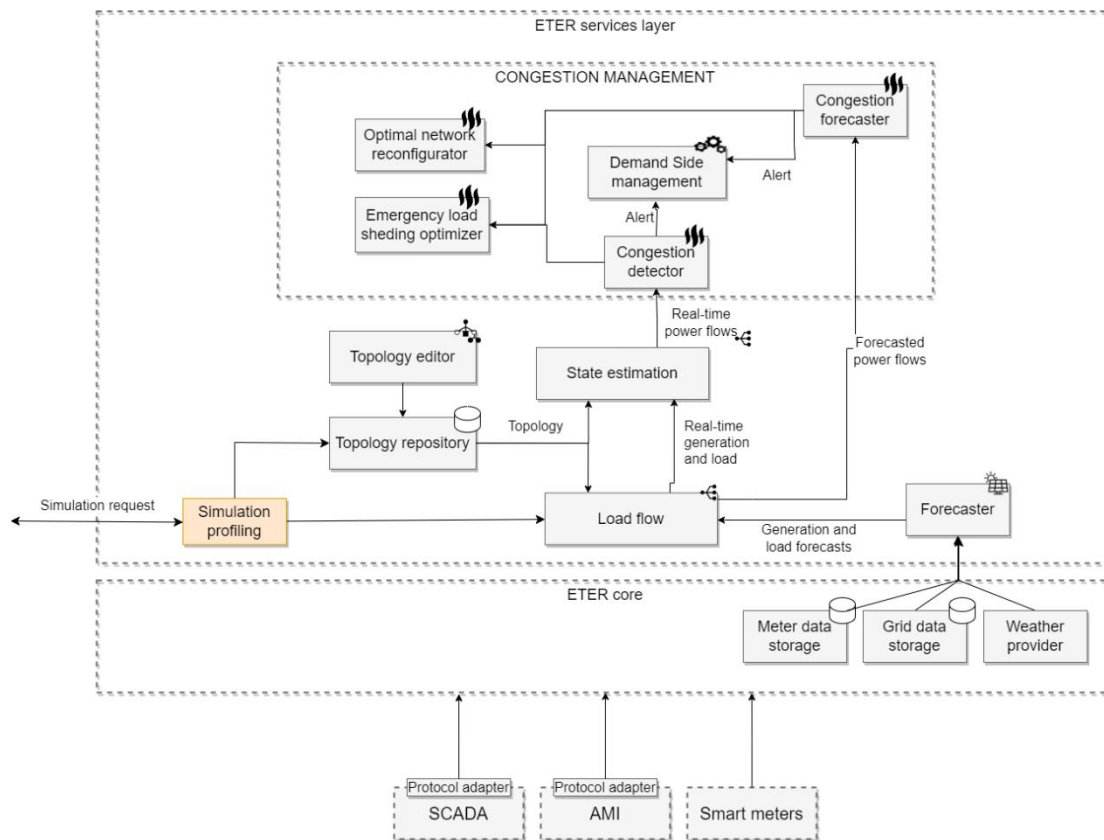


Figure A-3 - ETER product architecture with the new Simulation profiling module.

Even though TedisNet is not a Digital Twin *per se*, it has some of the DT functionalities such as power flow calculations and limited simulation capabilities which prove the usefulness of a DT in Anell's network. Nevertheless, its limited use and the risk of using a control system to run simulations and tests has highlighted the need for an independent Digital Twin. Therefore, the combination of these systems with ETER will set up a fully functional DT aimed at demonstrating the Use Cases and scenarios (both local and pan-European) defined within the project.

A.1.5 Cuerva's Distribution Grid DT

Cuerva's network DT is based on the Adaion Platform. Adaion is a Data driven platform to support Grid Operations and Planning with focus in the LV Network. In a nutshell Adaion transforms the Power

Grid into a Digital Asset to help DSOs gain visibility, predictability, and control by gathering data and generating valuable insights and tools.

This is an interoperable and modular platform, with high analytics capabilities and tools for the design, planning, operation, and maintenance of MV and LV grids. It's based on advanced algorithms, AI, third party Digital Twins integration, and a Data Integration Platform.

Adaion integrates multiple sources of data with different formats into a single, unified model. It generates the digital twin of the grid (HV, MV and LV), based on the real data from the measurements and the topology, which is created from the inventory info of the DSO typically provided by the GIS. Based on this digital twin, the platform offers different features that will be used as a solid base for creating new uses cases in this EU project. The most relevant features related to the DT for this project are listed below.

- Power flow capability
- Node Capacity calculation over all the nodes in a grid
- Technical feasibility of new access and connection requirements
- Optimal planner for EV charger massive deployment

From the physical infrastructure side, Cuerva has a highly digitized network included in the DT with the following measuring equipment:

- +5500 users (residential, commercial, and industrial)
- 2 substations
- 220/132 kV 1x160 MVA connected to REE
- 132/66/20 kV
- 31 km of HT lines
- 292 km of MT lines
- 315 km of LT lines
- 100% penetration of Smart Meters, both residential and industrial level
- High-resolution measuring devices in MV
- High-resolution measuring devices in LV

The structure illustrating the measurement map can be viewed in the following image.

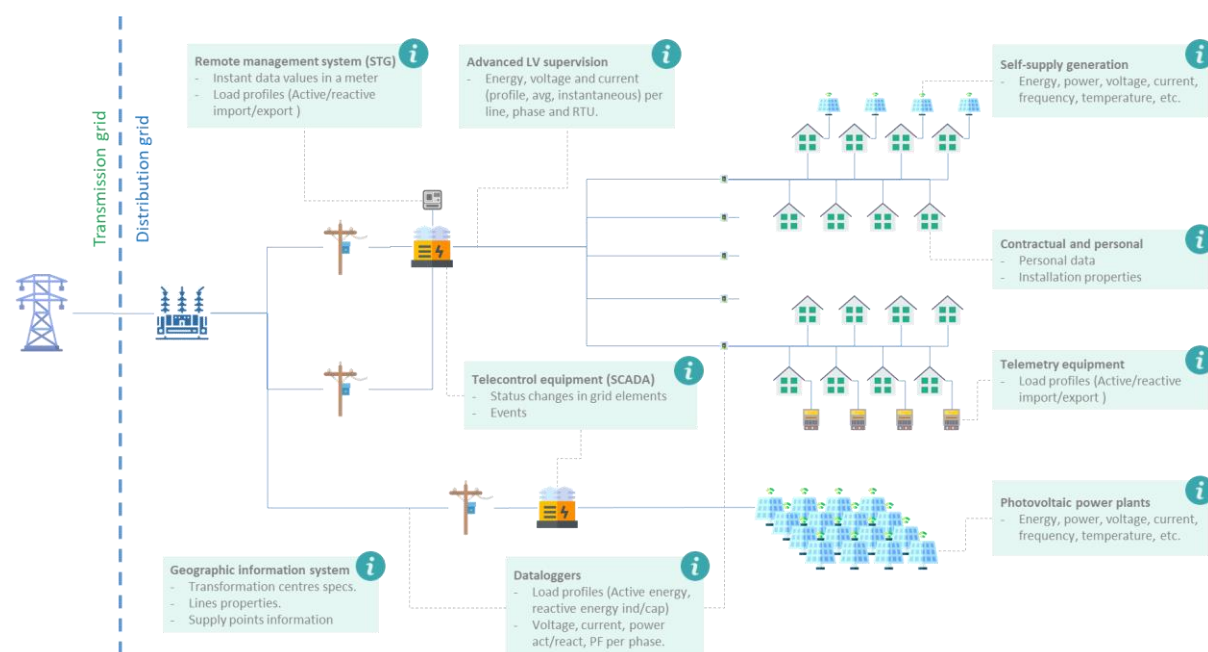


Figure A-4 - Measurement map of the Cuerva's living lab

This setup ensures the availability of reliable datasets concerning the network infrastructure (smart meters, transformers, lines, etc.). However, it's imperative that all this data is processed through a platform capable of aggregating diverse data sources and protocols. This fosters the development of proprietary tools such as APIs, Notebooks, IoT platforms, as well as planning and simulation tools.

A.1.6 INESC TEC's Iberian Electricity System high-level DT

The progressive integration of electronic converter based Renewable Energy Sources will lead to a reduction of the system synchronous inertia that can endanger the system frequency stability behaviour, especially in poorly interconnected systems, such as the case of Iberian system. A Digital Twin representing the dynamic behaviour of Iberian system interconnected with the central European system is therefore needed to assess the stability of the Iberian grid when facing large disturbances like a sudden loss a large amount of generation. Figure A-5 describes the dynamic model associated to the DT.

The DT needs to be calibrated using a parameter estimation methodology that tunes the model frequency response to the real system frequency response when facing large disturbances. An initial parameter identification, that involves the identification of the values for system inertia, system damping, generator droops, and synchronization coefficients, was performed solving an optimization problem, which corresponds to the minimization of the quadratic error summation between the model frequency response and the real system frequency response using in this case a metaheuristic approach based on a particle swarm algorithm. The real data exploited corresponds to the frequency behaviour during a disturbance related with the sudden loss of 1 GW of Active Power, due to the Almaraz II Nuclear plant unit disconnection in October 2011. The inertia parameters can afterwards be modulated using engineering judgment to evaluate the frequency behaviour for the scenarios of future years. Further calibration is expected during the project using data from frequency behaviour following large disturbances obtained from system operators records. Assessing this data is an important requirement for the quality of the results obtained when using this DT.

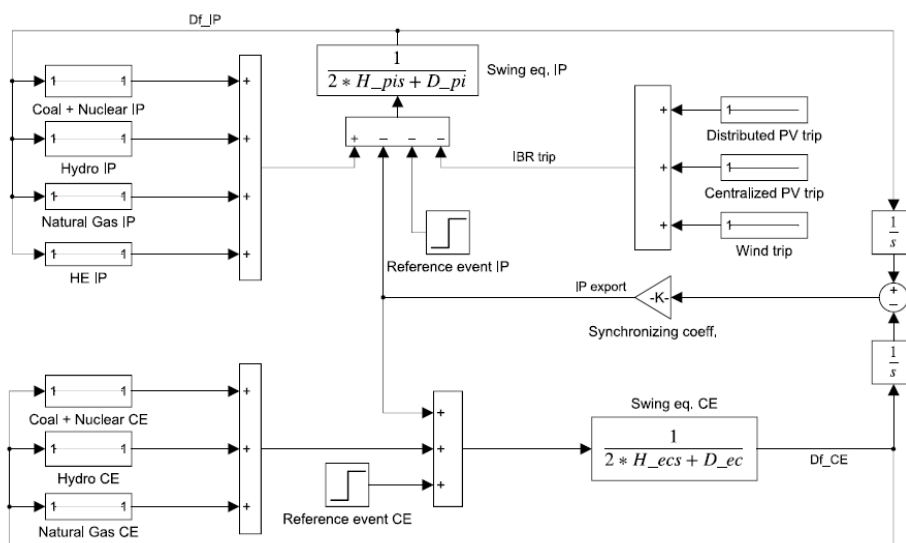


Figure A-5 - DT of the Iberian system interconnected with central Europe

The DT can be further expanded to include the AGC operation and control loops as described in the next Figure.

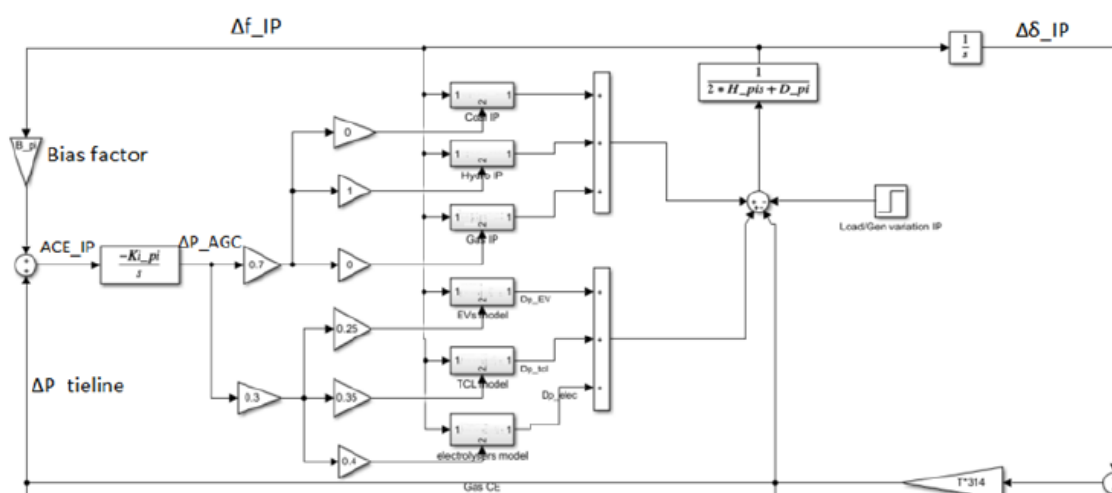


Figure A-6 - Dynamic model of the DT including the AGC control loops and load response

This DT allows modelling different generation technologies, including the ones using electronic power converters related to Renewable Energy Sources and their frequency sensitive modes. It is also possible to include blocks representing the dynamic response from demand like thermal loads, electric mobility and electrolyzers when responding to frequency excursions.

With this DT, and when properly calibrated, it will be possible to evaluate the dynamic behaviour of the Iberian system when facing active power disturbances, identifying the type, volume and characterization of frequency ancillary services (including innovative ones like FFR, virtual inertia) needed by the system and to be provided by both generation power converters (synchronous and non-synchronous), storage units (hydro pumps or batteries) and responsive demand.

A.2 Digital Twins involved in the Eastern Mediterranean Pilot Site Ecosystem

A.2.1 DT of the HVDC interconnection between the mainland Transmission System of Greece and the insular Transmission System of Crete

A digital twinning for the interconnection of the mainland Greek power system with the insular one of Crete (HVDC interconnection) will be developed to assess the impacts on the grid and the market operation. The developed digital twin will be used in market-clearing procedures by electricity day-ahead and balancing markets, including a day-ahead and balancing market simulator, based on a detailed unit commitment model. The balancing market simulator will include an iterative mechanism with relevant grid models (transmission and distribution network) to verify grid quality standards compliance through power flow calculation.

A.2.2 Greek Transmission System DT

The DT application in the Greek demo focuses on two pillars:

- (a) Pillar 1: Energy forecasting and optimal grid operation applications.
- (b) Pillar 2: Development of a balancing market model to determine the optimal balancing energy and reserves.

IPTO will provide the necessary technical data for the development of the digital twin (DT) for the Greek transmission grid. The data could be divided into two categories:

- Grid Topology and Configuration (e.g. transmission lines, substations, transformers, etc.)
- Load and Generation data (e.g. system load, RES generation, etc.)

For the development of the tool, power system analysis software (e.g. PSSE) can be employed to examine and assess the grid state (e.g. congestion management, voltage level etc.) in order to allow possible provision of balancing reserves from the LV grid. (in coordination with HEDNO).

A.2.3 Greek Distribution System DT

In line with the role of HEDNO in the TwinEU Project, HEDNO will collect information on the targets set out in the National Energy and Climate Plan (NECP) 2030, and then will proceed with modelling zones of the electricity distribution network, taking into consideration both the estimated consumption and the estimated integration of RES and Electric Vehicles in these particular zones.

Those models will be used to perform recurrent load flow analysis, based on data from balancing market obtained from the TwinEU data space, in order to estimate the state of the network, ensuring its seamless operation. At the same time, information on the impact of planning on distribution networks will be returned to the data space.

For the implementation of the above, on the HEDNO side, the following technologies will be developed:

- Modelling of electricity distribution sections based on the scenarios in the NECP 2030.
- Development of an interface for the communication of HEDNO's tools with the TwinEU data space, through which the signals generated by the energy balancing market simulator will be

received. This interface will be developed by HEDNO, based on the available data from the simulator.

- Development of an automated system for simulating distribution network sections by performing load flow analysis using PowerFactory software.
- Development of an interface for sending information to the market simulator through the data space, regarding the state of the network, as it will emerge from the load flow analysis.

A.2.4 Cyprus Power System DT ecosystem

The digital twin of the Cyprus power system comprises of the whole transmission system and a selected part of the Medium Voltage Level of the Cyprus distribution grid. It is implemented in MATLAB Simulink and can be emulated in OPAL-RT (real time simulator), offering the capability of running in real time dry run simulations. In the case of the digital twin of the Cyprus transmission system, real measurements acquired by Phasor Measurement Units (PMUs) installed in 18 high voltage substations are fed to the digital twin in order to represent the actual operating condition of the Cyprus transmission system to the digital twin system. Field measurements from distribution substations and smart meters data from consumers are also fed into the digital twin to emulate the distribution grid operating conditions.

In addition, an energy and ancillary services market tool will be considered in collaboration with the transmission and distribution digital twin in order to emulate realistic conditions for the use cases.

A.2.5 Greek Electricity Market DT

The Electricity Market DT will include the Day-Ahead and Balancing Market simulators. HENEX will develop a Day-Ahead market simulation tool of the Greek Day-Ahead electricity market considering current operating requirements and the market evolution towards 2030. The simulator will integrate the anticipated market changes, i.e. changes in market topology (new interconnectors), time resolution (15min products), generation mix (domination of RES, storage and DR), market design (e.g. asset-based participation) as these are formulated by the relevant regulations and targets or driven by current market inefficiencies. The results of the Day-Ahead market simulator are the market clearing prices and asset market schedules and are provided to the balancing simulator (operated by UPRC) as input for the Balancing Market. UPRC will develop the Balancing market simulator of the Greek power system. The future 2030 Greek power system based on the estimations of the country's National Energy and Climate Plan will be used as test case. Taking into account the submitted bids of the market participants for the balancing market, and the thermal units' techno-economic data, the balancing market simulator determines the optimal balancing energy and reserves scheduling. The balancing market products include: (i) upward and downward BE, and (b) several reserve types capacity, including Frequency Containment Reserve (FCR), Frequency Restoration Reserve with automatic activation (aFRR), Frequency Restoration Reserve with manual activation (mFRR), and operational congestion management.

A.3 Digital Twins involved in the Hungarian Pilot Site Ecosystem

A.3.1 DT1&2&3 –Digital Twin of MAVIR, EON EED and APG grids, constituting of sensor based physical conductor models (Task 6.8) and flow-based line capacity calculations (Task 7.3)

In the Hungarian Demonstration, a revolutionary approach is aimed to be adopted by developing a Digital Twin (DT) model that redefines the monitoring and management of power lines. One of the goals of the Hungarian Pilot is to create a digital twin that, in addition to providing real data parallel to the operation of the line monitor sensor, can replace it in particular cases.

Three separate DT of the network operator partners involved in demonstration of the market integration are involved:

- DT1: MAVIR's transmission system DT
- DT2: E.ON EED's distribution system DT
- DT3: APG transmission system DT

The three physical grid DT models integrate real-time data from strategically placed sensors on phase conductors, which measure temperature, with an advanced algorithm that defines the optimal locations for these sensors to mitigate sag-clearance issues and enhance system reliability. The algorithm considers various factors, including power line span, conductor specifications, tension at installation, and comprehensive cross-sectional drawings, ensuring sensors are positioned where they are most needed.

As part of the demonstration, previously acquired line monitoring sensors and weather stations will be installed on specific network parts of MAVIR (TSO), EON EED (DSO), and APG (TSO). The line monitoring sensors are mounted on the phase conductor, while the weather stations are mounted on the high-voltage towers. These surrounding weather stations contribute critical environmental data, capturing wind speed, solar radiation, ambient temperature, and more, while the SCADA system provides invaluable line load parameters.

Over a year of data collection lays the groundwork for creating an Artificial Neural Network (ANN), which, with weather conditions and SCADA load data inputs, is trained to accurately predict conductor temperature. This predictive capability is pivotal, enabling the DT to calculate phase conductor temperatures without direct sensor input, thereby allowing for strategically relocating sensors to other critical areas, optimizing the monitoring network, and reducing costs. Integrating this ANN into the DT framework empowers operators with dynamic line rating abilities and enhances asset management strategies, paving the way for a more resilient and reliable power grid. By leveraging predictive analytics, the DT model prevents potential sag-clearance problems and supports the power grid's adaptation to varying environmental and operational conditions. Ultimately, this DT concept embodies a forward-thinking strategy to increase grid resilience and ensure the reliable operation of power transmission networks, setting a new standard for the industry.

In the first year of the demonstration period, both sensors (phase conductor temperature measurement) and weather stations (ambient temperature, wind, solar radiation, etc. measurement) collect data with a temporal resolution of 10-15 minutes.

In parallel, an artificial neural network-based Digital Twin with optimized hyperparameters is developed for each transmission line. Its inputs are the load time series downloaded from the SCADA system and the data measured by the weather station, while the output is the conductor temperature. [After the one-year training period, it is possible to compare the accuracy of the data provided by the ANN-based DT regardless of the sensory measurements. The goal is to create the optimized DT to give the conductor temperature within the sensor's accuracy level with the shortest training time.] Some sensors can be freely dismantled and relocated to other power line sections when this is achieved. In contrast, the other part can remain on the network for further training dataset collection.

The DT created in this way leads to more accurate results than physical models (CIGRE, IEEE, IEC) and is more cost-effective than classic sensor systems. These results can be used as input parameters of a dynamic line rating (DLR) system with which real-time ampacity is calculated. These results can also be used for electricity market demonstrations.

For all grid DTs the resulting physical parameters, time series are used to define the market usability of the physical assets. Based on the existing Core Region flow-based solution and results, HU demo specific DLR inputs new cross-zonal transmission domains are calculated for day-ahead and intraday power exchange auctions. The resulting flow-based parameters are the basis of commercially feasible and required transactions on both cross-zonal energy and balancing capacity reservations. Grid DTs are thus combining the domain of physical measurements and modelled usable capacity for the market platform.

A.3.2 DT4 – HUPX (HU NEMO) DT – spot market platform for day-ahead and intraday auctions and Platform for data storage and visualization (Task 7.3)

The Hungarian pilot demonstrates the market impact of co-optimizing the energy and balancing capacity market. Fully accurate digital twin of the existing, EUPHEMIA algorithm-based day-ahead market operating software solution, is in place to ensure the feasibility of the analyses of additional market features: co-optimization of energy and balancing capacity products with dynamic line rating enabled additional cross-zonal capacity. The EUPHEMIA compatible, complex, mixed integer programming algorithm and the specialized solver-based software environment ensures the complete representation of the real market optimization carried out in SDAC. Further add-ons are delivered to provide the necessary functionality to intraday auctions: 15-min. products, cross-product matching, shortened delivery time frame.

Additionally, HUPX's DT is to be provided with the ongoing development of a new, web-based data platform serves dual purposes by combining dynamic data visualization functionalities with data queries through API (Application Programming Interface) integration.

The updated data visualization component allows users to explore energy market data, critical congestion data or simulation results on a map, providing a cross-zonal, and time series perspectives on trends. The platform also supports basic sorting options, enabling users to customize their analyses and visualizations more efficiently.

The API integration facilitates easy and real-time data download ensuring a more accessible user experience. Users will also have the capability to export sorted data into different file formats, such as CSV, JSON or XML. With the help of the data import function admin users will also be able to upload data sets via different file formats in a fixed structure, offering multiple methods for data retrieval.

A.4 Digital Twins involved in the Bulgarian Pilot Site Ecosystem

A.4.1 DT of the Bulgarian transmission system

First of the digital twins that will be necessary for the work of the Bulgarian demo is the EHV (extra high voltage) model of the transmission system of Bulgaria. Creation of this digital twin will be done in collaboration with the Bulgarian TSO in order to ensure that all of the information used is up-to-date. Therefore, it may and certainly will be (at least, to some extent) based on the already existing models of the analyzed grid, in the format currently used for this purpose. This will ensure the reliability of the calculations and analyses done on this DT. Out of the analyses, the ones that should be mentioned here are the load flow and voltage state calculations by which the impact of the suggested improvements will be estimated, with reliability assessments (N-1) and losses calculations carried out if and when deemed necessary.

Regarding the technology that will be used for creation of this digital twin, it will be harmonized with the tools and technologies that are commonly used for the grid modelling tasks. Here, the feedback of the Bulgarian TSO will be essential in order to make sure that accepted approach indeed follows the cutting-edge tendencies in the grid modelling. At this moment, it is the most likely that the basis for the development will be PSS/E software package, but this may be prone to change if another tool emerges once the activities start. Moreover, needed automation and existing models improvements will be incorporated through the scripts in Python or other similar programming language together with GeoServer functionalities. This will vouch for incorporation of the impact of the developed forecasts in the created grid model.

For purpose of the data storage, relational Postgres database with spatial plugins shall be established. This database forms backbone of GIS (Geographic Information System) system of entire analyzed energy grid. Since spatial plugins are used, each record besides preview of technical data can be displayed with geographical coordinates. Data is grouped in tables which hosts basic data and can further create more complex structures. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies.

Spatial query is implemented for purpose of easier calculation and better User Experience. Map view and datasets are displayed based on zoom level with zoomed out display of larger area and less details of analyzed POIs. Viewing in web environment above-described data requires using dedicated server solutions supporting WMS (Web Map Service) and WFS (Web Feature Service). Similar approach can be used to model even more detailed grid on lower voltage level and its relationship to various grid users with different roles.

A.4.2 Partial DT of the Bulgarian distribution system

Second digital twin needed for completion of the activities of the Bulgarian demo will be the model of the distribution grid in Bulgaria. but the Distribution System DT will be focusing on the geographical areas of interest for the demo. In particular, those will be the areas with the high potential for integration of renewable energy sources, such as wind and solar power plants, as well as for demonstration of the active consumer and prosumers concepts through the aggregation for variety

of services, including simulation of demand response as well. That will allow partners to fully estimate the effect of the improved generation and load forecasts on the functioning of the system, in line with one of the main targets of the Bulgarian demo. This DT will also be based on the existing models of the grid in the selected areas of interest, in the format currently used for this purpose.

For this model, the technologies already mentioned in the part related for the transmission grid will be taken once again, in order to ensure the compatibility between the two digital twins in question. This is particularly important since the two will be applied together (or even merged) for the benefits of the solutions to be calculated properly. This is needed since most of the RES are still connected to the distribution grid, whereas the impact of their work can also be seen at the transmission voltage levels. In line with that, the effects of improved forecast accuracy have to be determined taking both of those into account, leading to the decision to use the same tools for model building (along with the automatization codes). Of course, this approach will go through the detailed check by the Bulgarian DSO before the digital twin is created. It should be added that these two digital twins, when combined, should provide the developers with the capability of running the needed network analyses, such as the load-flow calculation, voltage value analysis, N-1 security assessment and the calculation of active losses in the grid.

A.4.3 DT of the cross-border energy market

Third digital twin that will be made during the work of the Bulgarian demo partners is the model of the energy market, focusing mostly on the cross-border flows between Bulgaria and other countries in the same region – cross zonal exchanges mostly. Creation of this model will allow the partners to estimate the impact that the new generation mix (affected by the improved integration of RES) will have on the parameters such as the costs of the system operation and values of the power delivery reliability indicators. Furthermore, the results obtained by using this model can be the basis for the creation of the network model, described in the previous two DTs. This DT will, to some extent, also be based on the existing models of the cross-border energy market, in the format currently used for this purpose.

Here, the tool that will be used needs to be changed, since the type of activities that will get done by its usage is also different from the analyses that will be done by using the two already mentioned digital twins. For this, the effort needs to be invested in order to identify the software tool that will at the same time provide the needed inputs for the network part of the activities and be robust and intuitive enough to easily adapt to the different needs that might come to be during the project's lifetime. With the help of the Bulgarian system operators, the ANTARES software tool was singled out as the one fulfilling all of the listed criteria, but this is also prone to change if the better solution is found down the track. In case the automatization of some parts of analyses turns out to be desirable, it will be done in R or some other similar coding language.

A.4.4 High-level digital twin of the Bulgarian power system

This digital twin will be developed for high level analysis usually performed by the governmental bodies, institutes, regulatory authorities and universities. It will be developed in order to illustrate the coordination between different parts of the energy system, such as the transmission grid, the distribution grid and the electricity market. Since it is bound to include lower level of details compared to the previous three models, it will be easier and faster to use and extract needed results from the point of view of the available hardware, thus optimizing the usage of resources.

Since this model should be sort of an amalgam of the previous three, it is logical that it will be treated as such in the technology selection part as well. Therefore, it will most likely be done in the same tool as the two already defined digital twins related to the different parts of the grid in Bulgaria. It will, thus, also be founded on the existing models of the Bulgarian energy system (both the network and market models). However, the change is that it may include even more automated processes than the previously mentioned three in order to be able to fully intertwine those digital twins. To add to this, the level of details for this model will be lower than in previous three, which is justified by the fact that this digital twin will be used only for quick and rough estimations, not for detailed results. Hence, efficiency and speed of doing the calculations and providing the results is the first priority for the development here. As already stated, this is not the model that will be used for the detailed simulations, but solely for providing the overview of situation in the entire grid.

The way in which the communication between all of these digital twins will be ensured can be found in the following subchapter of this report.

A.5 Digital Twins involved in the German Pilot Site Ecosystem

A.5.1 Westnetz' HV distribution grid DT

Westnetz's high-voltage distribution grid extends over a length of 5160 km and is monitored and managed via a central control system. All status data is recorded and visualized. Based on this data, the responsible system operator can carry out measures such as switching operations during maintenance work or after fault events, either manually or based on suggestions from the control system's internal algorithms (e.g., state estimation). This technology by itself cannot be described as a digital twin, but it does provide a basis. Due to the challenges of the energy transition, further functionalities are required to increase observability down to the low-voltage level. A possible digital twin should take into account the existing data from the control system and additional measured values from local grid stations and smart meters in order to guarantee the desired functionality. The necessary data exchange and process-related implementation represent a further challenge that could be met by Envelio's IGP in the future.

A.5.2 Westnetz MV/LV distribution grid DT (Envelio's intelligent grid platform)

Envelio's Intelligent Grid Platform (IGP) allows grid operators to build a comprehensive digital twin of their power distribution network by combining data from multiple sources in one smart system.

As a result, they attain unequivocal clarity regarding the operational dynamics within their grids - a feat previously unattainable due to the historically inadequate digitalization at the distribution level. This leads to, among other things, significantly faster integration of renewable energy resources into the grid through automated technical evaluation of connection requests and reduced administrative load associated with it. envelio's IGP acts, therefore, as an active component in the acceleration of energy transition and reaching our net-zero targets.

The purpose of envelio's technology is to support the energy transition by enabling standardization and automation of grid operation and planning processes. For that, a digital replica of the grid – the so-called grid digital twin – is created that dynamically reflects real-time or near real-time changes in the grid.

This grid digital twin acts as a basis for a variety of use cases where the optimization need is the highest. The most pressing need that is common to distribution grid operators EU-wide as well as beyond EU is the enablement of faster integration of renewable energy resources (RES) into the grid. In this area, the IGP supports grid operators with their digital twin by:

- automating technical evaluation of connection requests including the evaluation of the current grid capacity,
- visualizing the state of the low voltage and medium voltage grid area based on near real-time data.
- enabling self-service pre-evaluation of the most favourable connection points, thereby reducing the administrative load associated with it, and
- facilitating the development of grid reinforcement and expansion measures to support the ramp- up in deployment of the renewables.

The IGP combines data from various systems in one source-of-truth- system. These data are continuously validated with the help of algorithms developed specifically for this purpose, thereby reducing the factor of human error, and updated as soon as new data comes in.

The grid digital twin built upon these data, presents a grid model that "lives" online and, therefore, provides consistent data basis for decision-making across departments.

With its help, distribution grid operators gain a comprehensive and holistic view of the current grid status and capacity. Using these insights, they can evaluate much more precisely to what extent the integration of renewable energy sources will affect certain areas of the grid and where its expansion will prove to be most urgent.

In our German demonstrator, the IGP will be used as one Digital Twin basis and will demonstrate the grid from our DSO partner Westnetz, as well as expand its functionalities such as grid monitoring, grid planning and end-to-end flexibility. The IGP is scalable on cloud. provides interoperable functionalities via interfaces and will support third market participants and TSOs with corresponding interfaces.

A.5.3 E.ON Energie Deutschland's market aggregator

E.ON Energie Deutschland GmbH (EDG) is one of Germany's leading energy companies and the sales unit of E.ON in Germany. The company ensures a reliable supply of electricity and natural gas. With its energy solutions for photovoltaics, energy storage, electromobility, home energy management system, energy checks and efficiency measures, EDG is the provider for an increasingly decentralized, ecological and digital energy world. EDG's more than 14 million private, business and industrial customers benefit from both the strengths of the Group and its regional presence.

EDG's success in business with private, business and industrial customers thus provides the basis for implementing additional and far-reaching use and business cases in the future as part of the TwinEU project, as an aggregator of flexible prosumers. This aggregation includes diverse and very different data, such as data on flexible installations, envelope curves provided by other software solutions, smart meter data on consumption and generation, market prices and data from so-called technical aggregators.

EDG will summarize all this data in its role as an economic aggregator and, building on its existing customer platform, derive an optimal action strategy for flexibility for every hour of the next day. This can include business cases such as self-optimization by end customers or trading on the energy-only market as well as system-beneficial use cases, such as the use of flexibility at the low-voltage level to eliminate grid congestions in the transmission grids.

The first step within the project will be to aggregate the envelope curves provided by envelio's digital twin and use the included flexibility to ensure price optimal charging of end-customers.

A.6 Digital Twins involved in the Italian Pilot Site Ecosystem

A.6.1 ENEL's Distribution Grid DT for Design Validation

The Design Validation phase of BIM models is the process of evaluating and verifying the Digital Twin prototype of a building environment, in terms of geometries and the information (properties) related to each building element with the purpose of identifying potential design issues, conflicts or inconsistencies in the model and resolving them before they become a problem in the real constructed structure.

In the proposed use-case, users are able to dive into a solution that can use standard BIM Objects and propose a data validation based on the metadata present into the models. During the Design Validation the user should be able to join into a collaborative environment, also called Common Data Environment, that give the possibility to upload and view 3D models. The application will extract metadata and using a validation tool based on rule engine, can validate the correctness of data.

The Design Validation can achieve the maximum efficiency if the various actors, involved in the design of the projects and the constitution of the digital twin, work with open and interoperable formats, properties and define a set of guidelines that facilitate the interoperability of the different collaborative environments (CDE).

A.6.2 ENEL's Distribution Grid DT for DERs prequalification

In the realm of network grid operations, DTs have emerged as a powerful tool. These virtual replicas enable a deeper understanding of the grid's behaviour, facilitating better decision-making and operational efficiency. However, the successful integration of Distributed Energy Resources (DERs) remains pivotal for Distribution System Operators (DSOs). These DERs, such as solar panels and battery storage, require specialized management tools. By implementing innovative functionalities within the DSO's DER Management System (DERMS) which acts as a DT of the grid, we can streamline critical processes. In course of the project, this chapter will be further detailed to provide valuable elements for the analysis.

A.6.3 TRI's Transmission Grid DT for Design validation

According to Italian regulation, a prosumer that wants to connect to the power grid is allowed to design and build the needed infrastructure, according to the relevant System Operator indications. In this scenario, Terna needs to verify if all the elements are design and planned according to Terna's rules and constrains. In this scenario, the automated validation tool based on BIM will validate this proposed substation design in terms of geometries, information related to each element, compliance with national regulations and TSO standards.

The digital twin will be created and it will evolve into an Integrated Design Platform where the designer can easily access the information of the TSO standard BIM object library and the geographical information for constraints checks. The designer will have automated feedback from a Code & Model Checking Tool able to identify design errors, such as equipment technical properties and geometric interferences. This Integrated Design Platform can simplify the process of digital twin design validation and potentially save the 30% of current times. During the validation phase the user should be able to join into a virtual environment where the scenario displayed is a digital 1:1 scale representation of the BIM model developed.

The use case will be developed in different phases.

1. A first phase in which the rules for the validation of the digital twin will be analyzed and translated, where possible, in Design validation workflow and table of Machine-Readable Regulations;
2. from the rules and checks the data model and LOIN for an electrical substation, suitable for the purpose, will be built. The level of information needed is the cornerstone of the experimentation;
3. the following phase will be the construction of the BIM Model the asset (substation for power generator connection to the network) implemented with the defined Data Model and LOIN;
4. it will be then defined the requirements of the BIM Validation Tool in order to scout the market and find the right tool for the scope;
5. the final stage will see the configuration of the selected tool with all the ruleset elaborated in step 1.

After the demo, the possibility of scaling will be explored in greater detail with Cost-Benefit analysis, roadmap for scalability-interoperability of an extended solution.

A.6.4 Terna's Transmission Grid DT for RTS

Terna's Digital Twin (DT) will replicate of a portion of the Italian Transmission Grid; in particular, it aims at developing the DT of the Sardinia Island HV power system. This digital copy will be updated in real-time to consider the real status of the physical power system components. The DT eases the integration of multiple information coming from different sources. Moreover, it will enable sensitivity analyses that will be performed considering the evolution of system parameters according to future scenarios.

To realize the demo, Terna will use Real Time Simulators (RTS), able to simulate complex components like HVDC links, BESS, synchronous condensers, inverters and control systems of RES plants. The RTS will be connected to real hardware devices, like relays, able to measure the grid frequency and to operate commands when a threshold on frequency or its derivative is reached. With this composition, the DT will be able to investigate the behaviours of Defence System strategy applied on a detailed model of a portion of the Sardinian network. Based on the configured scenario, the relays connected to the RTS will send signals to the distribution network (simulated on the RTS environment) in verify how the grid frequency, currents and voltage reacts in the whole simulated network. Will also be analysed the impact of inverter-based resource operation on the distribution network after a transmission system grid event.

With the aim of simulating even more complex systems also using the hardware in the loop approach, it will be taken into account the possibility to connect the RTS facilities of Terna and Ensiel (Politecnico di Torino) to simulate the complete system framework by using a geographical distributed RTS approach.

A.7 Digital Twins involved in the Slovenian Pilot Site Ecosystem

A.7.1 ELES's Transmission Grid DT

The Transmission Grid DT, including the existing network operation and stability management process, will be upgraded, increasing system observability and controllability, particularly through services provided by PE-interfaced devices. This DT integrates diverse data sources including DSOs, energy traders, and environmental parameters to improve the grid's operation. It utilizes advanced modeling based on the CIM standard, enhancing data interoperability between different systems. The upgraded DT aims to facilitate more accurate modeling of the transmission network, incorporating accurate static and dynamic (load and generation) models to manage the high variability in consumption and production. One of the expected outputs will be a methodology for scenarios-based modeling of future operating conditions and network planning, allowing for system analysis with high shares of PE-based devices.

Additionally, this DT explores the balance between conventional power sources and converter-connected sources, aiming to optimize the rapid response capabilities essential for maintaining grid stability. It involves defining technical requirements for the Fast Frequency Response (FFR) service and evaluating its impact through simulations. This DT is crucial for ensuring the efficient establishment of the grid from the bottom up, facilitating a faster and more reliable response to power imbalances, and contributing significantly to the resilience and stability of the network.

A.7.2 EG's Distribution Grid DT

EG's Distribution Grid DT is under constant development. Significant progress has been made recently in the development of a DT particularly for the low-voltage distribution network, aimed at accelerating energy and green transitions. The implemented data module enables the storage and retrieval of test data and the integration of data analytics modules. Graphical support for network evaluations is fully designed and implemented, providing detailed simulation results for various network parameters. Various modules have been implemented and integrated, including those for generating time series of energy consumption and production, and for analysing measured time series. The development and testing of API interfaces for module integration and the ongoing integration of functional modules with the DT underscore the EG's commitment to enhancing network planning, investment decision-making, and the incorporation of distributed renewable energy sources into the network.

In TwinEU project EG's DT aims to enhance the dynamic modeling of the distribution network to accommodate the increasing integration of renewable energy sources. This DT focuses on the development of a detailed model distinguishing between different groups of loads and production units at the HV/MV TS. It incorporates an equivalent model for demand, segmented by consumption types (industrial, household, commercial) and an equivalent model for generation units, factoring in different types of generation like photovoltaic and rotating mass generators. This digital twin aids in

refining grid planning and dynamic analyses, enabling the grid to effectively handle variations in energy demand and supply, thus ensuring grid stability and efficiency.

A.7.3 HSE's Electricity Market DT

HSE as generation company in the transmission power system of Slovenia also participates as the provider of various system services, among which is the provision of the frequency containment reserve - FCR. In order to provide this service, certain generation units in its portfolio has qualified, as follows:

- Hydro power plants chain on the Drava river
- Hydro power plants chain on the Soča river
- Avče pumped storage power plant
- Šoštanj thermal power plant Blok6

In order to provide the FCR system service, the HSE obtained a certification of technical ability and fulfils all the legal and formal requirements and conditions in the auctions rules, thus obtaining the status of qualified BSP. As a qualified BSP, the HSE can bid for FCR balancing power in auctions.

The provision of the FCR system service is coordinated with the document »Rules and conditions for balancing service providers on the ELES balancing market« issued by the Slovenian TSO.

For generation planning and optimization, the HSE uses common platform based on the jROS system.

The amount and time frames of the FCR system services, which were bidded and activated on the platform, are imported by the short-term sales department into the jROS system, which automatically arranges the realization of the services to the corresponding generation units.

Through the jROS system, the generation planning department in the HSE dispatching centre receives data on the quantities of the FCR system services and includes them in the scheduling plans, which are then exported into the SCADA system.

Each generation unit that is qualified to provide the FCR system service must meet the following requirements:

- The technical unit must provide a symmetrical regulation range of the FCR and activates it proportionally to the frequency deviation, namely in the opposite direction of the frequency deviation. If the frequency deviation is greater than ± 200 mHz, the entire qualified FCR regulation range provided by BSP on this technical unit must be activated.
- Operating frequency range: 49,800Hz – 50,200Hz
- The sum of response insensitivity and deadband: $< \pm 10$ mHz
- The activation must not be delayed and must start within 2 seconds.
- At least 100% of the realization must be provided within 30s after activation occurs.

- The realization of the technical unit must increase linearly. In case of frequency deviation greater than 200mHz, the unit must provide at least 50% of realization in range 15s after activation occurs.
- Max overshoot: 20%
- The minimum of overall providing system service of the BSP portfolio: 1MW

The HSE Electricity Market Digital Twin focuses on developing a new system service, Fast Frequency Response (FFR), to enhance frequency stability in smaller island systems following a grid collapse. Additionally, this DT will also function as a data-exchange platform linking TSOs and aggregators as providers of fast frequency response. This platform aims to streamline the communication and coordination between the grid operators and aggregators, facilitating a more integrated and responsive energy system.

A.8 Digital Twins involved in the French/Dutch Pilot Site Ecosystem

A.8.1 Integrated Digital Twin for the Dutch Electricity System

The Dutch pilot partners recognize the challenges of developing separate digital twins for the transmission and distribution systems and their varying applications. Consequently, a unified approach is deemed essential for the manageability and effectiveness of the applications meant for the DT.

Recognizing the significant computational resources and memory required to accurately depict the complete Dutch electrical power system, the project will harness innovative dynamic model reduction techniques. These methods are designed to refine the models, with particular attention to enhancing details in key areas such as the integration points of large variable renewable energy sources (VRES).

In pursuit of comprehensive system models, partners will collaborate closely, starting with models of the transmission system. This will be followed by incorporating dynamic, reduced models of the rest of the system, offering a detailed and realistic depiction of the physical system. This strategy also includes deploying special equivalent models to properly represent interconnections with adjacent networks, ensuring a comprehensive and interconnected digital twin ecosystem.

The Dutch pilot is meticulously designed to showcase their pivotal role in the operational dynamics of future power systems, with a specific emphasis on assessing the impact of cyber-attacks. Equally important is its function in conducting thorough stability studies, encompassing aspects such as frequency fluctuations and voltage integrity. These investigations are critical for ensuring the resilience and reliability of power systems in the face of evolving threats and operational challenges.

The Dutch pilot demonstrator will involve the development of two distinct models: a digital twin and a synthetic data generator consisting of a steady-state model that produces time responses resembling data from actual power systems. This approach accounts for our industry partners' preference for confidentiality and limited data sharing. A report will be written highlighting the main findings on the DT usability for both stability studies (task 8.2) and cyber-attacks (tasks 5.1 and 5.2). This digital twin will collect synthetic data, that will interact with the power system digital twin modelled using the appropriate software tools.

The practical demonstrations of these capabilities will be conducted within the innovative environment of the Control Room of the Future (CRoF) located at the TU Delft campus. In the CRoF, the demonstration will also include a communication layer and tools to simulate interactions with typical SCADA systems. This setting provides a real-world context for evaluating the digital twin's effectiveness in simulating complex scenarios and devising proactive strategies to mitigate potential risks.

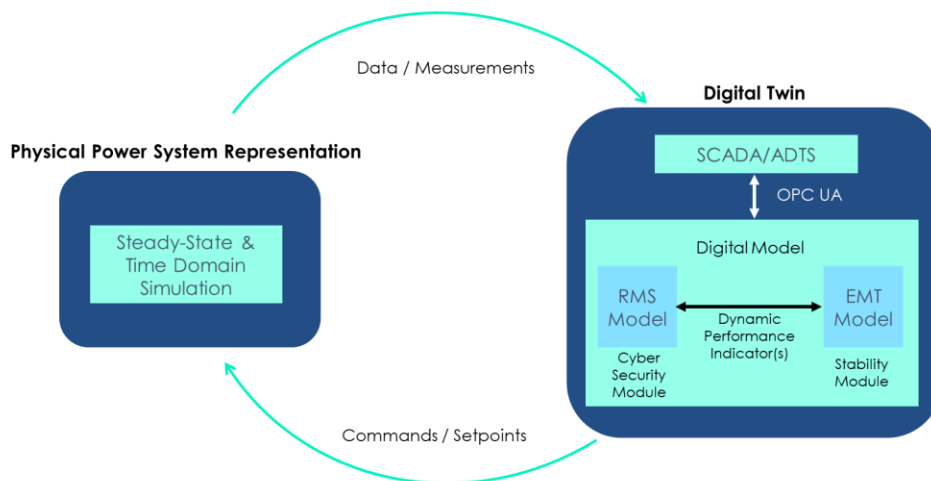


Figure A-7 - Overview of Dutch Integrated DT

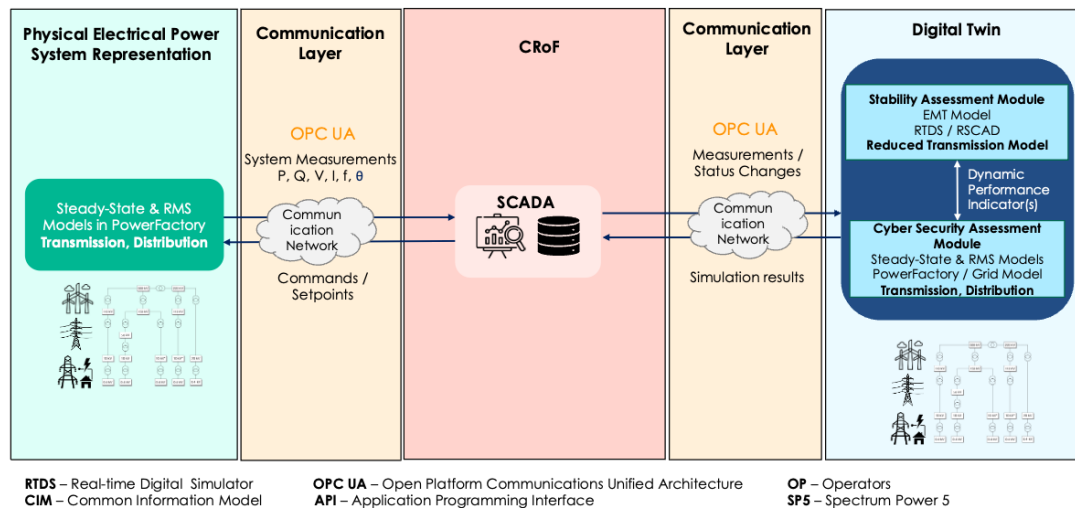


Figure A-8 - Architecture of Dutch Integrated DT

The digital twin incorporates an RMS model for cybersecurity assessment and slow dynamic simulations, and an EMT model for detailed analysis of specific instability issues and fast dynamic simulations. The RMS module consists of a complete model of the transmission network, some sections of the distribution network and equivalent models for the rest of the network. The EMT model includes only the extra-high-voltage transmission network and equivalent models for the rest of the network, since the computational requirements for the EMT real-time simulations are more demanding.

The transmission grid will constitute the backbone of the compound digital twin. TUD's research will focus on algorithms and techniques to automate the setup and initialization of parameters of power system components. TenneT, as the transmission operator, will advise in the development of the algorithms and validation of the results.

To account for the distribution grid, TU Delft's research is centred on assembling dynamic models that capture essential characteristics for accurate simulation of the system's variables. Alliander and Stedin play a critical role in reviewing and validating the assumptions of model development and its parameters and results against their proprietary distribution models and empirical data.

It is also important to mention that equivalent reduced models will be employed whenever possible. However, specific sections of the distribution network with high penetration of renewables or dynamic phenomena of interest will be modelled in greater detail. This is because, already today, the energy flows bidirectionally, and the distribution network becomes critical for dynamic studies.

Jedlix contributes by supplying data essential for modeling dynamic non-linear loads, like vehicle electric chargers, further enriching the transmission and distribution grid DT. In general, Jedlix will collaborate to build the digital twin from scratch.

This cooperative approach not only facilitates a detailed and realistic simulation of the power system's dynamics but also ensures the digital twins' adaptability to future challenges and integration capabilities with broader energy systems.

A.8.2 Integrated Digital Twin for the French Electricity System

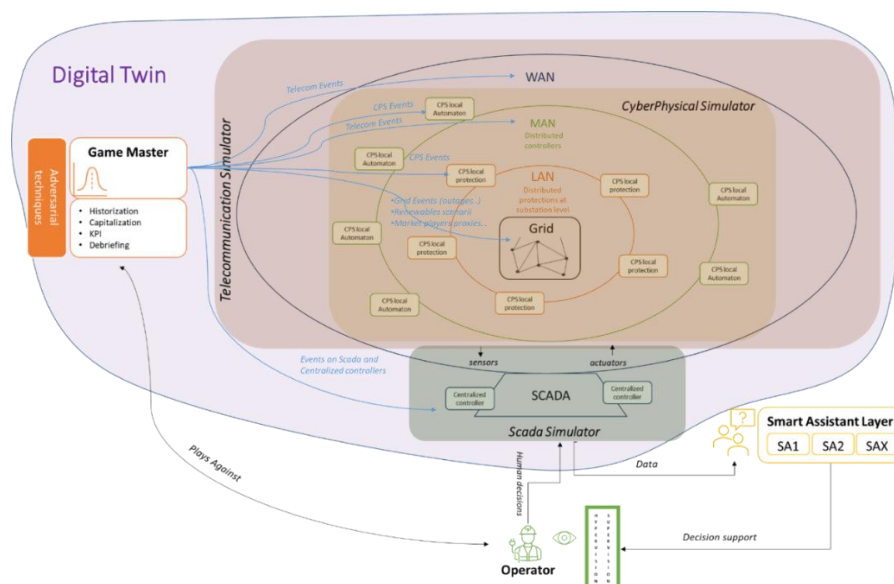


Figure A-9 - The French Digital Twin Framework

RTE is set to develop a specialized digital twin aimed at advancing the training of system operators. This digital twin will be an innovative educational tool specifically calibrated to analyze stability-critical scenarios, providing a comprehensive platform for operator readiness and response optimization. The integration of SCADA interfaces and a communication system simulator into the DT will enhance the training experience, offering a realistic and immersive environment for operators to hone their skills and adapt to dynamic grid conditions effectively.

This framework is made of:

- **Cyber-physical simulator** that can be like training simulators. They use real time data and scenario inputs and simulate the real-world physics and cyber layers (LAN and MAN layers). This simulator must give accurate results over time as the training session may last a while (hours) but should also run fast as the operator shouldn't experience any lagging or freezing effects. In other words, it must deal with all the time-domain simulation complexities (digital controllers, various automatons, etc.) while respecting short timing (less than 1 sec computation time for 1 sec simulated scenario). Co-simulation can be considered between the WAN and the cyber-physical simulator.
- **SCADA and a telecommunication network WAN** that are at the interface between the operator, the game master and the cyber-physical simulator. This SCADA displays the information (GUI) and receives the operators' orders as they would be sent/received as in the real world. Different levels of details are possible: a proxy of the real SCADA and WAN systems, a micro-WAN and an opensource SCADA simulator or replicas using the same protocols for sensors and actuators.
- **Game Master** that generates scenarios for the game (Training session) such as: wind scenarios – PV variations – classical generation outages, events affecting the data acquisition - delays, cyber-attacks, events that impact the automatons on the field, electrical grid failures (faults, overloads). Creates contrasted and "queue distribution" while realistic scenarios to stress the operators during the game. Historizes and capitalizes on the game and on decision making. It enables ex-post comparison of the various decision support modules. It gives the opportunity to debrief the sessions and enabling efficient comparison between the different modules tested.

Game master is also responsible for configuring the system modules (grid model, mapping of grid assets with their telecommunication correspondents, ...).

- **Smart assistant layer** is an independent module from the digital twin. Any proven convenient solution could be plugged into the framework.

Live demos will demonstrate the tool's ability to perform advanced training sessions, including the various features of each module.

The major components provide in Figure A-10 are SCADA, Grid Simulator, Orchestrator, Cyber Asset Simulator and Game Master.

SCADA simulator will be developed based on Powsybl framework (<https://www.powsybl.org/>) which is an open-source solution part of the LF Energy Foundation. TUD supports RTE by defining generic interfaces that could be used for SCADA.

The **Cyber physical simulator** aims to represent the real status of the system. There are two cyber physical simulators defined. They are Grid Simulator and Cyber Asset Simulator. **Grid Simulator** is the simulation tool for the power systems, and it will be based on **Dynawo**. It embeds models of grid assets; grid controls and performs steady state or long-term stability simulations. The grid simulator should be able to handle in the dynamic simulation any type of topologic, setpoint modification. This

includes assumptions that are yet to be clarified. This module will be developed by RTE in collaboration with Fraunhofer IEE.

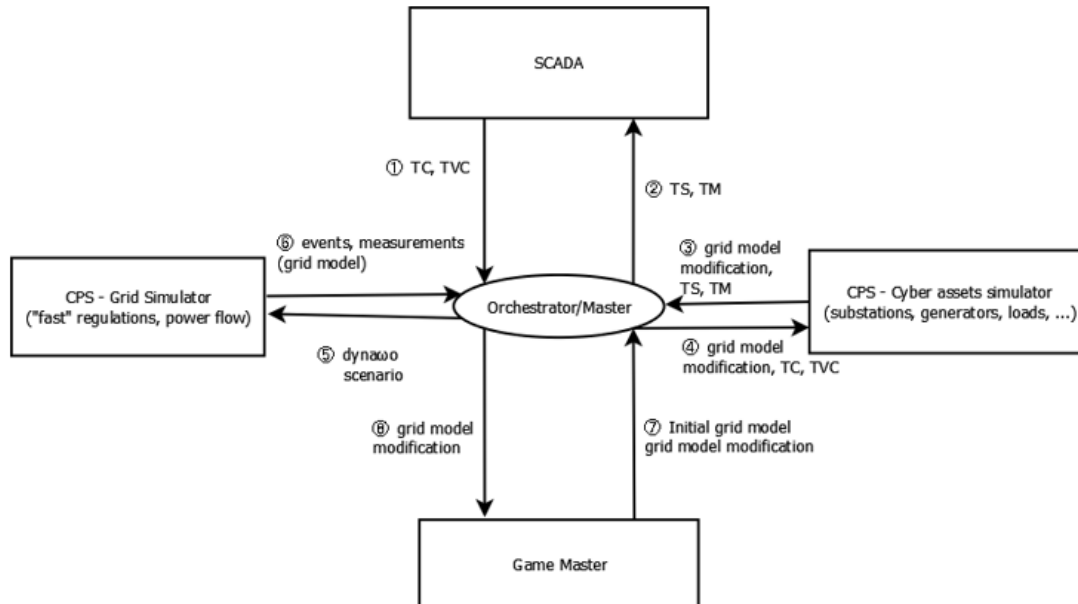


Figure A-10 - General Architecture- Power System Simulator tool

The **Cyber Asset Simulator** is a simulation tool that could simulate grid assets/control and communication asset. This includes features like bidirectional mapping of IIDM asset identifiers to their telecommunication address, transforms command (telecommand/ setpoint) coming from SCADA in dynawo scenarios sent to Grid Simulator, transforms event coming from Game Master in dynawo scenarios sent to Grid Simulator, Simulated grid and communication assets that are not simulated in Grid Simulator. This module will be developed by RTE in collaboration with TUD.

Orchestrator acts as a component handling co-simulation aspects such as receiving and buffering data from components, modifying or filtering data based on orders from the Game Master and also send data to its recipients with a given timestep or even based which is yet to be determined. This module will be developed by RTE in collaboration with TUD.

Game Master generates the scenario. The system configuration has been defined such as communicating the grid model to all the components of the system, configuring the roles and operations of each user, also setting up the automaton. For scenario generation, the process of generating and loading scenarios, as well as editing, playing and recording them has been identified but is yet to be defined in detail, which is in progress. This module will be developed by RTE in collaboration with RWTH.

Annex B The complete TwinEU IEC 62559 templates of the pilot UCs

B.1 Bulgarian Pilot Site UCs

B.1.1 Establishment of the data exchange between the Digital Twins [BG01]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg01	DT TSO, DT DSO, DT Cross-Border Market Exchange (CBME), ANN-trained DTs for forecasts	Establishment of the data exchange between the Digital Twins

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Establishment of the desired level of communication between the DTs that will be made in the scope of both tasks falling under the Bulgarian pilot. This will be one of the necessary prerequisites before the initiation of the procedures included in those tasks. As stated in the Deliverable 2.2 in which the communication flows between the DTs are defined, this will mostly be done by using special codes fit for purpose.
Objective(s)	- Validation of the DTs created in the scope of the Bulgarian pilot; - Establishment of the data exchange between those DTs; - Confirmation of sufficient quality of data exchange for foreseen tasks.
Related business case(s)	Bg02, Bg03, Bg04, Bg05, Bg06, Bg07, Bg08, Bg09, Bg10

1.4 Narrative of Use Case

Narrative of use case
Short description
This Use Case will be founded on establishing the proper connection and determining the information flow among created DTs in the Bulgarian pilot. The outcomes of this Use Case should encompass the streamlined and automatized flow of information from one DT in the pilot to another, with DT CBME and ANN-trained DTs feeding the information into the DTs TSO and DSO as inputs for the calculations.
Complete description
In this Use Case, three primary tasks can be seen, each of them having to be performed in the correct order and up to sufficient level of detail for the established objectives to be achieved. The high-level description of each of the steps that will have to be taken in the scope of this Use Case is given here: - First of all, the verification of the created DTs will need to be performed. Here, it needs to be underlined that the DTs (especially those of transmission grid, part of the distribution grid and cross-border energy exchange) will primarily be based on the models delivered by partners involved in the Bulgarian pilot, so no major issues regarding the input data quality are expected. Nevertheless, the accuracy of the modelling and implementation of the realistic characteristics of the equipment and the procedures in the Bulgarian power sector will need to be confirmed. This will be done by simulating some of the real-life situations from the operation of the system and checking the obtained values of predefined indicators to the respective values of those indicators from the practice. If there is a match (or slight differences that can be easily explained by nature of modelling), it will be stated that the DTs are of the high enough quality. - After that, the communication will need to be established among those DTs, which will mainly be done by applying the codes written in appropriate programming language. The selection of this programming language will be done based on the fact that the transmission and the partial distribution grid DT will be founded in the PSS/E network models that are already at disposal of the partners from the Bulgarian grid operators. Hence, the selected programming language will have to guarantee quick and efficient exchange of data between the DTs in the Bulgarian pilot and to be compliant with the PSS/E package (important in the communication between the remaining DTs and the DTs of the transmission grid and part of distribution grid in Bulgaria). - Finally, these data exchanges will need to be tested to see if the accuracy and reliability of information is preserved when it gets sent from one of the DTs in the pilot and received by the other one. The methodology for this kind of testing will be rather simple and will include the selection of random set of information that will be tracked as it gets exchanged among the DTs in the Bulgarian pilot. If the picked values stay the same throughout the entire testing process, it will be concluded that the data exchange mechanisms function as expected. When this level of accuracy is achieved, this Use Case will be deemed completed in its entirety.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Percentage of verified DTs [%]	This KPI will be based on verifying the accuracy of the created DTs for the needs of Bulgarian pilot. The target will depend on the ratio of verified DTs compared to the total number of DTs created.	1) DT verification
2	DT interoperability success rate [%]	This KPI will keep track of the possibility of the DTs to reliably exchange the information among one another. Target will be set in such a way to indicate the need for accurate data exchange in the pilot.	2) Communication establishment

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the DTs will be confirmed by comparing the random set of results with the same values obtained from the practical measurement.
Prerequisites	
1	Development of all the DTs foreseen for the Bulgarian pilot.
2	Availability of the measurements needed for the precision verification.

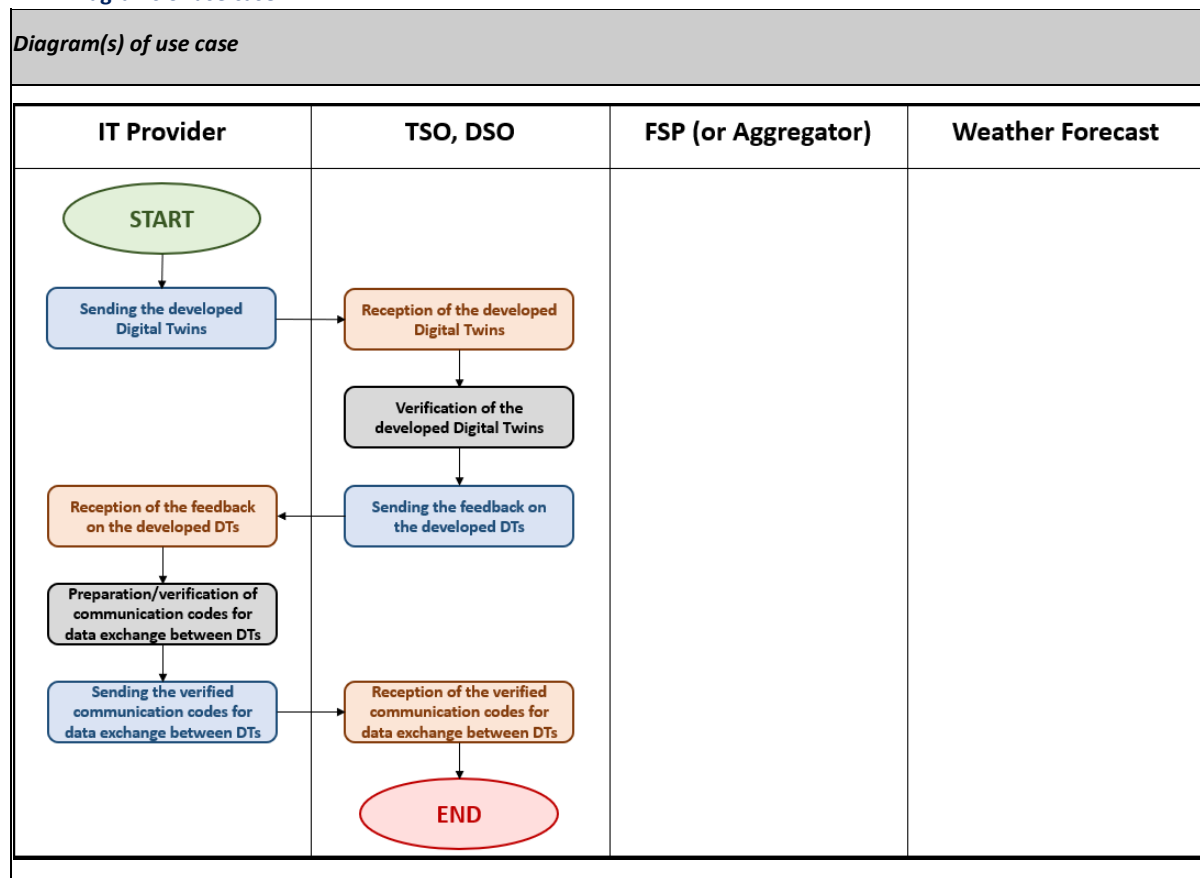
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
This Use Case is related to all of the other Use Cases developed in the Bulgarian pilot, as it represents a direct precondition for all of them.
Level of depth
High-level (connects to the TSO, DSO and cross-border exchange)
Prioritisation
High
Generic, regional or national relation
National and regional
Nature of the use case
BUC
Further keywords for classification
Digital twins, reliability verification, communication channels, data exchange

1.8 General remarks

None of interest for the Use Case.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Not active in this Use Case.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Not active in this Use Case.

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Not active in the scope of this Use Case.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Not needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Not needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Not needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg01 - S1	Data exchange establishment	Strictly speaking, this does not represent a single scenario per se. That is, however, not due to the conditions of the Use Case not fitting any scenario that could come to be in real life, but quite the contrary. Use Case actually covers the general topic referring to the communication between digital twins developed for the Bulgarian system, thus being the perfect fit for almost every possible scenario that could happen in the real-life operation of the grid. What is supposed to happen is that the IT provider, as one of the key actors in the Use Case, obtains the needed input data from the system operators, after which the creation of the codes for communication between the different digital twins will be developed. Those codes will be created and verified based on the reliability with which the data is exchanged between the models. Once done, these codes will represent a powerful tool for data exchange and creation of the intertwined model that covers different aspects of system operation. The successful implementation of this Use Case is also a precondition for the work on the remainder of the Use Cases, further highlighting the importance of it for the pilot.	- IT provider; - System operators.	Start of the work on the Bulgarian pilot, followed by the creation of the Digital Twins of the Bulgarian system.	- Existence of the DTs needed for the pilot; - Availability of measured data for the precision verification.	Communication codes will make sure that the exchange of information between the DTs goes smoothly and reliably, making it possible to move on to other UCs.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
<i>No.</i>	<i>Event</i>	<i>Description of event</i>	<i>Information exchanged (Y/N)</i>	<i>Information ID</i>	<i>Information producer</i>	<i>Information receiver</i>
1.1	SO Exchange of the developed DTs	Once the digital twins needed for the work in the Bulgarian pilot are developed, the IT providers need to verify those by delivering them to the system operators. The system operators receive the DTs, completing the first step in Use Case.	Y	I01-01	IT provider	System operators
1.2	SO Verification of the developed DTs	When the system operators receive the created DTs, they need to verify if those are compatible with the real-life data regarding the modelled systems. This will be done by the comparisons between the DTs and the measured values.	N	/	/	/
1.3	SO Conformation of DT's quality	If the verification of the DTs goes well and the system operators find them a fitting equivalent of the real-life systems, they send the quality confirmation to the IT provider, allowing them to move on to the communication code drafting.	Y	I01-02	System operators	IT provider
1.4	SO Drafting of codes for communication between DTs	Once the quality of the DTs developed beforehand gets confirmed, the IT provider moves on to the drafting of codes for the communication and data exchange between DTs. They also need to prove that the communication goes reliably by testing the developed codes on predefined number of cases.	N	/	/	/
1.5	SO Delivery of codes for communication between DTs	Finally, when the developed codes get tested and verified, they can be sent to the system operators, which concludes the process foreseen for this Use Case and allows for the remainder of the actions foreseen for the Bulgarian pilot to be initiated.	Y	I01-03	IT provider	System operators

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I01-01	Developed Digital Twins of Bulgarian power system	The digital twins of the different parts of Bulgarian power system (TSO and DSO grid, cross-border market, ANN-trained DTs) that have previously been prepared in line with the input data received from the system operators.	Communication between different participants in the Bulgarian pilot.
I01-02	Confirmation of the quality of the DTs	If the system operators confirmed through thorough testing that the quality of the developed DTs is sufficient for the needs of Bulgarian pilot, they need to confirm this by sending official confirmation to the IT provider.	Communication between different participants in the Bulgarian pilot.
I01-03	Developed codes for communication between the DTs	Communication codes made for data exchange between different DTs in the scope of the Bulgarian pilot. They will represent a key outcome of this Use Case and will get utilized in all other foreseen Use Cases of this pilot.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

- Digital Twins (DTs)**

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

- Flexibility Service Providers (FSPs)**

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.2 AI-Improved Forecast of WPP Production [BG02]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg02	DT TSO, DT DSO, DT Cross-Border Market Exchange (CBME), DT HL, ANN-trained DTs	AI-Improved Forecast of WPP Production

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this task will be the usage of the fit-for-purpose AI techniques in order to improve the quality of the forecasts of the production power of selected capacities in the grid. In this case those will be Wind Power Plants (WPPs). This is bound to provide the system operators with much clearer image of the potential FSPs in the grid, all that while allowing them to evaluate offers for services made by those FSPs.
Objective(s)	- Improved forecast of the WPP production power; - Enhanced identification of the potential FSPs in the grid; - Avoidance of congestions through better management of the FSPs; - Avoidance of voltage issues through better management of the FSPs; - Enhancement of system stability via better management of the FSPs; - Cost-efficient operation of the discussed system; - Improvement of the outage management in the system; - Application of the cutting edge techniques for TwinEU goals.
Related business case(s)	Bg01, Bg06, Bg07, Bg08, Bg09, Bg10

1.4 Narrative of Use Case

Narrative of use case	
Short description	
The use case will be based on the application of the AI-boosted algorithms and high-resolution weather forecasts for improvement of the existing methods of WPP production forecasting. This is expected to provide the system operators and the owners of those facilities with much clearer picture of the way those sources will behave and mitigate issues related to their variability and unpredictability.	
Complete description	
This Use Case will be based on the combination of the modern Artificial Neural Network (ANN)-based techniques for the goal of improving the accuracy of the common methods for WPP generation power prediction. In turn, this should give system operators better insight into the capabilities of generation units and chosen FSPs in their grid and help them in managing the system safely and cost-efficiently. In order for the goals of this Use Case to be achieved, three steps given below will need to be taken: • The data needed for the development of the ANN-trained DT needed for WPP forecast will be obtained, verified and converted into the format with which the ANN can work. This will require the joint efforts of all of the partners included in the Bulgarian pilot in order to make activities as quick and as error-proof as possible. The set of data needed for this will primarily be the list of the selected WPP capacities in the region of interest, their technical characteristics, production powers in the selected hours and the measured weather conditions corresponding to each of those WPP production powers. For the sake of anonymity, the names and other private details on the WPP capacities will be kept hidden and only numeric values will be utilized and shown. • Second step will include training of the ANN that will be used for the forecasting purposes. For that to be achieved, the set of WPP production powers in certain hours will be designated as the <i>training data</i>. Each of those production powers will be accompanied by the high-resolution weather conditions that were valid on the location of the capacity in question in that very hour. This will allow the ANN to establish the connections between the different climatic parameters and the production power of the WPP, which will be the key to improving the accuracy of the forecasts and the development of the DT that will be focused on the behaviour of WPPs. • Finally, once the ANN is finished with the establishment of the connection between the input data and the output of the WPP capacity, it will need to go through the testing phase. This will be done by designating the particular set of data (named the <i>testing data</i>). This set has to be made out of the same information as the training dataset, but for different hours in the observed time-period. Once the choice is made, the ANN will be fed the input data (weather parameters) and commanded to calculate the production power of the WPP for which those parameters are relevant. Since this is done on the set of hours from the previous several years, the measured production values will also be available for those points in time. This will allow the comparison between the given forecast and the measured data for the same facility, in the same hour. If there is a match (or the difference are less then significant), it will be stated that the forecast is done properly. Otherwise, the ANN will need to go through another training phase. These two steps will need to be repeated until the desired level of forecasting accuracy is achieved.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Improvement of WPP forecast accuracy [%]	This KPI will be based on comparing the accuracy of the forecast obtained by using ANN techniques with the reference value (either from the literature, or from one of the tools used at the moment, will be decided once the full set of data is available).	All of the listed objectives

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the forecasts will be confirmed by comparing the set of the forecasted values with the measured values for the same units in the same hours.
Prerequisites	
1	The completion and verification of all of the DTs relevant for the Bulgarian pilot (also known as part of the Use Case 01 of this pilot).
2	The availability of all of the needed input data, both for the training and for the testing of the ANN.

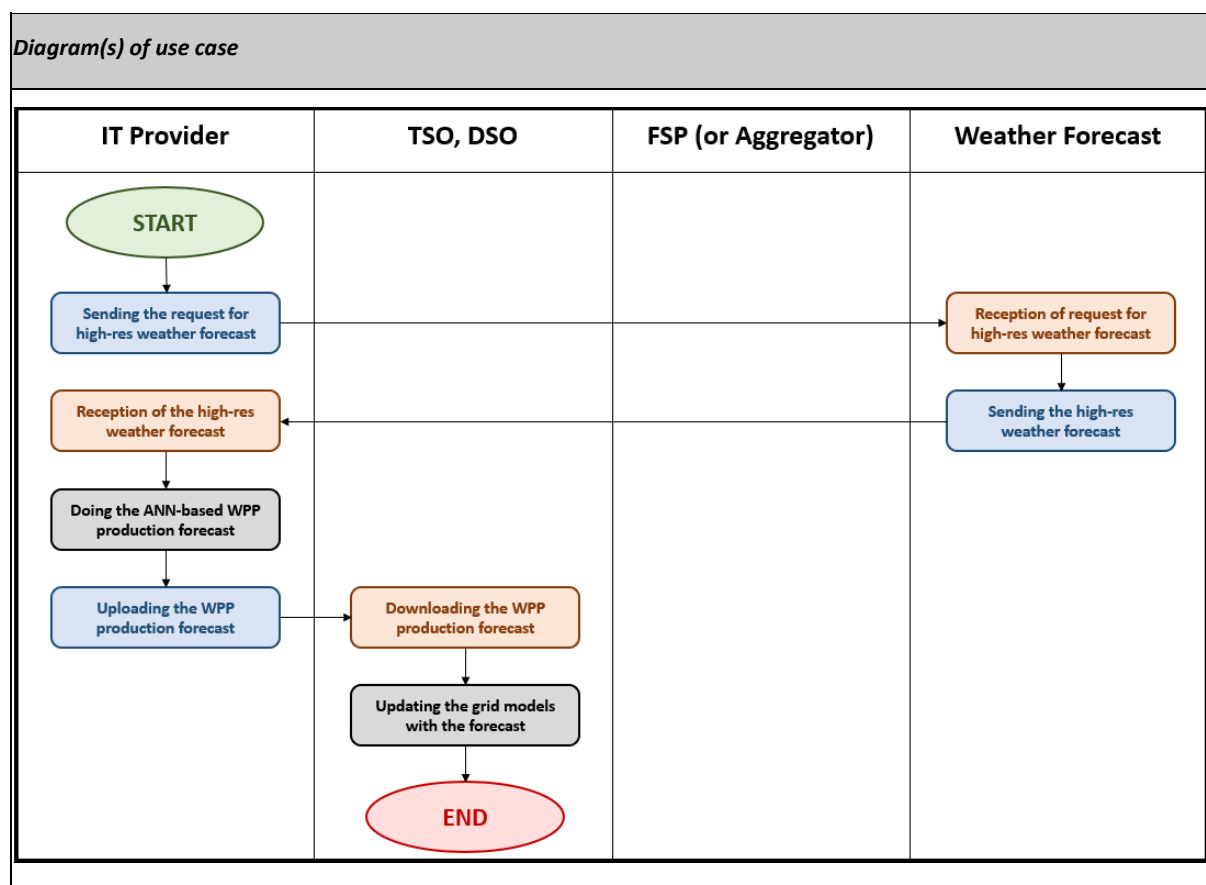
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
The Use Case 01 of this pilot is the prerequisite for this Use Case. In turn, it is the prerequisite for the Use Cases 06, 07, 08, 09, and 10).
Level of depth
High-level (connects to the TSO and DSO primarily)
Prioritisation
High
Generic, regional or national relation
National and regional
Nature of the use case
BUC
Further keywords for classification
System state forecasting, WPP forecasting, artificial neural networks, AI algorithms

1.8 General remarks

In order for this algorithm to achieve its full potential, it will need to be paired with the high-resolution weather forecasts for the locations in which the WPPs of interest are placed.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Not active in this Use Case.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Not needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Not needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg02 - S1	WPP forecast improvement	In line with what was already provided in the part of this document that referred to the scope and narrative of this Use Case, the scenario that will be considered in it will include the situation in which the system operators are willing to improve the manner in which the forecast of the WPP production power is done. For that to be achieved, SO will give the IT provider the necessary input data to develop and verify the accuracy of the ANN-based forecasting tool and the appropriate DT that will be developed here. Paired with the high-resolution numerical weather forecasts, the information given by the system operators will be vital for this task. One part of the delivered information will then be used as the training set for ANN, whereas the other part will represent the information on which the created tool can be tested until the desired level of accuracy is reached. Once the ANN-based forecasts are done, there will be a need to prove if they really represent an improvement over the commonly used forecasts. This will be done either by comparing the obtained forecasts with the values from the relevant literature or by direct comparison with the SO forecasts.	- IT provider; - System operators; - Weather forecast provider.	Request for the weather forecasts sent by IT provider	- Completion of the UC01 of this pilot; - Availability of other data needed for the forecasts.	Highly accurate forecasts of WPP production will be available to the system operators, allowing them to implement those forecasts into their own models and enhance the quality of the analyses.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
SO 2.1	Requesting the weather forecasts	In order to be able to do the forecasts of the WPP production power for the facilities of interest, IT provider needs to have the weather forecast of sufficient quality. In this step, they ask for those forecasts from the appropriate partner.	Y	I02-01	IT provider	Weather forecast provider
SO 2.2	Reception of the weather forecasts	Since the weather forecast provider should have all of the needed high-resolution numerical forecasts at their disposal, they should send those to the IT provider that will afterwards pair those with the developed ANN-based forecasting tool.	Y	I02-02	Weather forecast provider	IT provider
SO 2.3	Performing the ANN-based WPP production forecast	In this step, IT provider will need to combine the data delivered by system operators beforehand, data sent by the weather forecast provider and the created ANN-based forecasting tools in order to obtain the improved forecasts of the production power for selected WPPs and periods of time.	N	/	/	/
SO 2.4	Uploading the forecasts of WPP production power	Those forecasts are then uploaded to the predefined destination in which they will be available to the system operators. Once the upload is completed, the system operators will be able to download and save desired forecasts.	Y	I02-03	IT provider	System operators
SO 2.5	Update of the grid models based on the forecasts	In the last step of this Use Case, system operators will use the downloaded forecasts of the WPP productions to update their own grid models, thus increasing their accuracy and the reliability of the results obtained by using those models.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I02-01	Request for the weather forecasts	Official request sent by IT provider to weather forecast provider in order for the former to obtain high-resolution weather forecasts needed for WPP power predictions. Format of this request will be agreed bilaterally.	Communication between different participants in the Bulgarian pilot.
I02-02	High-resolution numerical weather forecast	Forecasts of the desired climate indicators sent by the weather forecast provider to the IT provider, covering the period of time defined in the initial request of the IT provider. Format of data delivery will be agreed later.	Communication between different participants in the Bulgarian pilot.
I02-03	Forecast of the WPP production power	Once the ANN-based tool does its work, the forecasts of the production power for the selected WPPs can be uploaded by the IT provider to agreed location and, subsequently, downloaded by the system operators.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

• Digital Twins (DTs)

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

• Flexibility Service Providers (FSPs)

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.3 AI-Improved Forecast of SPP Production [BG03]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg03	DT TSO, DT DSO, DT Cross-Border Market Exchange (CBME), DT HL, ANN-trained DTs	AI-Improved Forecast of SPP Production

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this task will be the usage of the fit-for-purpose AI techniques in order to improve the quality of the forecasts of the production power of selected capacities in the grid. In this case those will be Solar Power Plants (SPPs). This is bound to provide the system operators with much clearer image of the potential FSPs in the grid, all that while allowing them to evaluate offers for services made by those FSPs.
Objective(s)	- Improved forecast of the SPP production power; - Enhanced identification of the potential FSPs in the grid; - Avoidance of congestions through better management of the FSPs; - Avoidance of voltage issues through better management of the FSPs; - Enhancement of system stability via better management of the FSPs; - Cost-efficient operation of the discussed system; - Improvement of the outage management in the system; - Application of the cutting edge techniques for TwinEU goals.
Related business case(s)	Bg01, Bg06, Bg07, Bg08, Bg09, Bg10

1.4 Narrative of Use Case

Narrative of use case	
Short description	
The use case will be based on the application of the AI-boosted algorithms and high-resolution weather forecasts for improvement of the existing methods of SPP production forecasting. This is expected to provide the system operators and the owners of those facilities with much clearer picture of way those sources will behave and mitigate issues related to their variability and unpredictability.	
Complete description	
This Use Case will be based on the combination of the modern ANN-based techniques for the sole goal of improving the accuracy of the commonly used methods for the SPP generation power prediction. In turn, this should give the system operators much better insight into the capabilities of generation units and chosen FSPs in their grid and help them in managing the system safely and cost-efficiently. In order for the goals of this Use Case to be achieved, the three steps will need to be taken, as explained below: • The data needed for the development of the ANN-trained DT needed for SPP forecast will have to be obtained, verified and converted into the format with which the ANN can work. This will require the joint efforts of all of the partners included in the Bulgarian pilot in order to make activities as quick and as error-proof as possible. The necessary data set will primarily include a list of selected SPP capacities within the region of interest, their technical characteristics, production power at chosen hours, and the corresponding weather conditions measured for each SPP output. For the sake of anonymity, the names and other private details on the SPP capacities will be kept hidden and only numeric values will be utilized and shown. • Second step will include training of the ANN that will be used for the forecasting purposes. For that to be achieved, the set of SPP production powers in certain hours will be designated as the <i>training data</i>. Each of those production powers will be accompanied by the high-resolution weather conditions that were valid on the location of the capacity in question in that very hour. This will enable ANN to identify relationships between the various climatic parameters and the production power of the SPP, which is essential for enhancing the forecast accuracy of this tool compared to current methods, as well as the development of the ANN-trained DT for SPPs. • Finally, once the ANN is finished with the establishment of the connection between the input data and the output of the SPP capacity, it will need to go through the testing phase. This will be done by designating the particular set of data (named the <i>testing data</i>). This set has to be made out of the same information as the training dataset, but for different hours in the observed time-period. Once the choice is made, the ANN will be fed the input data (weather parameters) and commanded to calculate the production power of the SPP for which those parameters are relevant. Since this is done on the set of hours from the previous several years, the measured production values will also be available for those points in time. This will allow the comparison between the given forecast and the measured data for the same facility, in the same hour. If there is a match (or the difference are less then significant), it will be stated that the forecast is done properly. Otherwise, the ANN will need to go through another training phase. These two steps will need to be repeated until the desired level of forecasting accuracy is achieved.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Improvement of SPP forecast accuracy [%]	This KPI will be based on comparing the accuracy of the forecast obtained by using ANN techniques with the reference value (either from the literature, or from one of the tools used at the moment, will be decided once the full set of data is available).	All of the listed objectives

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the forecasts will be confirmed by comparing the set of the forecasted values with the measured values for the same units in the same hours. This will provide a strong basis on top of which the additional impact of the developed algorithms can be estimated.
<i>Prerequisites</i>	
1	The completion and verification of all of the DTs relevant for the Bulgarian pilot (also known as part of the Use Case 01 of this pilot).
2	The availability of all of the needed input data, both for the training and for the testing of the ANN.

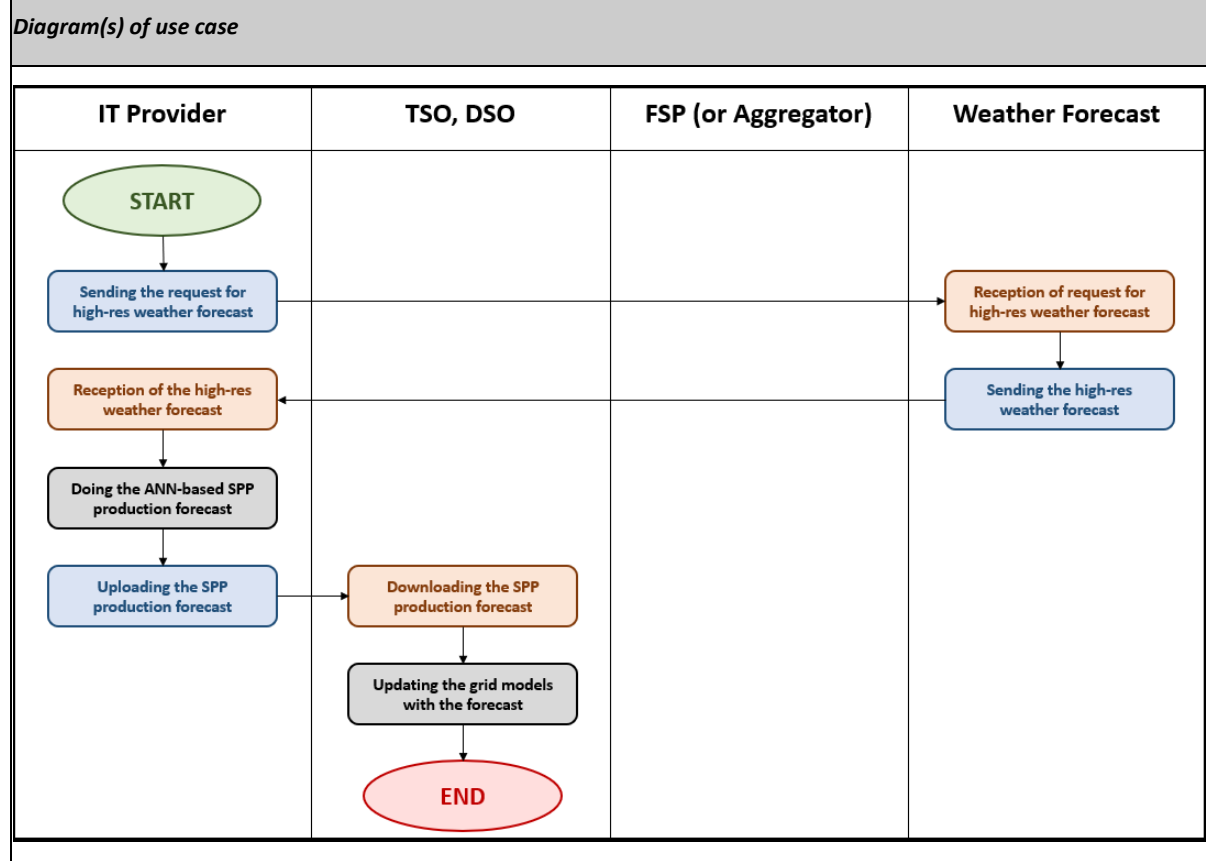
1.7 Further information to the use case for classification/mapping

<i>Classification information</i>
<i>Relation to other use cases</i>
The Use Case 01 of this pilot is the prerequisite for this Use Case. In turn, it is the prerequisite for the Use Cases 06, 07, 08, 09, and 10).
<i>Level of depth</i>
High-level (connects to the TSO and DSO primarily)
<i>Prioritisation</i>
High
<i>Generic, regional or national relation</i>
National and regional
<i>Nature of the use case</i>
BUC
<i>Further keywords for classification</i>
System state forecasting, SPP forecasting, artificial neural networks, AI algorithms

1.8 General remarks

In order for this algorithm to achieve its full potential, it will need to be paired with the high-resolution weather forecasts for the locations in which the SPPs of interest are placed.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be considered that FSPs are either WPPs, SPPs or controllable demand.	Not active in this Use Case.

Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Not needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Not needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg03 - S1	SPP forecast improvement	In line with what was already provided in the part of this document that referred to the scope and narrative of this Use Case, the scenario that will be considered in it will include the situation in which the system operators are willing to improve the manner in which the forecast of the SPP production power is done. For that to be achieved, SO will give the IT provider the necessary input data to develop and verify the accuracy of the ANN-based forecasting tool and the appropriate DT that will be developed here. Paired with the high-resolution numerical weather forecasts, the information given by the system operators will be vital for this task. One part of the delivered information will then be used as the training set for ANN, whereas the other part will represent the information on which the created tool can be tested until the desired level of accuracy is reached. Once the ANN-based forecasts are done, there will be a need to prove if they really represent an improvement over the commonly used forecasts. This will be done either by comparing the obtained forecasts with the values from the relevant literature or by direct comparison with the SO forecasts.	- IT provider; - System operators; - Weather forecast provider.	Request for the weather forecasts sent by IT provider	- Completion of the UC01 of this pilot; - Availability of other data needed for the forecasts.	Highly accurate forecasts of SPP production will be available to the system operators, allowing them to implement those forecasts into their own models and enhance the quality of the analyses.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
S03.1	Requesting the weather forecasts	In order to be able to do the forecasts of the SPP production power for the facilities of interest, IT provider needs to have the weather forecast of sufficient quality. In this step, they ask for those forecasts from the appropriate partner.	Y	I03-01	IT provider	Weather forecast provider
S03.2	Reception of the weather forecasts	Since the weather forecast provider should have all of the needed high-resolution numerical forecasts at their disposal, they should send those to the IT provider that will afterwards pair those with the developed ANN-based forecasting tool.	Y	I03-02	Weather forecast provider	IT provider
S03.3	Performing the ANN-based SPP production forecast	In this step, IT provider will need to combine the data delivered by system operators beforehand, data sent by the weather forecast provider and the created ANN-based forecasting tools in order to obtain the improved forecasts of the production power for selected SPPs and periods of time.	N	/	/	/
S03.4	Uploading the forecasts of SPP production power	Those forecasts are then uploaded to the predefined destination in which they will be available to the system operators. Once the upload is completed, the system operators will be able to download and save desired forecasts.	Y	I03-03	IT provider	System operators
S03.5	Update of the grid models based on the forecasts	In the last step of this Use Case, system operators will use the downloaded forecasts of the SPP productions to update their own grid models, thus increasing their accuracy and the reliability of the results obtained by using those models.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I03-01	Request for the weather forecasts	Official request sent by IT provider to weather forecast provider in order for the former to obtain high-resolution weather forecasts needed for SPP power predictions. Format of this request will be agreed bilaterally.	Communication between different participants in the Bulgarian pilot.
I03-02	High-resolution numerical weather forecast	Forecasts of the desired climate indicators sent by the weather forecast provider to the IT provider, covering the period of time defined in the initial request of the IT provider. Format of data delivery will be agreed later.	Communication between different participants in the Bulgarian pilot.
I03-03	Forecast of the SPP production power	Once the ANN-based tool does its work, the forecasts of the production power for the selected SPPs can be uploaded by the IT provider to agreed location and, subsequently, downloaded by the system operators.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

- **Digital Twins (DTs)**

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

- **Flexibility Service Providers (FSPs)**

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.4 AI-Improved Forecast of OHL Ampacity [BG04]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg04	DT TSO, DT DSO, DT Cross-Border Market Exchange (CBME), DT HL, ANN-trained DTs	AI-Improved Forecast of OHL Ampacity

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	This Use Case will be focused on the benefits of the accurate determination of line rating based on the weather conditions that are valid in the locations of interest. It will be revolving around two main points – the ways in which the ampacity forecasts can aid in usage of power system infrastructure and development of the AI-boosted tool that will be able to calculate those ampacities in a swift and reliable manner.
Objective(s)	- Improved forecast of the line rating by using AI; - Clearer gradation of the seriousness of the issues in the system; - Enhanced maintenance planning of the grid; - Improved overview of the system state and capabilities; - Cost-efficient operation of the discussed system; - Better investment planning due to higher utilization of existing elements; - Application of the cutting-edge techniques for TwinEU goals.
Related business case(s)	Bg01, Bg05, Bg06, Bg07, Bg08, Bg09, Bg10

1.4 Narrative of Use Case

Narrative of use case

Short description	
The Use Case will be based on using AI-boosted algorithms and high-resolution weather forecasts for improvement of the Overhead Lines (OHL) ampacity forecasts. In case seasonal ratings are used, lines can be underutilized due to the security precautions. This Use Case will be focused on determining the benefits of the accurate forecasts of the line ampacities in order to enhance the total system flexibility.	
Complete description	
Similar to the majority of the Use Cases suggested for the Bulgarian pilot and the tasks included in it, the approach that will be applied for this Use Cases can also be divided into three major steps. Those are listed below, along with the brief descriptions of what will be done in which of the steps: - The first step will be the definition of the needed input data and the collection of those. This is primarily focused on the determination of the lines for which it makes sense to apply methods for ampacity forecasts. The criteria that will be used for this, aside from the obvious interviews of the system operators and their suggestions given in that step, encompass (but are not limited to) percentual loading of the lines and extraction of the lines passing through the windy areas. For the former, it should be mentioned that it is only useful to consider this kind of approach for the lines that are highly loaded when their seasonal rating is applied. In case this rating remains seasonal, there would be a need to invest either in refurbishment of the existing infrastructure or in the construction of the new one. This may be avoided if the ampacity forecasts are applied. For the windy areas, they would need to be targeted since the wind is one of the main cooling manners for the overhead lines and seasonal line ratings often prove to be too conservative in the areas in which wind speeds are high (corresponding to the potential for WPP construction). - After the input data (including the set of lines and the set of climatic parameters of high enough resolution in the areas through which the routes of those lines go) is collected, next step would be creation of the AI-boosted algorithm that would be able to calculate the ratings of the chosen lines based on the defined set of weather-related indicators. For this, the existing methods for the similar purpose would be evaluated and enhanced if and where needed for the achievement of the maximal benefits. The created technique will be tested thoroughly both for the reliability (by conducting multiple calculations with the same sets of input data and checking if the results are the same) and for common sense (by observing the results and comparing the obtained rating growth with the benchmark values from literature). If the method passes both of these tests, it can be used for the next stage of analyses that will be performed in the scope of this Use Case and for the foreseen development of the ANN-trained DT for the OHL ampacity forecast. - In the end, the developed method will be used to obtain the forecasted line ratings for the picked set of lines for each hour in the predefined observed period. Those will then be compared with the seasonal ratings of the same lines, with the percentual growth being the parameter that will be primarily observed. Moreover, the load flow calculations can be conducted for some hours that are selected as characteristic (high loading of the lines and major difference between the seasonal and the forecasted ampacities). The point of these calculations would be to show just how much the percentual loading of the lines drops if their actual rating is used instead of the seasonal one, potentially reducing the needs for investments in the observed part of the grid.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Increase of overhead line rating [%]	This KPI will be calculated by comparing line ratings calculated by using the AI-boosted method and the climate parameters to seasonal limits. The indicator will provide a clear view of the effects obtained by applying the suggested innovative technique.	All of the listed objectives
2	Better utilization of the existing lines [%]	KPI will be calculated by comparing the loading (percentual) of same lines, under same conditions, for the situations in which seasonal and forecasted ratings are used. This will be the major	All of the listed objectives

		indicator of potential that these forecasts hold for enhanced utilization of the existing infrastructure in the grid.	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of forecasted line rating calculations will depend on the reliability of the input data, such as the relevant climate parameters (wind speed, temperature, etc.).
Prerequisites	
1	The completion and verification of all of the DTs relevant for the Bulgarian pilot (also known as part of the Use Case 01 of this pilot).
2	The availability of all of the needed input data, both from climatic and technical point of view.

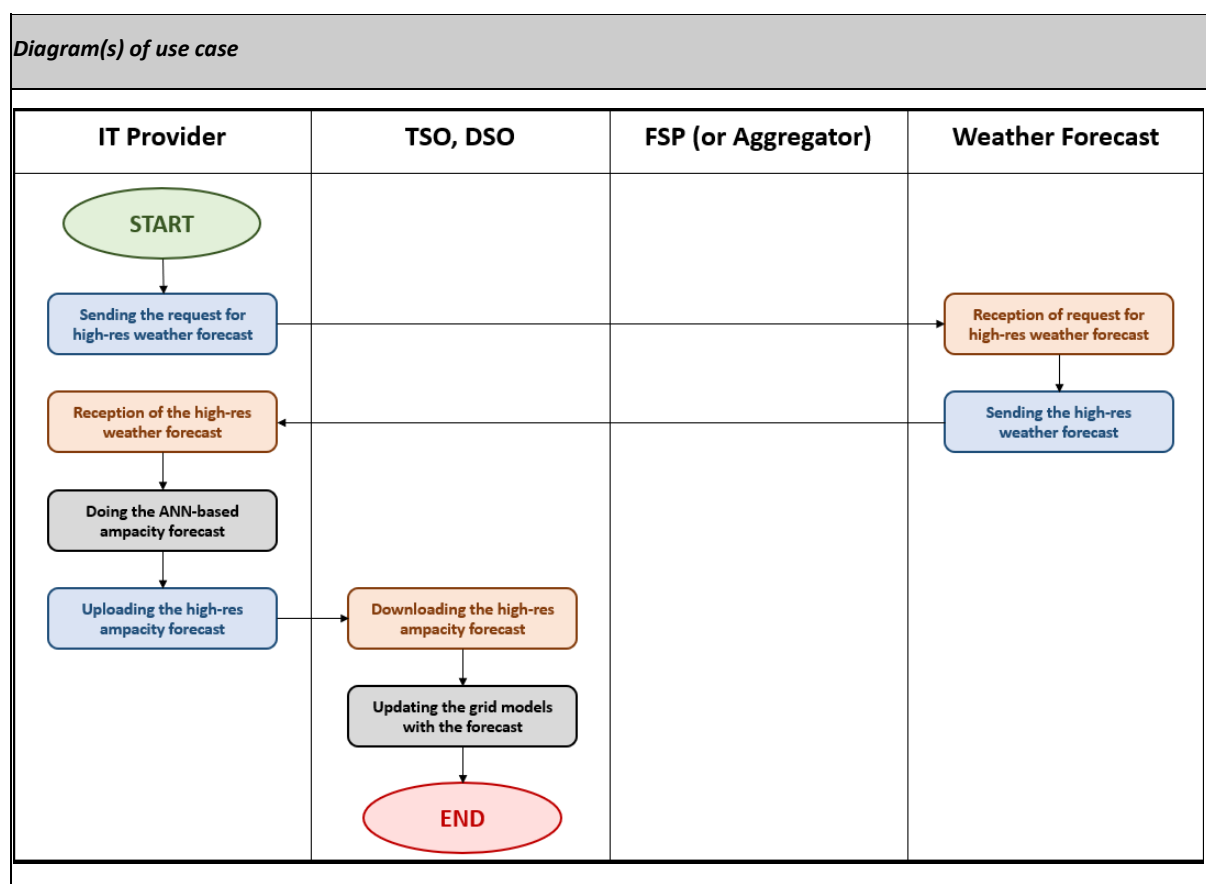
1.7 Further information to the use case for classification/mapping

Classification information	
Relation to other use cases	
The Use Case 01 of this pilot is the prerequisite for this Use Case. In turn, it is the prerequisite for the Use Cases 05, 06, 07, 08, 09, and 10).	
Level of depth	
High-level (connects to the TSO and DSO primarily)	
Prioritisation	
High	
Generic, regional or national relation	
National and regional	
Nature of the use case	
BUC	
Further keywords for classification	
AI-based tools, overhead lines, ampacity forecast, investment optimization	

1.8 General remarks

In order for this algorithm to achieve its full potential, it will need to be paired with the high-resolution weather measurements and forecasts along the routes of the overhead lines of interest.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be considered that FSPs are either WPPs, SPPs or controllable demand.	Not active in this Use Case.
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Not needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg04 - S1	Ampacity forecast improvement	The scenario that will be considered in the scope of this Use Case will be based on the potential decision of the system operators to examine moving on from the seasonal line ratings and on to the ampacity forecasts. The necessary forecasts will be done by taking into consideration the climate parameters along the routes of the selected lines and the impact that those parameters may have on the cooling and heating of those lines. For the ampacity forecast to be calculated, SO will give the IT provider the necessary input data, especially regarding the lines of interest for trying out realistic ampacity calculation principle. This set of data will, along with the high-resolution numerical weather forecasts, be a base upon which the forecasts of ampacities can be made by the ANN-founded tool. These will then be taken over by the system operators and compared with the seasonal line ratings valid for the same lines and for the same periods. After the download, system operators will implement forecasts in the simulation model in which the percentual differences in line loadings between the two approaches can be calculated rather easily.	- IT provider; - System operators; - Weather forecast provider.	Request for the weather forecasts sent by IT provider	- Completion of the UC01 of this pilot; - Availability of other data needed for the forecasts.	Highly accurate ampacity forecasts will be available to the system operators, allowing them to implement those forecasts into their own models and enhance the quality of the analyses.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
SO 4.1	Requesting the weather forecasts	In order to be able to do the forecasts of ampacities for the lines that were selected, IT provider needs to have the weather forecast of sufficient quality. In this step, they ask for those forecasts from the appropriate partner.	Y	I04-01	IT provider	Weather forecast provider
SO 4.2	Reception of the weather forecasts	Since the weather forecast provider should have all of the needed high-resolution numerical forecasts at their disposal, they should send those to the IT provider that will afterwards pair those with the developed ANN-trained DT for OHLs.	Y	I04-02	Weather forecast provider	IT provider
SO 4.3	Performing the ANN-based ampacity forecast	In this step, IT provider will need to combine the data delivered by system operators beforehand, data sent by the weather forecast provider and the created ANN-trained DT for forecast in order to obtain the improved forecasts of the ampacities for the selected overhead lines and periods of time.	N	/	/	/
SO 4.4	Uploading the ampacity forecasts	Those forecasts are then uploaded to the predefined destination in which they will be available to the system operators. Once the upload is completed, the system operators will be able to download and save desired forecasts.	Y	I04-03	IT provider	System operators
SO 4.5	Update of the grid models based on the forecasts	In the last step of this Use Case, system operators will use the downloaded ampacity forecasts to update their own grid models, increasing their accuracy and reliability in the process. This can also be followed by several tests in which the benefits of ampacity forecasts may be pointed out.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I04-01	Request for the weather forecasts	Official request sent by IT provider to weather forecast provider in order for the former to obtain high-resolution weather forecasts needed for ampacity predictions. Format of this request will be agreed bilaterally.	Communication between different participants in the Bulgarian pilot.
I04-02	High-resolution numerical weather forecast	Forecasts of the desired climate indicators sent by the weather forecast provider to the IT provider, covering the period of time defined in the initial request of the IT provider. Format of data delivery will be agreed later.	Communication between different participants in the Bulgarian pilot.
I04-03	Ampacity forecasts for the selected lines	Once the ANN-trained DT does its work, the forecasts of the ampacities for the selected overhead lines can be uploaded by the IT provider to agreed location and, subsequently, downloaded by the system operators.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

• Digital Twins (DTs)

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

• Flexibility Service Providers (FSPs)

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.5 Increase of power flow on cross border transmission lines [BG05]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg05	DT TSO, DT HL, DT Cross-Border Market Exchange (CBME), ANN-trained DTs for forecasts	Increase of power flow on cross border transmission lines

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	This Use Case will be rather similar to the Use Case Bg04, focusing, instead of the general approach, on the possibility of applying the created AI-based algorithm on the cross-border lines in order to enhance energy and flexibility exchange between the neighbouring systems for the sake of system stability and security.
Objective(s)	- Improved forecast of the line ratings by using AI; - Enhanced energy exchange between the neighbouring systems; - Enhanced flexibility exchange between the neighbouring systems; - Improvement of the level of system stability and security; - Cost-efficient operation of the system; - Better investment planning due to higher utilization of existing elements; - Application of the cutting edge techniques for TwinEU goals.
Related business case(s)	Bg01, Bg04

1.4 Narrative of Use Case

Narrative of use case

Short description	
This Use Case will be based on the usage of AI-forecasted ampacity of the cross-border lines in order to improve their ability to respond to the ever increasing needs for the energy and flexibility exchange among the neighbouring systems. Better utilization of these lines could aid with the security of supply and system stability issues without the need to invest time and money in building new infrastructure.	
Complete description	
Quite similar to the procedure foreseen for the Bg04 Use Case, three individual steps will have to be taken here in order for the developers to ensure that the goals set by this Use Case are achieved as expected. Those steps, along with the short descriptions can be found below: • Once again, the first step will be the definition of the input data and its collection. This time, it will primarily be focused on the determination of the lines that either cross the border of the observed grid or are located close enough to the borders to have an impact on the cross-border exchanges of energy and flexibility. Along with the technical characteristics of those lines, the data collection will also include the collection of relevant climate parameters for the routes of those lines (especially targeting parameters such as the wind speed and the temperature, set to impact the possibilities of cooling the conductors down). Once the weather and technical data is collected, the set of lines may or may not be shortened (this can happen if it's concluded that the temperature and the wind speeds do not allow optimal usage of ampacity forecasts). • Next, the ANN-trained DT for OHL ampacity forecasts that had been developed and verified in the scope of the Use Case Bg04 will be utilized in order to do ampacity forecasts of the lines that were included in the set relevant for observation. This will be done on an hourly basis, with the time-frame determined based on the availability of the sufficient amount and quality of the input data. The hours selected could also include the hours in which the energy exchange on the system border was rather high or limited by the rating of the cross-border line. The quality issues regarding the data are mostly related to the chance of obtaining the climate parameters with the high level of resolution and precision that would then be converted into line ratings. • Finally, the obtained values of the hourly line ratings will be compared to the seasonal ratings of the same lines, with the percentual growth being the parameter that will be primarily observed here. Moreover, the load flow calculations can be conducted for some hours that are selected as characteristic (high loading of the cross-border lines and major difference between seasonal and forecasted ampacities). The point of these calculations will be to show just how much the percentual loading of the lines drops if their actual rating is used instead of common seasonal one, thus potentially reducing the needs for new investments in the observed part of the grid.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Increase of cross-border line rating [%]	This KPI will be calculated by comparing line ratings calculated by using the AI-boosted method and the climate parameters to seasonal limits. It will focus on the selected set of cross-border lines.	All of the listed objectives
2	Better utilization of the cross-border lines [%]	This KPI will be calculated by comparing the loading (percentual) of same lines, under same conditions, for the situations in which seasonal and forecasted ratings are used. This will be the major indicator of potential that ampacity forecasts hold for the better utilization of the existing infrastructure in the grid. It will focus on the selected set of cross-border lines.	All of the listed objectives

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the calculated ampacity forecasts will depend on the reliability of the input data.
Prerequisites	
1	The completion and verification of all of the DTs relevant for the Bulgarian pilot (also known as part of the Use Case 01 of this pilot).
2	The completion of the technical part of the Use Case 04 of the Bulgarian pilot (to make sure that the AI-based algorithms for ampacity forecasts are available).
3	The availability of all of the needed input data, both from climatic and technical point of view.

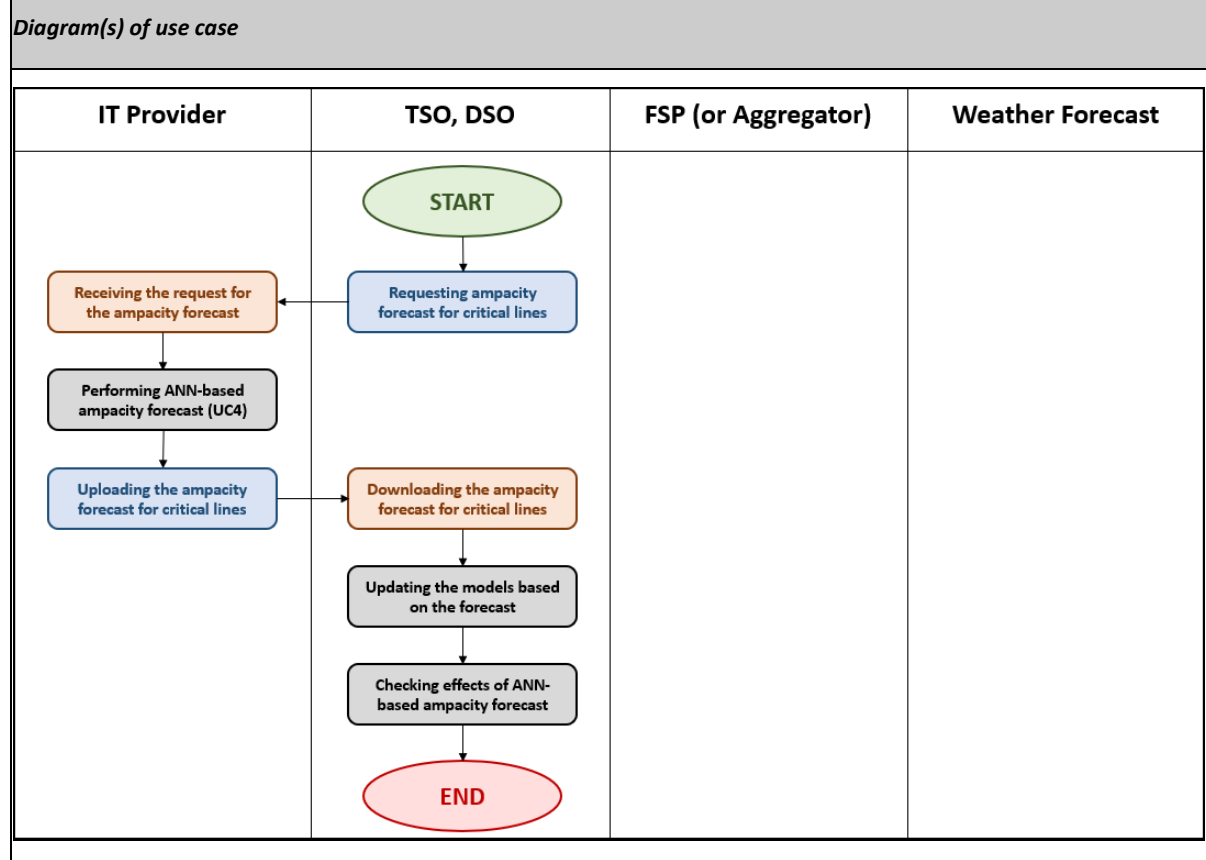
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Both the Use Case 01 and Use Case 04 of the Bulgarian pilot are the preconditions for the activities foreseen for this Use Case.
Level of depth
High-level (connects to the TSO and cross-border energy exchange primarily)
Prioritisation
High
Generic, regional or national relation
National and regional
Nature of the use case
BUC
Further keywords for classification
AI-based tools, overhead lines, ampacity forecasts, investment optimization, cross-border energy exchange

1.8 General remarks

In order for this algorithm to achieve its full potential, it will need to be paired with the high-resolution weather measurements and forecasts along the routes of the overhead lines of interest.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be considered that FSPs are either WPPs, SPPs or controllable demand.	Not active in this Use Case.
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Implicitly active (through the activities that are already included in Use Case 4).

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Not active in the scope of this Use Case.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Not needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg05 - S1	Cross-border energy exchange enhancement	The scenario that is relevant for this process represents a logical continuation of the scenario that was taken into account for Use Case 04 of the Bulgarian pilot. As a reminder, that is the Use Case that deals with the improved ampacity forecasts of the lines in the grid based on the climatic parameters and their distribution along the selected lines. The scenario created for Use Case 05 will further narrow down the targets of those forecasts to the list of critical elements included in the cross-border exchange. Once this list is created, the IT provider will apply the same ANN-trained DT for the ampacity forecast from Use Case 04 to determine the actual capacities of the designated lines in the defined time period. When these forecasts get downloaded by the system operators, they will be able to update their simulation models based on the new ampacities. In addition to this, they will also be able to run calculations on those models and determine the benefits (in this area) that can be achieved in case the realistic ampacity forecasts become the standard principle instead of the commonly used seasonal transfer limits of the lines.	- IT provider; - System operators; - Weather forecast provider (implicitly).	Submission of the critical line list from the operator side	- Completion of the UC01 and UC04 of pilot; - Availability of other data needed for the forecasts.	System operators will be supplied with the ampacity forecasts of lines important for the cross-border exchange, which will give them easier insight into the actual energy exchange options, affecting the grid resilience and the system security in a positive manner.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
<i>No.</i>	<i>Event</i>	<i>Description of event</i>	<i>Information exchanged (Y/N)</i>	<i>Information ID</i>	<i>Information producer</i>	<i>Information receiver</i>
5.1	S0 Request for ampacity forecast of the critical lines	In this step, transmission system operator designates the lines they find critical from cross-border energy exchange point of view. When this is done, they deliver the prepared list to the IT provider, asking for improved ampacity values.	Y	I05-01	System operators	IT provider
5.2	S0 Performing ANN-based ampacity forecast	Here, IT provider uses the ANN-trained DT for the ampacity forecast in order to deliver the required values. As Use Case 04 needs to be completed before initiation of Use Case 05, it is considered that the tools (and possibly even the results) are already at disposal of the IT provider.	N	/	/	/
5.3	S0 Uploading the ampacity forecast	After extracting the values necessary for the TSO, IT provider uploads them to the designated location. Following this, the TSO can download them and, once that is done, save them in the predefined location in the internal storage.	Y	I05-02	System operators	IT provider
5.4	S0 Updating the models based on the forecast	When the values of ampacity forecasts for the critical lines get downloaded, TSO can upload the simulation models (both grid and market) based on them. In the market modelling tool, these values may affect the available transfer capacities between the neighbouring systems.	N	/	/	/
5.5	S0 Evaluation of the effects of the new forecast method	Finally, once the models are updated, TSO can conduct a series of tests in order to evaluate the effects of applying the new methodology for the ampacity forecast. The tests themselves will be determined by the TSO, based on experience.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I05-01	Request for ampacity forecasts of critical lines	First information exchanged here is the request for the ampacity forecasts, sent by the TSO to the IT provider. It also needs to be accompanied by the list of relevant lines for which ampacity forecasting principle shall be used.	Communication between different participants in the Bulgarian pilot.
I05-02	Ampacity forecasts for the critical lines	Once the ANN-trained DT does its work, the forecasts of the ampacities for the selected overhead lines can be uploaded by the IT provider to agreed location and, subsequently, downloaded by the system operators.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

• Digital Twins (DTs)

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

• Flexibility Service Providers (FSPs)

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

• Artificial Neural Networks (ANNs)

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.6 Determination of optimal locations for RES connection [BG06]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg06	DT TSO, DT DSO, DT HL, DT Cross-Border Market Exchange (CBME), ANN-trained DTs	Determination of optimal locations for RES connection

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	This Use Case will be focusing on the determination of the optimal connection points for the RES capacities (either WPPs or SPPs) in the region of interest. An attempt will be made to take into consideration both the interest of the investors in the RES and the interest of the system operators (meaning that the reliable operation of the system cannot be put at risk due to the work of RES at any point).
Objective(s)	• Detection of the optimal connection points for the RES connection; • Achievement of the higher utilization factor of RES; • Reduction of the possibility of RES curtailments; • Better utilization of the potentials for RES construction; • Maintenance of the system security and reliability; • Usage of the optimization techniques for the connection point selection.
Related business case(s)	Bg01, Bg02, Bg03, Bg04

1.4 Narrative of Use Case

Narrative of use case

Short description	
In order to aid both the system operators and the potential investors in the RES-driven projects, this Use Case will focus on the evaluation of different potential RES connection points in the grid, using the optimization techniques to ensure reliability. This should lead both to the improved yearly capacity factor of those RES and also to the avoidance of the issues in the system as much as it is possible.	
Complete description	
The process needed for the completion of the activities foreseen for this Use Case can be divided into three sequential stages. Each of those is briefly described in the continuation: - In the beginning of the procedure, the geographic regions of interest for the analyses will be selected. This will be done in the tight cooperation between the system operators involved in the pilot and the remainder of the partners. The selection will consider several factors, including investors' interest in developing new RES facilities in these regions and the likelihood of issues arising if these capacities are connected sub-optimally. With that out of the way, the input data for this region will be gathered, focusing on the system technical characteristics, information on the planned capacities (anonymized for confidentiality), and weather parameters that could impact capacity performance. - Next, the realistic yearly-time-series of the production power of the capacities foreseen for the region will be generated based on the weather parameters and the ANN-trained DTs developed in scope of BUCs Bg02, Bg03 and Bg04. For the wind power plants, the wind speeds on the hourly basis will be combined with the typical production diagrams for this to be done. For the solar power plants, hourly values of temperature and irradiance will be taken into account when generating yearly time-series of production power. When this is completed, the characteristic hours (either with the high demand in the system or the extreme work of RES in the region of interest) will be picked. For those hours, the capacities of the lines in the region will also be calculated based on the available climatic parameters and routes of those lines. - The third and final step will be based on utilizing one or more optimization techniques (such as genetic algorithm) and successive optimal load flow calculations. These will be done in order to determine to which point in the observed part of grid should each of the considered capacities be connected in order to boost its production as much as possible. The optimal power flow will allow for that to happen without causing any issues in the grid, such as the overloading of lines or appearance of the voltages out of the predefined permitted range. This will be done on the selected characteristic operational regimes, with the power of RES generation in the region of interest getting utilized as the main criterion for optimization.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Number of optimized connections [#]	This KPI will be based on the number of RES in the region of interest for which the optimization of the connection points will be performed. It will depend both on the interest of the investors in this area and on the capabilities of the created optimization tool.	All of the listed objectives

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.

2	The accuracy of the conducted calculations will depend on the reliability of the input data.
Prerequisites	
1	The completion and verification of the Use Cases listed as prerequisites for this Use Case, but in particular the Use Cases 01 and 04 of the Bulgarian pilot.
2	The availability of all of the needed input data, both from climatic and technical point of view.

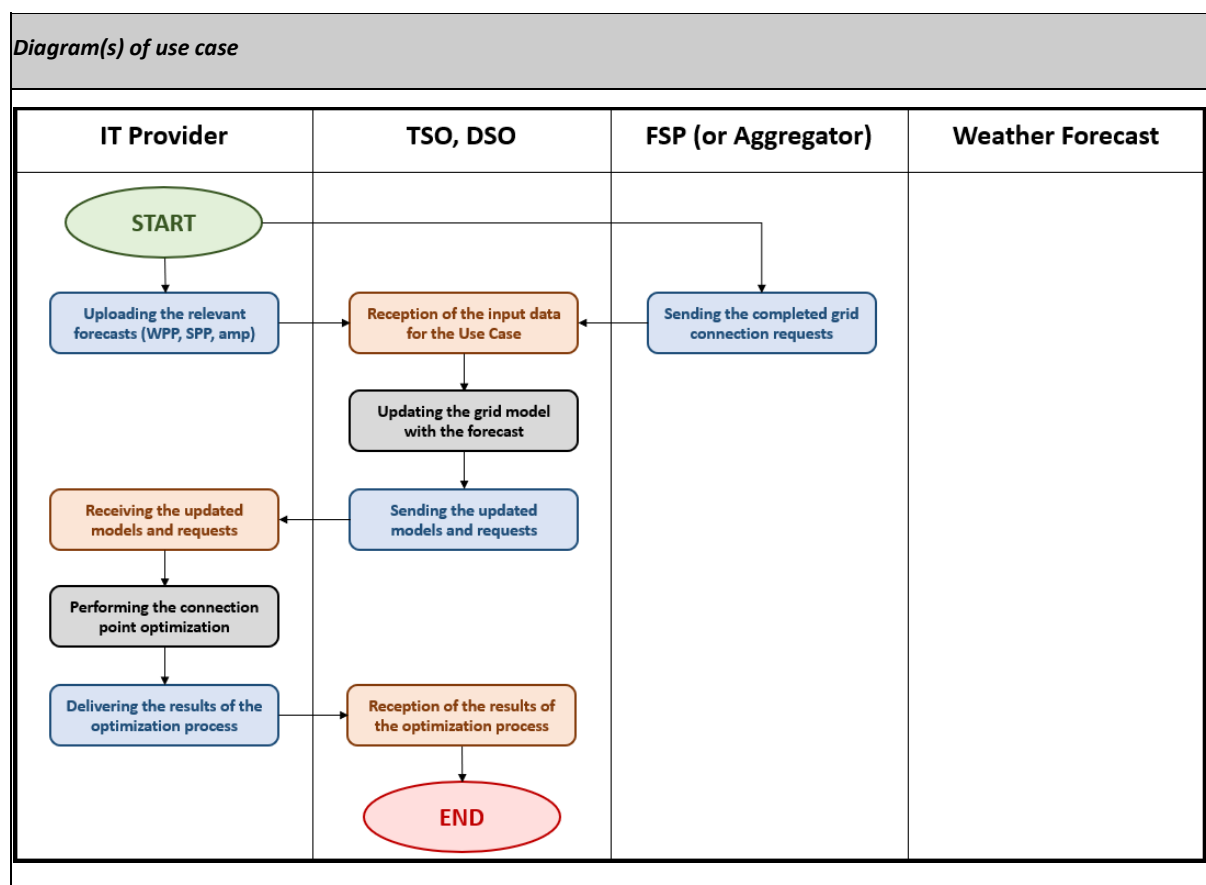
1.7 Further information to the use case for classification/mapping

Classification information	
Relation to other use cases	
This Use Case is related to the Use Cases 01, 02, 03, and 04 of the Bulgarian pilot, with all of them being the prerequisites for the successful completion of this Use Case.	
Level of depth	
High-level (connects to the TSO, DSO and cross-border energy exchange)	
Prioritisation	
High	
Generic, regional or national relation	
National and regional	
Nature of the use case	
BUC	
Further keywords for classification	
Optimization tools, optimal power flow, connection of RES, curtailment avoidance, energy transition	

1.8 General remarks

No major remarks are related to this Use Case.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Implicitly active (through the delivery of the data to the IT provider beforehand).

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Not needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg06 - S1	RES connection optimization	This scenario will consider the situation in which the IT provider involved in Bulgarian pilot completed the forecasts listed in the Use Cases 02, 03 and 04 beforehand. At the same time, system operator gets the requests for connection of larger capacities of RES in one of the regions for which the forecasts are available. In order to decide upon the connection points of each of those capacities, system operator asks the IT provider to conduct the optimization procedure, taking both the interest of SO (by applying the realistic limits of transfer capacities and voltages of the nodes) and the interest of the clients (by aiming at maximal production of their respective power plants during the observed time-period). Once the results of the optimization procedure become available, IT provider uploads them to the predefined location from which the system operator can then download them and save them. Afterwards, the connection points provided can either be used as the assumptions for some internal analyses conducted within the system operator or can even be forwarded to clients, depending on the SO's decision.	All of the listed actors.	System operator having all of the data needed for the Use Case	- Completion of UC01-UC04 of this pilot; - Availability of other data needed for the analyses.	Once the process is done, system operators will have the optimized (both from their own side and from clients' side) ways of connecting the designated set of RES to the grid.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
6.1 SO	System operator obtaining all of the needed input data	When the ANN-based forecasts are completed by the IT provider and sufficient number of RES applies for the connection to the grid in the certain geographical region, system operator is capable of initiating the actions on this Use Case.	Y	I06-01; I06-02	IT FSP provider;	System operator
6.2 SO	Updating of the models	Before the optimization procedure, the system operator needs to complete the preparatory activities, primarily based on the updates of the grid models by implementing the forecasts and provisional connection points of included RES.	N	/	/	/
6.3 SO	Delivery of the updated models	When the update is completed, TSO sends the models to the IT provider, along with the rest of the technical information relevant for optimization process. In case some data is missing, IT provider and system operator will work together in order to get full set as soon as possible.	Y	I06-03	System operator	IT provider
6.4 SO	Optimization process	Once the complete set of needed input data is available, IT provider can conduct optimization process by which the connection points of all listed RES will be determined. The method by which this process will be conducted will be determined later, depending on the number of requests and characteristics of the grid.	N	/	/	/
6.5 SO	Delivery of the optimization results	In the end, the IT provider uploads the results obtained from the optimization process to the predetermined location. The system operator can download them and store them for further use.	Y	I06-04	IT provider	System operator

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I06-01	Forecasts of the WPP and SPP production and the ampacity	After the completion of Use Cases 02-04 of Bulgarian pilot, IT provider will have the updated forecasts of the relevant parameters at their disposal. Here, they will provide the obtained values to the system operator.	Communication between different participants in the Bulgarian pilot.
I06-02	Connection requests	In line with the national regulation, the connection process starts with the FSP applying for connection to grid. This information encapsulates all of the requests that the SO receives for the geographic area of interest.	Communication between different participants in the Bulgarian pilot.
I06-03	Updated grid models	When the grid models get updated by the system operator by including the new RES that will be considered and the improved forecasts, system operator sends them to IT provider to start optimization process.	Communication between different participants in the Bulgarian pilot.
I06-04	Results of the optimization	Finally, when the optimization procedure is fully done, IT provider uploads the obtained results to the predefined location from which the system operator can download them and store them internally for the further application.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

• **Digital Twins (DTs)**

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

• **Flexibility Service Providers (FSPs)**

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when

the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the capacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.7 N-1 assessment on the DT level [BG07]**1 Description of the use case****1.1 Name of use case**

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Bg07	DT TSO, DT HL, DT Cross-Border Market Exchange (CBME), ANN-trained DTs for forecasts	N-1 assessment on the DT level

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	This Use Case will be created around the idea of detecting those elements in the transmission grid of Bulgaria whose outage could cause severe issues in the normal operation of the system. This can be used for the risk assessment and, in turn, can be an indicator of the potential action that would need to be taken by the Bulgarian TSO in the next couple of years in order to ensure the proper work of the system.
<i>Objective(s)</i>	• Load flow calculations and detection of congestions; • Single element outage examination on the DT TSO level; • Enhancement of the system resilience; • Improvement of the level of security of supply; • Indication of the hot spots for investments in the upcoming period; • Risk assessment; • Easier maintenance and planned outages scheduling.
<i>Related business case(s)</i>	Bg01, Bg02, Bg03, Bg04, Bg08

1.4 Narrative of Use Case

<i>Narrative of use case</i>

Short description	
Here, the assessment of system reliability on the DT TSO will be performed. This will be done by simulations of single outages of every element in the grid of interest and checking if some problems occur in the system. After that, the recommendations regarding the operational measures that can mitigate those issues will be given where doable. The results of this Use Case will be used for risk assessment and improvement of the level of reliability that can be expected from the TSO grid.	
Complete description	
This Use Case will, as stated before, primarily be focused on the behaviour of the transmission grid of Bulgaria in the situations in which, for the characteristic system regimes, the outage of any element in it happens. The possibility of two elements being out of operation at the same time will not be included in this analysis. For this to happen, three basic steps will need to be taken: • The initial of these three steps will be based on the selection and collection of the needed input data. This, first of all, refers to the handpicking of the extreme system regimes for which these calculations will be done. For this, the feedback from the Bulgarian TSO will be necessary in order to make sure that the selection was done in line with their practical experiences. These regimes may be selected on the basis of the high demand in the system, high production of the renewable sources connected to the grid, or high voltages that are the consequence of the low line loading, for instance. Once this is done, the assumptions that are valid for these selected regimes will be implemented into the DT transmission grid, allowing for the next step to start. • The second step will be the running of the N-1 analyses, meaning that the unplanned outage of every single element in the transmission grid (except if indicated otherwise by the TSO) will be simulated. For each of the new system states (after the outages), the load flow calculations and the voltage situation estimation will be done. This will allow for the all-encompassing view of both the outages that result in most issues in the grid and the elements that become critical for the most single outages. The monitoring will hence need to include the branches that are overloaded in certain situations and the buses for which the voltages get out of the defined bounds. The results will be carefully collected and forwarded into final step. • In the last step of the procedure, the spotted criticalities will be detailly analysed, after which the assessment of the potential mitigation measures will be done. Those measures, depending on the situation, may include switching operations (for which the tight coordination with TSO will be necessary) or re-dispatching of the units connected to the grid. If the problem that gets noticed is related to the overloading of the line, an estimation will also be made if the issue can be resolved by applying the realistic ampacity forecasts. If both of these approaches fail to tend to the problem properly, the recommendations will be made of the possible need for developing the grid further in order to avoid the risks that were seen in the scope of this Use Case.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Number of detected critical outages [#]	This KPI will be centred around the detection of the outages in the transmission system of Bulgaria for which there are issues in the TSO grid. KPI will be verified in tight cooperation with the TSO.	All of the listed objectives
2	Percentage of considered congestions [%]	As stated before, one of the main goals of this UC will also be examination of the possible mitigation measures based on different operational actions. This KPI will be the measurement of success of this process. Those issues that remain after the chosen measures are implemented will be highlighted as the ones that need to be resolved by new projects.	All of the listed objectives

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	The Use Case will be developed in a non-invasive environment, chosen by the partners in demo.
2	The accuracy of the conducted calculations will depend on the reliability of the input data.
3	The possibility of two elements of the grid being out of operation simultaneously will not be included in this analysis.
<i>Prerequisites</i>	
1	The completion and verification of the Use Cases listed as prerequisites for this Use Case, in particular the Use Cases 01 to 04 of the Bulgarian pilot.
2	The availability of all of the needed input data, both from climatic and technical point of view.

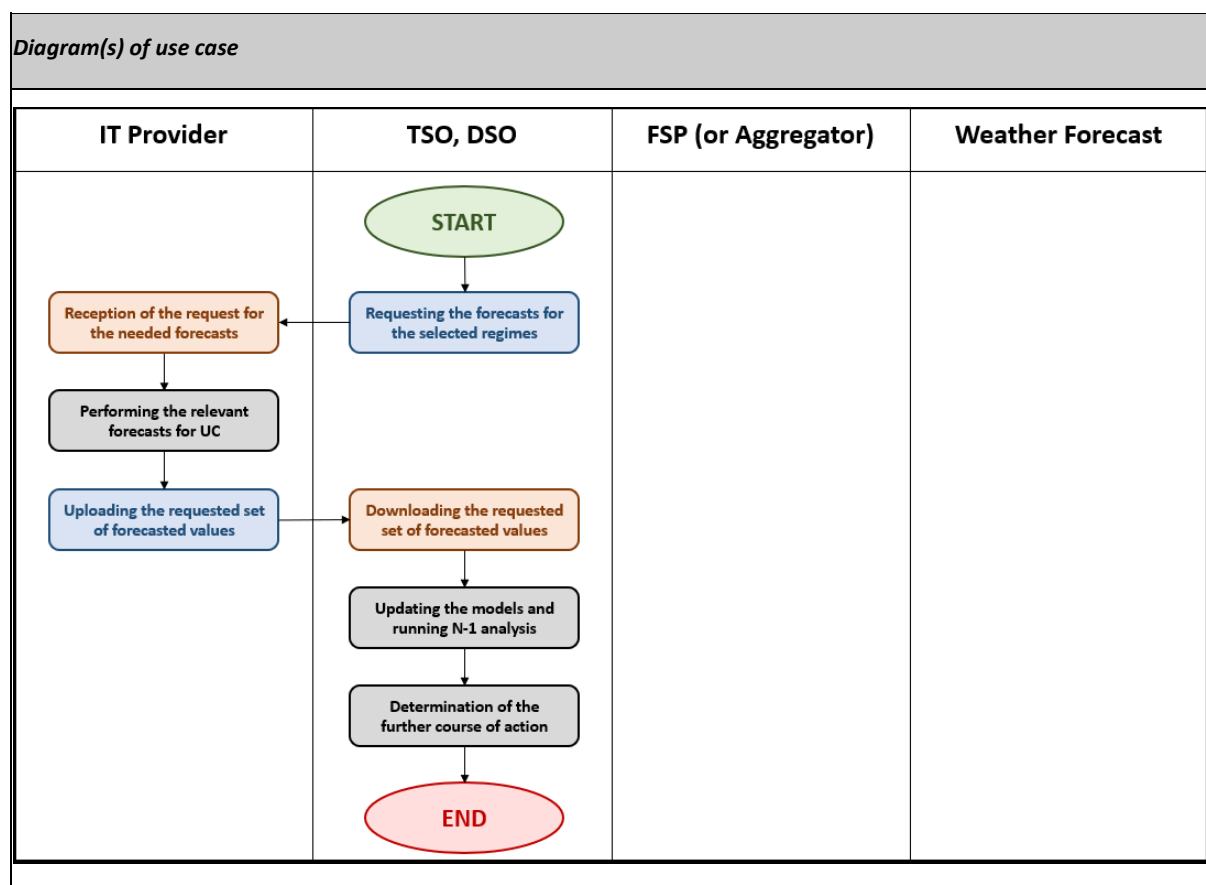
1.7 Further information to the use case for classification/mapping

<i>Classification information</i>
<i>Relation to other use cases</i>
This Use Case is related to the Use Cases 01, 02, 03, 04, and 08 of the Bulgarian pilot, with the former four being the prerequisites for the successful completion of this Use Case. On the other hand, the conclusions of this Use Case will be fed directly into the Use Case 08 of the Bulgarian pilot.
<i>Level of depth</i>
High-level (connects to the TSO mostly)
<i>Prioritisation</i>
High
<i>Generic, regional or national relation</i>
National and regional
<i>Nature of the use case</i>
BUC
<i>Further keywords for classification</i>
Reliability assessment, risk estimation, mitigation measures, load flow, system state estimation

1.8 General remarks

No major remarks are related to this Use Case.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Not active in this Use Case.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Implicitly active (through the delivery of the data to the IT provider beforehand).

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Not active in the scope of this Use Case.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg07 - S1	N-1 assessment of the grid	The scenario will take into account the situation in which the system operator desires to improve the way in which the N-1 assessment of the system operation is performed. For that to happen, they will give the IT provider basic information regarding the system regimes that tend to be critical from technical point of view (regimes in which voltages are out of allowed range or in which the lines can get overloaded). IT provider will then use the ANN-trained DTs for forecasts (created and tested before in the scope of Use Cases 02-04) to determine the key parameters of the grid's operation more efficiently and accurately compared to the methods commonly used in the system operators' work. After that, the system operator will be able to update the simulation models based on the enhanced forecasts and to run standard N-1 analysis of the grid. With that out of the way, system operator will finally be able to check the results obtained by the application of these models and to decide upon the course of action that needs to be taken in order to mitigate or fully remove the problems. The measures will also be tested in the models.	- IT provider; - System operators; - Weather forecast provider (implicitly).	System operator requesting the forecasts for the critical regimes	- Completion of UC01-UC04 of this pilot; - Availability of other data needed for the analyses.	When the analyses are done, the TSO will have the N-1 assessment done with the improved forecasts of key parameters of the grid, allowing for better decisions on needed actions.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
SO 7.1	Request for forecasts for the critical regimes	System operator here creates and verifies the list of the operational regimes in the system that can be marked as critical from technical point of view, after which the list is forwarded to the IT provider that will need to do forecasts for those regimes.	Y	I07-01	System operator	IT provider
SO 7.2	Performing forecasts for the critical regimes	Based on the ANN-trained DTs, developed and tested in some of the earlier Use Cases of the Bulgarian pilot, IT provider runs the forecasts of the selected parameters (WPP production, SPP production, ampacity) for the critical regimes.	N	/	/	/
SO 7.3	Exchanging the forecasts for the critical regimes	Once the required forecasts are fully done, IT provider uploads them to the predefined location and informs system operator of that. System operator then downloads the forecasts and saves them in the internal storage for further use.	Y	I07-02	IT provider	System operator
SO 7.4	Updating models and running N-1 assessment	When the forecasts are downloaded and saved, system operator includes them in the simulation models that represent the grid in the designated critical operational regimes. After that, system operator utilizes the enhanced models to run N-1 assessment and extracts the obtained results.	N	/	/	/
SO 7.5	Deciding upon the further actions	Finally, system operator is able to determine the further course of action based on which the issues spotted by using the updated models can be removed or mitigated. These actions can include the new infrastructure projects in the grid or appropriate switching operations, for example.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I07-01	Request for forecasts for the critical regimes	In order to start the activities in this Use Case, system operator asks IT provider to deliver the set of forecasts for the critical operational regimes. These regimes are also listed as the part of this request, along with the rest of the necessary input parameters for the forecast.	Communication between different participants in the Bulgarian pilot.
I07-02	Forecasts for the critical operational regimes	Once the forecasting process is completed, the results need to be uploaded by the IT provider to the location agreed beforehand between IT provider and the system operator. The system operator then downloads the forecasts and stores them for the further activities.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

• Digital Twins (DTs)

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

• Flexibility Service Providers (FSPs)

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

• Artificial Neural Networks (ANNs)

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the capacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.8 DT-based Maintenance plan of TSO grid [BG08]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg08	DT TSO, DT Cross-Border Market Exchange (CBME), ANN-trained DTs	DT-based Maintenance plan of TSO grid

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	This Use Case will deal with one of the major issues frequently spotted in the work of the transmission system operator – the problem of properly planning maintenance of the grid so that the minimal strain is put on the remaining elements of the grid. In order for that to be done, the N-1 analysis will be conducted for the situations in the grid in which some other element is already under maintenance. By doing this, the elements during whose maintenance the issues are the most likely to appear will be pointed out. This can be used for performing the proper risk assessment afterwards.
Objective(s)	• Load flow calculations and detection of congestions; • Single element outage examination on the DT TSO level; • Enhancement of the system resilience; • Improvement of the level of security of supply; • Indication of the hot spots for investments in the upcoming period; • Risk assessment; • Easier maintenance and planned outages scheduling.
Related business case(s)	Bg01, Bg02, Bg03, Bg04, Bg07

1.4 Narrative of Use Case

Narrative of use case

Short description	
In the scope of this Use Case, the simulations of the planned maintenance activities in the DT TSO will be conducted. On each of the system states that occur once some maintenance action happens, N-1 reliability assessment will be conducted in order to determine the potential situations in which issues could happen while the maintenance is underway. This will also be used for risk assessment.	
Complete description	
This Use Case will, similar to the Use Case 07 of Bulgarian pilot, primarily be focused on the behaviour of the transmission grid of Bulgaria in the situations in which the forced outage of some element in it happens during maintenance season. This means the analysed system state will mean simultaneous unavailability of more than one element. For this to happen, three basic steps will need to be taken: • The start of the process here will include the selection and collection of the needed input data. This will, before everything else, once again mean the selection of the operational regimes of the system for which the system state will need to be estimated. This time, however, the main criterion for the selection will be whether or not the examined regime of work matches the time of maintenance season or not. Out of those proposed regimes that belong to the maintenance period (most of the Spring, Summer and Autumn), the characteristic ones will be selected (the ones with the high demand, high RES production or low loading of the lines that could cause the high voltages). Once this is done, the assumptions that are valid for these selected regimes will be implemented into the DT transmission grid, allowing for the following step to start. • The next step will be the selection of the elements that will be considered to be undergoing the maintenance in the simulations (one at a time). This selection will be done based on previous experience of the TSO partner in the demo, expert-level estimation of the critical elements and the evaluation of the results obtained through the Use Case Bg07 (the one related to the usual N-1 analyses done on the DT transmission grid). For each of those maintenance scenarios, the element that is marked as being worked on will be switched off in the grid model, after which the N-1 procedure will be repeated on the newly acquired topologies of the grid. Monitoring of the criticalities will once again include the branches that are overloaded in some of the analysed situations and the buses for which the voltages are spotted to be out of the defined bounds. • The final phase of the Use Case will involve evaluating the identified issues within the grid and proposing appropriate solutions or mitigation measures for each. Initially, these measures will focus on implementing the recommendations outlined in Use Case Bg07. If some issues persist despite these efforts, additional measures will be explored, including switching actions or activating available FSPs. If these steps turn out to be insufficient, modifications to the TSO maintenance plan will be proposed, ensuring that maintenance of the critical grid elements is scheduled in such a way that it does not overlap with the periods of extreme system operation.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Percentage of addressed issues in the system [%]	This KPI will be calculated based on the share of the spotted problems in the grid while some of the elements are undergoing maintenance. The ways in which these issues will be addressed may include some operational measures (new or taken from UC 07) or recommendations for maintenance planning.	All of the listed objectives

1.6 Use case conditions

Use case conditions
Assumptions

1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the calculations will depend on the reliability of the input data. Selecting the critical system operating conditions and identifying the elements whose maintenance could challenge the system will be key to drawing meaningful conclusions from this case.
Prerequisites	
1	The completion and verification of the Use Cases listed as the ones related to this Use Case, but in particular the Use Cases 01, 02, 03, 04, and 07 of the Bulgarian pilot.
2	The availability of all of the needed input data, both from climatic and technical point of view.

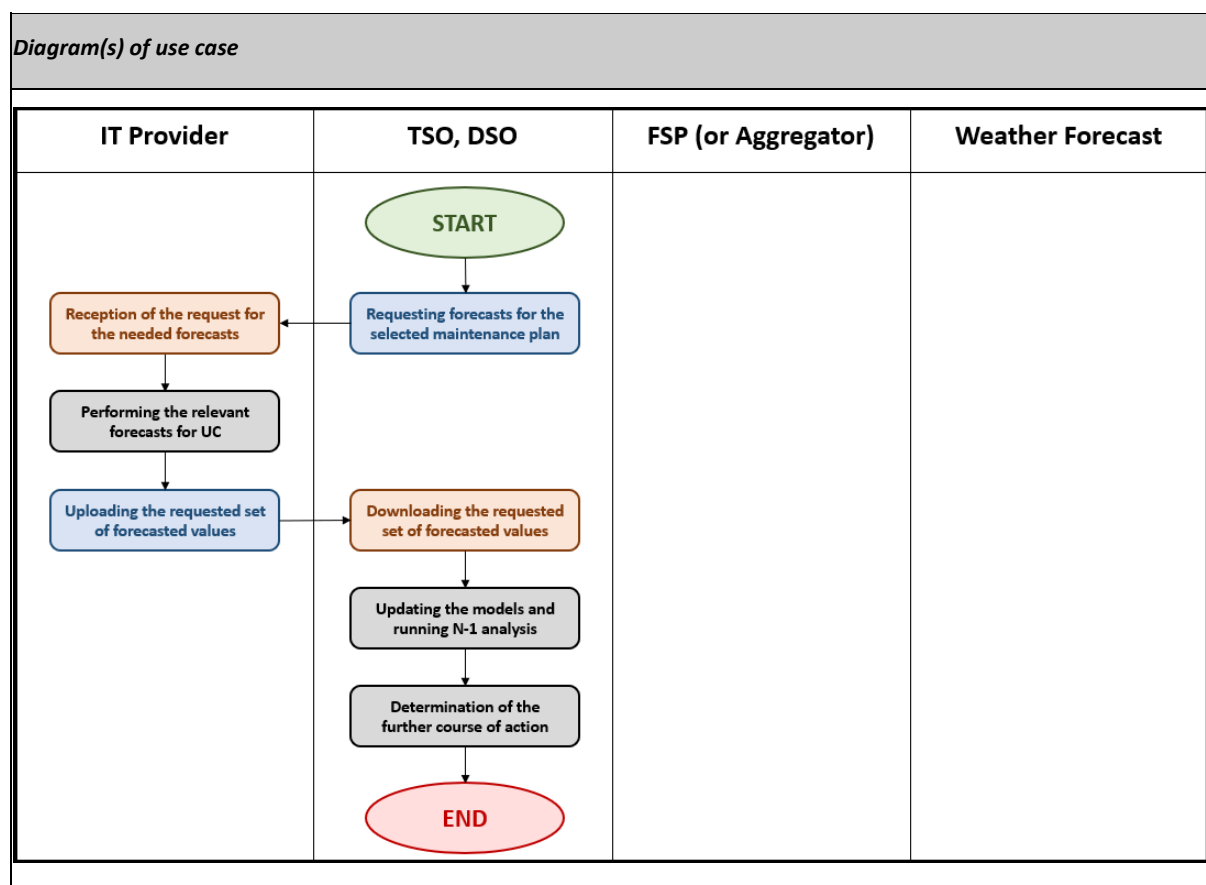
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
This Use Case is related to the Use Cases 01, 02, 03, 04, and 07 of the Bulgarian pilot, with all of them being the prerequisites for the successful completion of this Use Case.
Level of depth
High-level (connects to the TSO mostly)
Prioritisation
High
Generic, regional or national relation
National and regional
Nature of the use case
BUC
Further keywords for classification
Reliability assessment, risk estimation, mitigation measures, maintenance planning

1.8 General remarks

No major remarks are related to this Use Case.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Not active in this Use Case.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Implicitly active (through the delivery of the data to the IT provider beforehand).

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Not active in the scope of this Use Case.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg08 - S1	Maintenance plan verification	The scenario will take into account the situation in which the system operator desires to check the selected maintenance plan by running the N-1 assessment for the state of the system under maintenance. For that to happen, they will give the IT provider basic information regarding the critical system regimes (regimes in which voltages are out of allowed range or in which the lines can get overloaded), determined so that they are relevant for the maintenance season. IT provider will then use the ANN-trained DTs for forecasts (created and tested before in the scope of Use Cases 02-04) to determine the key parameters of the grid's operation. After that, the system operator will be able to update the simulation models based on the enhanced forecasts and to run standard N-1 analysis of the grid, all while taking into account the delivered plan of maintenance. With that out of the way, system operator will be able to check the results obtained by the application of these models and to decide upon the course of action that needs to be taken in order to mitigate or fully remove the problems that were spotted in the analyses.	- IT provider; - System operators; - Weather forecast provider (implicitly).	System operator requesting the forecasts for the critical regimes and the selected maintenance plan	- Completion of UC01-UC04 and UC07 of this pilot; - Availability of other data needed for the analyses.	When the analyses are done, the SO will be able to verify if the system will be put in the potential risky state if the maintenance takes place as foreseen by the initial plan.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
S08.1	Request for forecasts for critical system regimes under maintenance	System operator here creates the list of the regimes that may be critical in the season of the grid maintenance. Once the list is done and verified, it will be sent to the IT provider that will need to do forecasts for the selected regimes.	Y	I08-01	System operator	IT provider
S08.2	Performing forecasts for the critical regimes	Based on the ANN-trained DTs, developed and tested in some of the earlier Use Cases of the Bulgarian pilot, IT provider runs the forecasts of the selected parameters (WPP production, SPP production, ampacity) for the critical regimes.	N	/	/	/
S08.3	Exchanging the forecasts for the critical regimes	Once the required forecasts are fully done, IT provider uploads them to the predefined location and informs system operator of that. System operator then downloads the forecasts and saves them in the internal storage for further use.	Y	I08-02	IT provider	System operator
S08.4	Updating models and running N-1 assessment	When the forecasts are downloaded and saved, system operator includes them in the simulation models that represent the grid in the designated critical regimes for system undergoing the maintenance. Afterwards, the operator utilizes the enhanced models to run N-1 assessment.	N	/	/	/
S08.5	Deciding upon the further actions	Finally, system operator is able to determine the further course of action based on which the issues spotted by using the updated models can be removed or mitigated. These actions can include new projects, switching operations or adjusting the maintenance plan accordingly.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I08-01	Request for forecasts for the critical regimes in maintenance season	In order to start the activities in this Use Case, system operator asks the IT provide to deliver the set of forecasts for the critical operational regimes. These regimes are determined so that they are relevant for the time period in which system may be undergoing maintenance, and are also listed as the part of this request, along with the rest of the input parameters that are needed for the forecast.	Communication between different participants in the Bulgarian pilot.
I08-02	Forecasts for the critical operational regimes	Once the forecasting process is completed, the results need to be uploaded by the IT provider to the location agreed beforehand between IT provider and the system operator. The system operator then downloads the forecasts and stores them for the further activities.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

- **Digital Twins (DTs)**

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

- **Flexibility Service Providers (FSPs)**

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.9 Flexibility Requirements to Avoid Congestions [BG09]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg09	DT DSO, DT TSO, DT Cross-Border Market Exchange (CBME), ANN-trained DTs for forecasts	Flexibility Requirements to Avoid Congestions

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The Use Case will address a scenario of the congestion in the distribution grid and explore potential solutions through the application of FSPs in the same region. The FSPs that will be considered here will be the ones connected to the distribution grid. The type of the FSP will depend on the analysed part of the grid, but can potentially include the WPPs, SPPs (paired with ANN-trained DTs) or controllable demand.
Objective(s)	- Better utilization of the existing FSPs in the distribution grid; - Reduction of contingencies in the distribution grid; - Improvement of the security of energy supply to the customers; - Improvement of the level of system resilience; - Prevention of the issues in the DSO grid from affecting the TSO grid; - Cost-efficient operation of the system; - Avoiding potential investments needed for mitigating the congestion.
Related business case(s)	Bg01, Bg02, Bg03, Bg04

1.4 Narrative of Use Case

Narrative of use case

Short description	
The situation that will be simulated here is the one in which the congestion happens in the distribution grid. After that, the appropriate flexibility measures will be applied to avoid the outages. Depending on the part of the grid, these measures could include the DSR or the modifications of the production the WPPs and SPPs in the area (depending on their capabilities determined in the ANN-trained DTs).	
Complete description	
In the same fashion as it was done for all of the remaining Use Cases in the Bulgarian pilot, the process that was foreseen to be performed in the scope of this Use Case will also be split into three successive steps, allowing for easy tracking of progress through the procedure. Those steps are the following: • The first step will be the definition of the input data and its collection here as well. That will, this time, be focused on the determination of the critical elements in the distribution grid that might get congested in some of the extreme operational regimes of the system. The single condition that will need to be fulfilled will be the one that the congestion is located in the area in which it can be affected by one or more FSPs connected to the distribution grid in the same region. The nature of the FSPs will be varied based on the region that is analysed in each of the observed cases, allowing them to belong to the categories of renewable energy sources or controllable demand, for example. Even though the technical characteristics of those FSPs will already be included in the appropriate DT, the collection of the weather parameters relevant for those FSPs in troublesome system regimes will need to be conducted in order to prepare for the next step. • In this next step, the DT DSO will be adjusted to replicate conditions that could potentially lead to the congestion. The success of this task will need to be checked in tight cooperation with the DSO itself. Once this is completed, the behaviour of each of analysed FSPs (connected to the distribution grid) in the region of interest will be carefully observed. In case the FSP is the demand, the potential for the reduction of requested power will be estimated on the basis of the information already available to the DSO. On the other hand, in cases in which the FSP belongs to the category of WPPs or SPPs, the potential that they have for increasing their production will be calculated based on the selected weather conditions and ANN-trained DTs (developed in Business Use Cases Bg02 and Bg03). The potential reduction in production power will not be estimated, as it can be assumed that it could be reduced to zero if necessary. • Finally, the load flow calculations will be performed for the selected part of the system, adjusting the level of services provided by the FSP (or multiple FSPs, depending on their number) within defined limits, until a congestion-free system state is achieved. If there is a case in which this kind of system state cannot be achieved by the FSP management, there will have to be another way of dealing with the congestions in the grid and the consequences of those. All of this will be thoroughly detailed in the conclusions of this Use Case, with the focus on highlighting the potential of FSPs regarding the resolutions of the observed grid congestions.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Percentage of the mitigated congestions in DSO grid via FSP services [%]	This KPI will be determined by comparing the total number of congestions considered in DSO grid with the number of congestions that were mitigated (or, in some cases, removed) by using the services that are offered by the FSPs in the distribution grid.	All of the listed objectives

1.6 Use case conditions

Use case conditions
Assumptions

1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the conducted calculations and the results and conclusions drawn from those will depend on the reliability of the input data. Thus, the quality of the input data needs to be kept very high throughout the project.
Prerequisites	
1	The completion and verification of all of the DTs relevant for the Bulgarian pilot (also known as part of the Use Case 01 of this pilot). Completion of the Use Cases 02, 03, and 04 of this pilot, as they are needed for the proper estimation of the potential that the considered FSPs hold.
2	The availability of all of the needed input data, both from climatic and technical point of view.

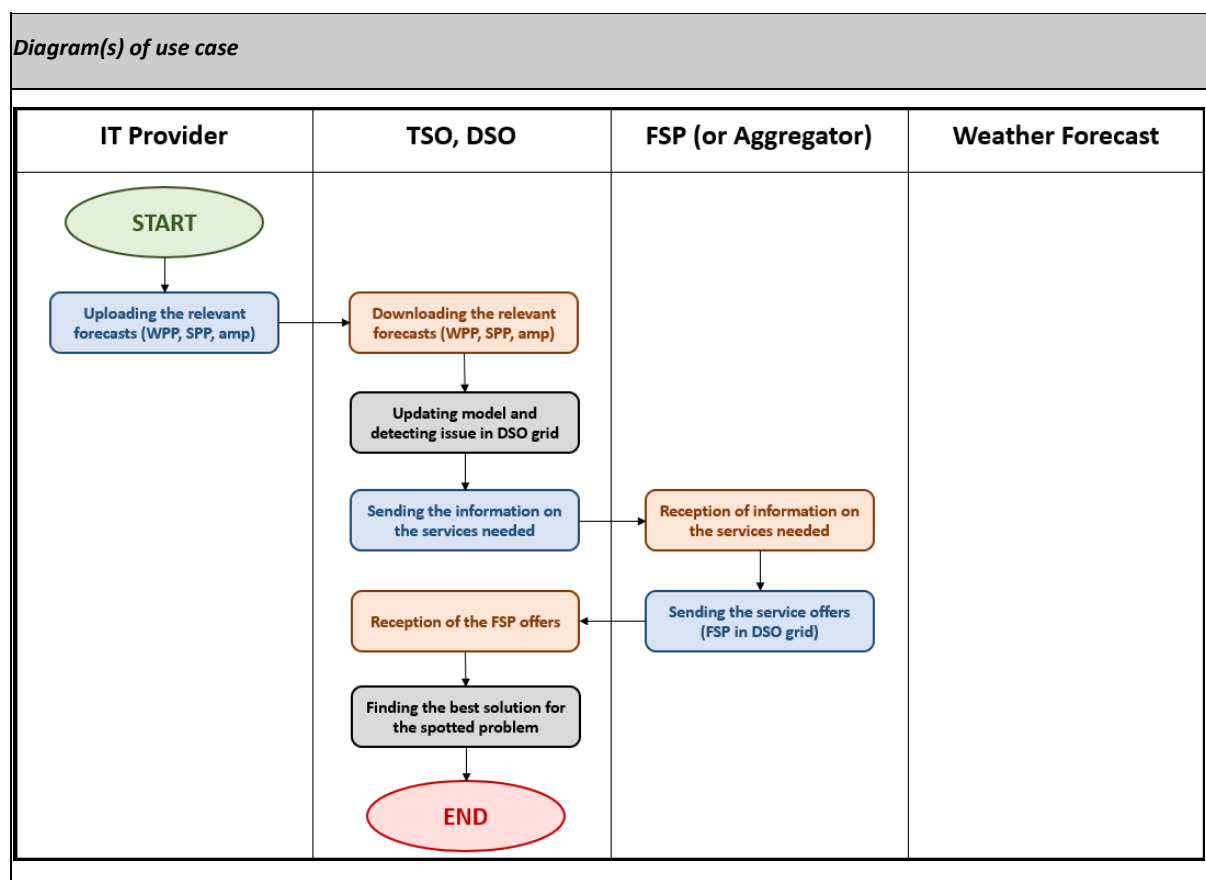
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Use Cases 01-04 of the Bulgarian pilot are the preconditions for the actions planned for this Use Case.
Level of depth
High-level (connects to the DSO level primarily)
Prioritisation
High
Generic, regional or national relation
National and regional
Nature of the use case
BUC
Further keywords for classification
Congestion mitigation, FSP utilization, ANN-based forecasts, AI-tools, DSO operation issues

1.8 General remarks

In order for this algorithm to achieve its full potential, it will need to be paired with the high-resolution weather measurements.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Implicitly active (through the delivery of the data to the IT provider beforehand).

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Not active in the scope of this Use Case.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg09 - S1	Flexibility usage to avoid the congestions	The scenario listed here simulates the situation in which the congestion is spotted in some area of distribution grid. Of course, as already stated before, this area of distribution grid needs to fulfil one condition – it needs to have sufficient amount of the FSPs connected to the distribution grid. The type of these FSPs may vary depending on the observed area, so they may be the WPPs, they can be SPPs or they can be the demand that can be controlled by the system operator in order to provide the flexibility to the grid. In order to mitigate the problem and prevent the undesired consequences, system operator will ask the FSPs to offer their services that may help. The offers will later on be evaluated by using the models updated by the forecasts of relevant system parameters (done in the scope of one of the earlier Use Cases of the Bulgarian pilot). This will allow the DSO to evaluate the potential that each of the FSPs has for resolving the congestions in the grid and to enhance the reliability of the planned mitigation measures. That will, in turn, improve the quality of the energy delivery to the customers and increase grid resilience.	All of the listed actors.	Results indicating contingency in the DSO grid in the region in which the FSPs connected to the DSO exist	- Completion of UC01-UC04 of this pilot; - Availability of other data needed for the analyses.	DSO will be able to evaluate the potential of certain FSPs to help in removing or mitigating the congestions in the grid in a quick and reliable fashion.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
S09.1	Exchange of the relevant forecasts	When the IT provider performs the forecasts of the relevant system parameters for the selected part of the grid. Once done, these forecasts will be uploaded to the predefined location, after which the system operator can download them.	Y	I09-01	IT provider	System operator (DSO)
S09.2	Detection of the problem	When the system operator (for this Use Case, it will be the DSO) downloads the forecasts of the selected parameters, they update the grid models and run the needed calculations. If the calculations show that there is an issue in the part of grid in which the FSPs exist, the Use Case can move on to the next step in process.	N	/	/	/
S09.3	Requesting the services from the FSPs in the area	In case the problem was detected in the previous step, the system operator asks the FSPs to send their offers for the provision of the service that may mitigate the situation. Along with this, the specifications of the service are also delivered.	Y	I09-02	System operator (DSO)	FSPs
S09.4	FSPs in the area submit the offers for services	If the FSPs are able to provide the service to the DSO, they send their offers, giving detail on the amount of the needed resource that they can provide in the determined timeframe. These offers are then stored together for further use.	Y	I09-03	FSPs	System operator (DSO)
S09.5	Decision on the optimal method to solve the problem	Finally, system operator uses the delivered offers and the models on which the issue was detected to determine the optimal combination of available resources (if any) that will help in mitigating the issue and maintaining reliable work of the grid.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I09-01	Forecasts of the WPP and SPP production and the ampacity	After the completion of Use Cases 02-04 of Bulgarian pilot, IT provider will have the updated forecasts of the relevant parameters at their disposal. Here, they will provide the obtained values to the system operator.	Communication between different participants in the Bulgarian pilot.
I09-02	Information on the needed services	Once the issue has been spotted in the DSO grid, the system operator in charge of it sends the information to all of the relevant FSPs in the region, asking them to submit offers related to the requested system services.	Communication between different participants in the Bulgarian pilot.
I09-03	Offers regarding the required services	The last set of information exchanged here is the one related to the offers that the FSPs submit once they get the information on which services are needed to the system. Form of offer submission will be predefined in order to reduce the possibility of human error in process.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

- **Digital Twins (DTs)**

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

- **Flexibility Service Providers (FSPs)**

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.1.10 Inter-SO Flexibility Exchange [BG10]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Bg10	DT DSO, DT TSO, DT Cross-Border Market Exchange (CBME), ANN-trained DTs for forecasts	Inter-SO Flexibility Exchange

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	BG partners	Added basic description	
0.2	17.06.2024	BG partners	Extended the description	
0.3	25.07.2024	BG partners	Added diagrams and actors	
0.4	16.09.2024.	BG partners	Finished document draft	
0.5	05.02.2025.	BG partners	Responded to comments	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The Use Case will address a scenario of the congestion in the transmission grid and explore potential solutions through the application of FSPs in the same region. The FSPs that will be considered here will be the ones connected to the distribution grid. The type of the FSP will depend on the analysed part of the grid, but can potentially include the WPPs, SPPs (paired with ANN-trained DTs) or controllable demand.
Objective(s)	• Better utilization of the existing FSPs in the distribution grid; • Reduction of contingencies in the distribution grid; • Improvement of the security of energy supply to the customers; • Improvement of the level of system resilience; • Utilization of DSO-based FSPs for mitigating issues in TSO grid; • Cost-efficient operation of the system; • Avoiding potential investments needed for mitigating the congestion.
Related business case(s)	Bg01, Bg02, Bg03, Bg04

1.4 Narrative of Use Case

Narrative of use case

Short description	
Here, the situation in the DT TSO will be simulated in which the congestion is spotted. After that, the appropriate flexibility measures will be applied in order to avoid the outages. The problem will not be solved by activating the flexibility resources connected to TSO grid, but by those connected to DSO grid. This will highlight the potential of TSO-DSO cooperation and coordination in order to avoid issues in the system, giving a boost to the flexibility exchange discussions in the process as well.	
Complete description	
In the same fashion as it was done for all of the remaining Use Cases in the Bulgarian pilot, the process that was foreseen to be performed in the scope of this Use Case will also be split into three successive steps, allowing for easy tracking of progress through the procedure. Those steps are the following: • The first step will be the definition of the input data and its collection here as well. That will, this time, be focused on the determination of the critical elements in the transmission grid that might get congested in some of the extreme operational regimes of the system. The single condition that will need to be fulfilled will be the one that the congestion is located in the area in which it can be affected by one or more FSPs connected to the distribution grid in the same region. The nature of the FSPs will be varied based on the region that is analysed in each of the observed cases, allowing them to belong to the categories of renewable energy sources or controllable demand, for example. Even though the technical characteristics of those FSPs will already be included in the appropriate DT, the collection of the weather parameters relevant for those FSPs in troublesome system regimes will need to be conducted in order to prepare for the next step. • In this next step, the DT TSO will be adjusted to replicate conditions that could potentially lead to the congestion. The success of this task will need to be checked in tight cooperation with the TSO itself. Once this is completed, the behaviour of each of analysed FSPs (connected to the distribution grid) in the region of interest will be carefully observed. In case the FSP is the demand, the potential for the reduction of requested power will be estimated on the basis of the information already available to the DSO. On the other hand, in cases in which the FSP belongs to the category of WPPs or SPPs, the potential that they have for increasing their production will be calculated based on the selected weather conditions and ANN-trained DTs (developed in Business Use Cases Bg02 and Bg03). The potential reduction in production power will not be estimated, as it can be assumed that it could be reduced to zero if necessary. • Finally, the load flow calculations will be performed for the selected part of the system, adjusting the level of services provided by the FSP (or multiple FSPs, depending on their number) within defined limits, until a congestion-free system state is achieved. If there is a case in which this kind of system state cannot be achieved by the FSP management, there will have to be another way of dealing with the congestion and its consequences, such as operational measures in the grid. All of this will be included and carefully elaborated in the conclusions of this Use Case. This will highlight the potential of FSPs in resolving detected grid congestions and emphasize the importance of flexibility exchange between the transmission and distribution systems.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Percentage of the mitigated congestions in TSO grid via FSP services [%]	This KPI will be determined by comparing the total number of congestions considered in TSO grid with the number of congestions that were mitigated (or, in some cases, removed) by using the services that are offered by the FSPs in the distribution grid.	All of the listed objectives

1.6 Use case conditions

Use case conditions

Assumptions	
1	The Use Case will be developed and demonstrated in a non-invasive environment, selected by the partners in the demo.
2	The accuracy of the conducted calculations and the results and conclusions drawn from those will depend on the reliability of the input data.
Prerequisites	
1	The completion and verification of all of the DTs relevant for the Bulgarian pilot (also known as part of the Use Case 01 of this pilot). Completion of the Use Cases 02, 03, and 04 of this pilot, as they are needed for the proper estimation of the potential that the considered FSPs hold.
2	The availability of all of the needed input data, both from climatic and technical point of view.

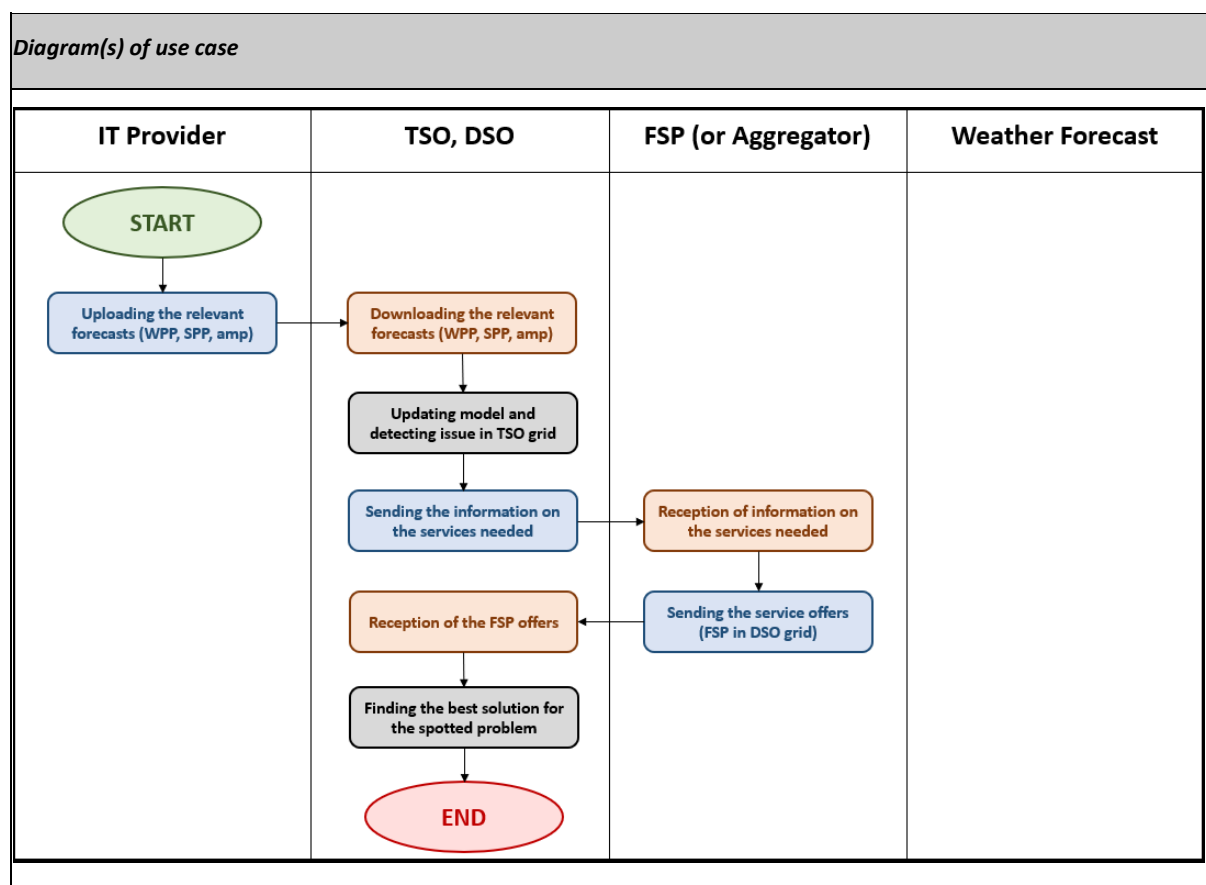
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Use Cases 01-04 of the Bulgarian pilot are the preconditions for the actions planned for this Use Case.
Level of depth
High-level (connects both to the TSO and the DSO level)
Prioritisation
High
Generic, regional or national relation
National and regional
Nature of the use case
BUC
Further keywords for classification
Congestion mitigation, FSP utilization, ANN-based forecasts, SO flexibility exchange

1.8 General remarks

In order for this algorithm to achieve its full potential, it will need to be paired with the high-resolution weather measurements.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
Information Technology Provider (IT provider)	Business	Providers of the information technologies needed for the implementation of the expected functionalities in the work of the pilot. Since two of the partners belong in this group, their efforts will need to be coordinated for the maximal benefits of the Bulgarian pilot to be achieved.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
System Operators (TSO and DSO)	Business	System operators of Bulgaria, in line with the official regulations describing the rights and obligations of the TSO and DSO. Since both TSO and DSO of Bulgaria are involved in the project, their knowledge and experience will be crucial for expected outcomes of the pilot.	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.
Flexibility Service Provider	Business (simulated)	Flexibility Service Provider that is able to provide needed services to the grid. Since no partners in the pilot belong in this category, FSP behaviour will be simulated based on the available data. It will be	Active in line with the diagram from part 2 and scenario description from part 4 of this Use Case Description.

		considered that FSPs are either WPPs, SPPs or controllable demand.	
Weather Forecast Provider	Business (or part of TSO and DSO)	Providers of the high-resolution weather forecast needed for implementing some of the advanced functionalities of the developed tools. They can either be an individual entity or be a part of the designated units in TSO and DSO.	Implicitly active (through the delivery of the data to the IT provider beforehand).

3.2 Systems

Systems			
Grouping (e.g. domains, zones)		Group description	
Digital Twin System		Digital Twin Systems Involved in the pilot	
System name	System owner	System description	Further information specific to this system use
DT TSO	Bulgarian Grid Operators (TSO)	The DT models the Bulgarian transmission grid. It is responsible for managing and simulating the transmission of electricity across high-voltage lines. The system will be based on existing network models to represent the grid, thus enabling the efficient data exchange and simulation capabilities for grid operations.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT DSO	Bulgarian Grid Operators (DSO)	This DT models the Bulgarian distribution grid. It handles the distribution of electricity from the transmission system to end-users and it will be integrated with the DT TSO to ensure seamless data exchange, particularly important for the TSO-DSO coordination.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT CBME (Cross-Border Market Exchange))	Bulgarian Grid Operators (TSO)	This DT facilitates cross-border energy exchanges. It ensures that energy trading between Bulgaria and neighbouring countries is efficiently managed and recorded. It interacts with both DT TSO and DT DSO to align cross-border energy flows with domestic grid operations and to ensure data exchange needed for cross-border energy transactions.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
DT HL (High-Level Digital Twin)	Bulgarian authorities or other relevant stakeholders	This DT will utilize the work that will be conducted on the other three DTs in order to make a merged model. It will be made in the same tool as DT TSO and DT DSO, accompanied by the codes for needed level of automation.	Not active in the scope of this Use Case.

Systems			
Grouping (e.g. domains, zones)		Group description	
ANN-DTs (ANN-trained Digital Twins)	Bulgarian operators	ANN trained Digital Twins will be used in order to enrich and enhance the core Digital twins for system operations and planning simulations, based on the existing network models and market data of Bulgarian system.	Active in this Use Case, in line with the descriptions given in part 2 and part 4 of this document.
Grouping (e.g. domains, zones)		Group description	
Technical Implementation		Functionalities needed for the implementation of the pilot	
System name	System owner	System description	Further information specific to this system use
Data Exchange Establishment	TSO, DSO, CBME, ANN	Establishes communication channels between all of the listed DTs by using the scripts for data transfer.	Needed for this Use Case.
Data Quality Assurance	TSO, DSO, CBME, ANN	Maintains the quality of data exchanged between systems through the means of random sampling and analysis.	Needed for this Use Case.
Grid Indicator Calculations	TSO, DSO, CBME, ANN	Calculates the load flows and voltage values in the selected part of grid (both in base case and in the N-1 situations).	Needed for this Use Case.
Forecasts of production or transfer capacity	TSO, DSO, CBME, ANN	Predicts the production power of the chosen units in the grid and the ampacities of the lines in the system based on the high-res weather forecasts.	Needed for this Use Case.
Optimization of the connection points	TSO, CBME, ANN	Checks different options for the connection points of the defined set of facilities, selecting the optimal option in the end.	Not needed for this Use Case.
Evaluation of the proposed solution	TSO, DSO, CBME, ANN	Evaluates the compatibility of the proposed solution for the problem spotted in some part of the grid (for example, this can be congestion or voltage that is out of the defined boundaries).	Needed for this Use Case.

4 Step by step analysis of use case

4.1 Overview of scenario

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
Bg10 - S1	Flexibility exchange to avoid the congestions	The scenario listed here simulates the situation in which the congestion is spotted in some area of transmission grid. Of course, as already stated before, this area of grid needs to fulfil one condition – it needs to have sufficient amount of the FSPs connected to the distribution grid. The type of these FSPs may vary depending on the observed area, so they may be the WPPs, they can be SPPs or they can be the demand that can be controlled by the system operator in order to provide the flexibility to the grid. In order to mitigate the problem and prevent the undesired consequences, system operator will ask the FSPs to offer their services that may help. The offers will later on be evaluated by using the models updated by the forecasts of relevant system parameters (done in the scope of one of the earlier Use Cases of the Bulgarian pilot). This will allow the TSO to evaluate the potential that each of the FSPs connected to DSO has for resolving the congestions and to enhance the reliability of the planner mitigation measures. That will, in turn, improve the quality of the energy delivery and increase the grid resilience.	All of the listed actors.	Results indicating contingency in the TSO grid in the region in which the FSPs connected to the DSO exist	- Completion of UC01-UC04 this pilot; - Availability of other data needed for the analyses.	TSO will be able to evaluate the potential of certain FSPs connected to DSO grid to help in removing or mitigating the congestions in the grid in a quick and reliable fashion.

4.2 Step-by-step decomposition of scenario

<i>Steps of the scenario</i>						
No.	Event	Description of event	Information exchanged (Y/N)	Information ID	Information producer	Information receiver
S10.1	Exchange of the relevant forecasts	When the IT provider performs the forecasts of the relevant system parameters for the selected part of the grid. Once done, these forecasts will be uploaded to the predefined location, after which the system operator can download them.	Y	I10-01	IT provider	TSO
S10.2	Detection of the problem	When the system operator (for this Use Case, it will be the TSO) downloads the forecasts, they update the grid models and run the needed calculations. If the calculations show that there is an issue in the part of grid in which the FSPs connected to DSO grid exist, the Use Case can move on to the next step in the process.	N	/	/	/
S10.3	Requesting the services from the FSPs in the area	In case the problem was detected in the previous step, TSO reaches out to DSO that asks the FSPs to send their offers for the provision of the service that may mitigate the issue. Along with this, the specifications of service are also sent.	Y	I10-02-a; I10-02-b	TSO; DSO	DSO; FSPs
S10.4	FSPs in the area submit the offers for services	If the FSPs are able to provide the services, they send their offers to DSO, giving detail on the amount of the needed resource that they can provide in the determined timeframe. The DSO then forwards the received offers to the TSO.	Y	I10-03-a; I10-03-b	FSPs; DSO	DSO; TSO
S10.5	Decision on the optimal method to solve the problem	Finally, the TSO uses the delivered offers and the models on which the issue was detected to determine the optimal combination of available resources (if any) that will help in mitigating the issue and maintaining reliable work of the grid.	N	/	/	/

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I10-01	Forecasts of the WPP and SPP production and the ampacity	After the completion of Use Cases 02-04 of Bulgarian pilot, IT provider will have the updated forecasts of the relevant parameters at their disposal. Here, they will provide the obtained values to the system operator.	Communication between different participants in the Bulgarian pilot.
I10-02 (a & b)	Information on the needed services	Once the issue has been spotted in the TSO grid, the system operator in charge of it sends the information to the DSO (-a) that then forwards it to all of the relevant FSPs in the region, asking them to submit offers related to the system services needed for mitigation of issue (-b).	Communication between different participants in the Bulgarian pilot.
I10-03 (a & b)	Offers regarding the required services	The last set of information exchanged here is the one related to the offers that the FSPs submit to the DSO once they get the information on which services are needed to the system (-a). DSO then sends these offers to TSO (-b). Form of offer submission will be predefined in order to reduce possibility of human error in process.	Communication between different participants in the Bulgarian pilot.

6 Requirements (optional)

None thus far.

7 Common terms and definitions

- **Digital Twins (DTs)**

By definition, digital twin represents a digital model of an intended or actual real-world physical product, system, or process (also called a physical twin). In the scope of the Bulgarian pilot, Digital Twins will be created to demonstrate the behaviour of different parts of the Bulgarian power system, such as the transmission grid, the distribution grid and the cross-border energy exchange. Fourth Digital Twin that will be developed will illustrate the combined behaviour of the previous Digital Twins, but on a higher level. In addition to these, minor ANN-trained DTs of wind and solar parks will be created for the accurate forecasting purposes.

- **Flexibility Service Providers (FSPs)**

In simple terms, Flexibility Service Provider is an entity that provides flexibility services to the system by making temporary modifications to the ways in which it consumes, generates or stores electricity in the moments the need for such a service in the system arises. As stated, it could, for instance, belong to the category of controllable demand that could be switched on or off when

the grid needs that, it could be a generator (wind or solar unit, for example) that could be limited or even brought down to zero if the grid is overloaded, or it could be a storage that could be charged or discharged in the moments that action becomes optimal.

- **Artificial Neural Networks (ANNs)**

Neural network, as initially envisaged, is a method in the artificial intelligence area that teaches the software tools to analyse data in a fashion inspired by work of an animal brain. Generally, an ANN consists of the connected units or nodes that are called neurons, since they loosely resemble the neurons in the brain. In the scope of the Bulgarian pilot, ANN will be used as a method to enhance the forecasts of several relevant power system parameters, such as the production powers of the wind and solar units and the ampacities of the lines. This is enabled as the ANNs allow the efficient and reliable work with large amounts of data.

- **Wind Power Plants (WPPs)**

Basically, a wind power plant (alternatively known as the wind park or the wind farm) is a group of wind turbines in the same location used to produce electricity. Wind power plants vary in size from a small number of turbines to several hundred wind turbines, with most of them having horizontal rotation axis and only a small share applying the vertical rotation axis. The expansion of the wind power plants in the previous years happened as they are, alongside solar power plants, considered to be the most developed renewable energy production technology. They can either be connected to the transmission grid or to the distribution grid.

- **Solar Power Plants (SPPs)**

In continuation to the wind power plants, a solar power plant (also known as solar park, solar farm or photovoltaic power station) is a large-scale grid-connected photovoltaic power system designed for the supply of electricity. The solar cells, which comprise one solar power plant, perform the conversion of the energy of the solar irradiation into the electrical energy. As mentioned in the previous definition, they are considered to be among the most developed renewable energy production technologies, explaining their rapid expansion in the past decade. They can also be connected either to the transmission or to the distribution grid.

- **Ampacity**

Ampacity (line rating, ampere capacity) of the power line is defined as the maximum current that the line can carry under predefined conditions without exceeding its temperature rating. It primarily depends on the ability of the conductor to dissipate heat to its surroundings, so it can easily be concluded that the ampacity is directly dependant on the factors such as the air temperature, wind speed and wind direction, icing, etc. The better conditions for cooling the conductor lead to the higher ampacity values, and vice versa. This dependence is what allowed using the ANNs primarily related to the climate conditions for forecasting ampacity.

8 Custom information (optional)

None thus far.

B.2 Dutch-French Pilot Site UCs

B.2.1 DT-enabled cyberattack impact analysis on the operation of integrated power grid [NL01]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
NL01	Transmission, Distribution	DT-enabled real-time cyberattack detection and impact analysis on the operation of integrated power grid

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.3	30.07.2024	Alex Stefanov May Myat Thwe	Added UML Diagrams, Technical Details, Use Case Analysis, Information Exchanged, Common Terms and Definitions	
0.4	15-11-2024	May Myat Thwe Shafiulla Syed	Added Use Case Diagram and Revised KPI section	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this use case is to monitor and detect anomalies associated with cyberattacks, analyze the impact of cyberattacks on stability and cascading failures in real-time on the operation of interconnected power grids.
Objective(s)	The objective of this use case is to leverage the potential of the DT at TSO and DSO level to assess operation of power grids to various cyberattacks and analyze the impact of cyberattacks on system stability and cascading failures.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description

In this use case, digital twin will be used to simulate the cyber-attacks and assess the impact of cyber-attacks on interconnected power grids. The use case will simulate real-time cyber-attacks to evaluate their effects, such as loss of generation capacity, effect on power system components, and the overall impact on power system operations. Additionally, the use case will investigate how cyber-attacks could trigger N-k contingencies, leading to cascading failures and a widespread blackout. Machine learning algorithms will also be used for real-time monitoring and anomaly detection, continuously analysing network traffic and operational data to quickly identify deviations from normal patterns.

Complete description

TSOs and DSOs are responsible for the planning and operation of the physical power grid infrastructure. However, digitalization of the power sector has induced strong interdependencies between communications (IT and OT systems) and power equipment. The tools widely used for power system analysis, e.g., DlgSILENT PowerFactory and PSS/e, cannot model Information Technology (IT) – Operational Technology (OT) communication networks for power grids, do not consider IT-OT disruptions and cannot simulate cyber-attacks and assess their impact on power system operation. Alternatively, system operators must adopt simplifying assumptions, which cannot capture the complexity and uncertainty in cybersecurity threats. Hence, the current power system analysis is limited to the physical domain and is not suitable for power grid cybersecurity and resilience investigations.

This use case will demonstrate analyze and plan the cyber security and operational resilience of power grids to cyberattacks through scenario analysis and modeling. It extends current modelling, simulation and analysis capabilities of power system planners from physical domain only to integrated cyber-physical domains. This use case includes a digital twin (cyber-physical system model) of the power grid operated in the Control Room of the Future (CRoF), which will serve as a demonstrator test-bench at TUD, the Netherlands.

The Cyber Resilience Demonstrator focuses on interconnected power grids at the TSO and DSO levels which include

- transmission-connected generators,
- TSO-DSO bulk supply points
- selected/representative parts of MV and LV distribution networks including microgeneration, battery storage, DERs and EV charging infrastructure

The use case will present the general applicability and flexibility of cybersecurity and grid resilience innovations without revealing sensitive TSO/DSO information or vulnerabilities of the interconnected power grids. In this use case, the following functionalities will be developed and tested.

Functionalities

Conduct real-time cyberattack simulations on digital twins of interconnected power grids to evaluate the impacts of various attack scenarios on power system operations. These simulations will focus on scenarios that result in the loss of generation, interconnector failures, and the disconnection of multiple transmission lines. Different cyberattack scenarios will be designed and executed on the digital twins, aiming to understand their effects on grid stability and resilience. Mininet will be utilized to simulate the network environment, providing a realistic platform for network configurations and attack scenarios. Additionally, an Open Platform Communication Unified Architecture (OPC UA) server will be employed and used as an interface between the physical and cyber simulated layers for data exchange and interactions within the power grid, enhancing the simulation's realism as shown in Figure 1. OPC UA Client and Server are modelled as interacting components in the OPC UA architecture. Preparing attack datasets will further enhance the realism of these simulations and provide valuable data for further analysis.

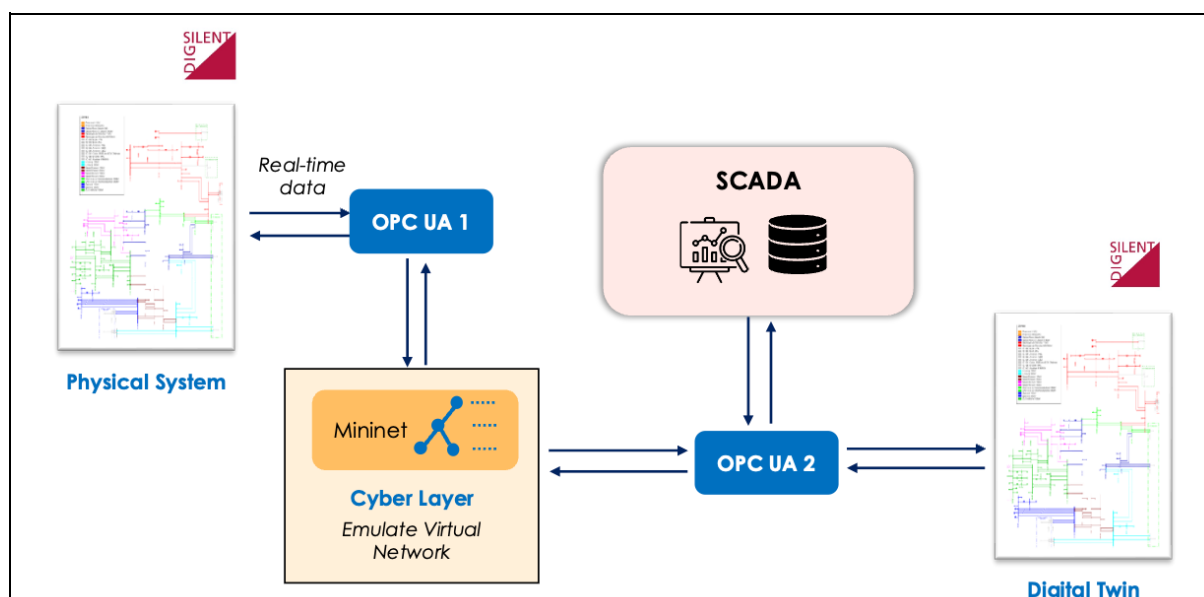


Figure 1. Implementation aspects for cybersecurity assessment

Assess in real-time the impact on the operation of interconnected power grids: Cyberattacks will be simulated in real-time on the digital twin of the interconnected power grids, which can result in loss of generation and interconnectors, and disconnection of multiple transmission lines. The impact on power system operations will be evaluated by computing impact indices based on the loss of load, frequency, voltage deviations, survived islands, and affected power system components.

Analyse how cyber-attacks can initiate cascading failures and cause a blackout: Cyber-attacks can cause multiple contingencies, e.g., N-k. The probability of occurrence of such contingencies is almost null when caused by physical disturbances. However, cyber-attacks can trigger them simultaneously. This significantly speeds up the point of no return, leading to cascading failures and blackout. A computational method and tool will be developed and demonstrated that is used to assess the cascading failure mechanism and analyse how cyber-attacks can cause a blackout.

Implement anomaly detection using machine learning algorithms to continuously monitor network traffic and operational data, quickly identifying deviations from normal patterns. By analyzing these deviations, the system can promptly detect potential cyber threats and operational anomalies. This integrated approach, leveraging Mininet for network simulation and an OPC UA server for protocol simulation, will enhance the ability to protect power grids from cyberattacks and ensure stable and reliable power system operations.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI-01	Number of Simulated Cyberattacks	Number of cyberattacks to be simulated will be 3 types of attacks	Directly related to the objective of conducting scenario analysis and modeling to understand the effects of various cyberattacks on power grids.
KPI-02	Impact Index of Cyberattacks	Will measure and evaluate the overall impact of cyberattacks, considering loss of load, frequency deviations, voltage deviations, survived islands, and affected components.	Aligns with the objective of evaluating the impacts of various cyberattack scenarios on power system operations.

KPI-03	Time to Cascading Failures	Will measure the time taken from the initiation of a cyberattack to the point where cascading failures begin.	Aligns with the objective of analysing how cyberattacks can lead to cascading failures and potential blackout
KPI-04	Machine Learning Anomaly Detection Accuracy	The accuracy of machine learning algorithms in correctly identifying anomalies within the power grid will be over 85%.	Relates to the objective of using machine learning for anomaly detection to promptly identify and respond to cyber threats, ensuring enhanced protection of power grid operations.

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	Power Factory's steady-state time-domain simulations are assumed to represent the real physical power system since generating time domain power flow from the actual infrastructure is not feasible. In addition, another Power Factory Model will act as digital twin of power system, to perform RMS simulations.
2	The Dutch integrated electricity grid model includes the Dutch transmission system model and an equivalent representation of distribution at connection points, covering both TSO and DSO aspects. It can portray that the digital twin reflects the integrated nature of the Dutch electricity grid, including interactions between transmission and distribution systems.
3	When setting up network topology, it is assumed that a hacker is already present in the system and has the capability to execute different cyberattacks. This focuses the assessment on anomaly detection and impact analysis, rather than on the initial breach.
4	Communication channels between different components of the digital twin are stable and reliable and there is uninterrupted data flow and accurate simulation of cyber-physical interactions.
<i>Prerequisites</i>	
1	Access and Configuration of synthetic Dutch Transmission and Distribution Model: Secure access to the synthetic Dutch transmission and distribution model within PowerFactory, ensuring it is properly configured and licensed for both steady-state time-domain simulation and RMS simulations in PowerFactory.
2	Setup and Configuration of Simulation Tools: Properly set up and configure all necessary tools and technologies to accurately model the digital twin's cyber-physical environment. This includes power system simulation tools such as PowerFactory, Mininet, OPC UA Server, SCADA system, etc.
3	CRoF Infrastructure Readiness: Ensure the physical and digital infrastructure for the Control Room of the Future (CRoF) at TU Delft is fully operational and equipped with the necessary tools, virtual machines, servers to support high-performance computing resources for complex simulations and real-time data processing.
4	Network Environment Simulation: Configure and simulate network environments using Mininet to replicate real-world network conditions and cyberattack scenarios. This includes setting up virtual networks, configuring routers and switches, and simulating realistic network traffic patterns.
5	Availability of Datasets for Machine Learning: Ensure the availability of required datasets for training machine learning models, generated from simulations.

1.7 Further information to the use case for classification/mapping

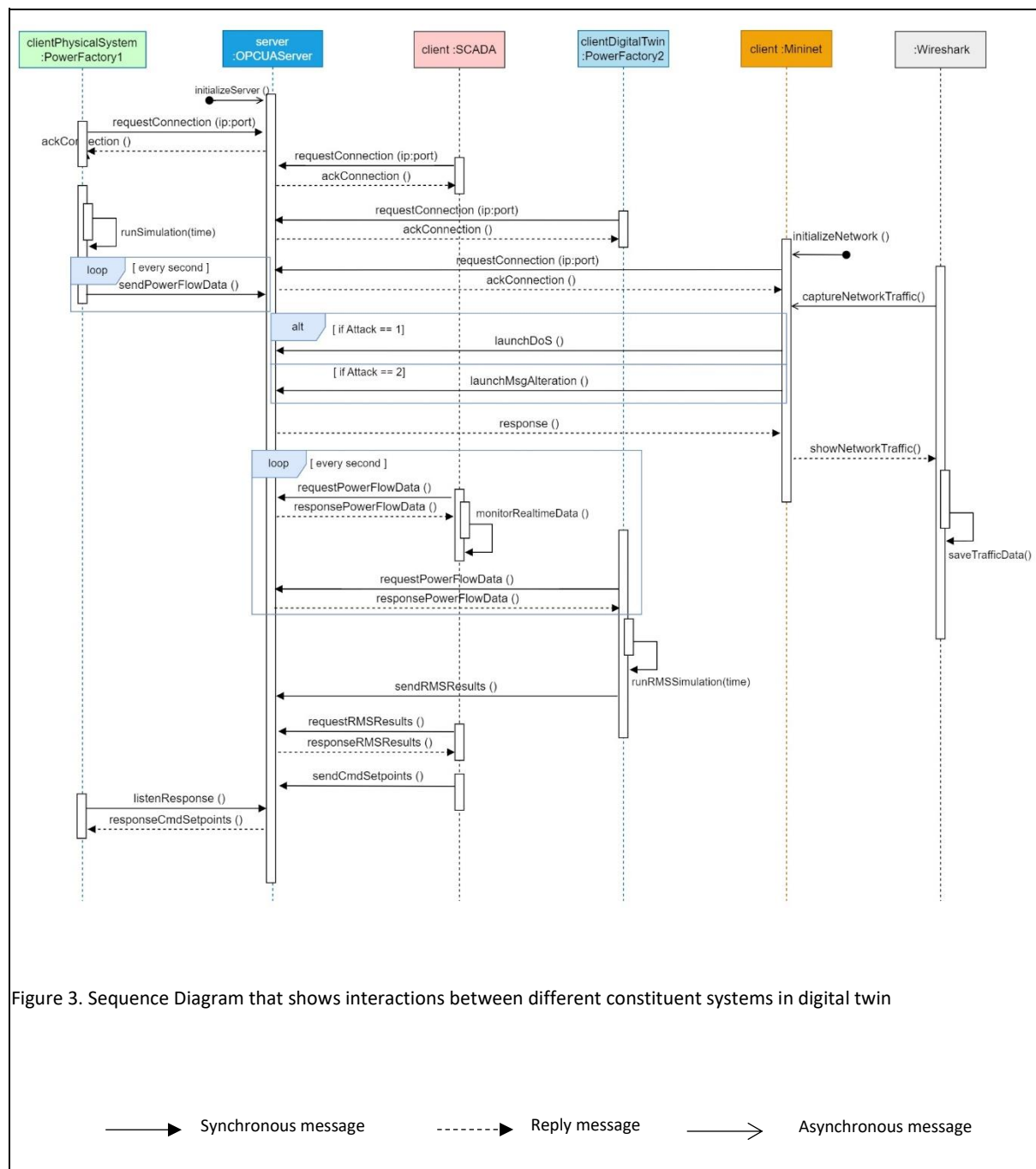
<i>Classification information</i>
<i>Relation to other use cases</i>

NL02
Level of depth
The use case involves detailed scenario analysis and real-time simulations, providing deep insights into the effects of cyberattacks on power grid operations. It covers both theoretical aspects (modeling and simulation) and practical applications (real-time monitoring and processing).
Prioritisation
Primary Focus: Simulating different types of cyberattacks, performing impact analysis, and studying cascading failures and stability issues.
Secondary Focus: Collecting network traffic data and using machine learning for anomaly detection. While still important, these activities are considered less critical in the initial stages of the use case.
Generic, regional or national relation
This use case has specific relevance to regional power grids, it considers the Dutch transmission grid, as well as part of Dutch distribution grid in a certain region.
Nature of the use case
Demonstrative, Analytical and Methodological
Further keywords for classification
Cybersecurity, Digital Twin, Cyber-Physical Systems, Modeling and Simulation, Cascading Failures, Machine Learning, Anomaly Detection, Impact Analysis

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case
UML Diagrams Figure 2. Use Case Diagram



3 Technical details

3.1 Actors

3.2 Systems

Individual systems included in this use case are considered as actors.

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
PF_PhysicalSystem	Academic Institute	Used for performing time-domain steady-state simulations of the power system. It allows for generating It allows for generating voltage profiles, and current distributions, etc. under normal operating conditions.	
PF_DigitalTwin	Academic Institute	Serves as a digital twin for the power system, enabling RMS simulations. It is used for detailed dynamic analysis, including attack impact analysis, and cascading failures analysis. The digital twin helps in investigating the behaviour of the power system under different scenarios and facilitates optimization or control strategies.	
OPCUA_Server	Academic Institute	Facilitates secure and reliable data exchange between the power simulation tools (PowerFactory), SCADA system, and Mininet. It acts as a central communication hub, ensuring interoperability and data consistency. The server supports real-time data monitoring, historical data access, and event-driven communications.	
SCADA	Academic Institute	This system monitors and controls the power system in real-time. It collects data from various sensors and devices, allowing operator to make informed decisions. It also responses to system events such as providing commands and setpoints.	
Mininet	Academic Institute	Mininet is a network emulator that creates a realistic virtual network, running real kernel, switch, and application code, on a single machine. It is used for testing and developing network configurations and protocols.	
Wireshark	Academic Institute	Wireshark is a network protocol analyser used for network analysis, software and communications protocol development, and education. It captures and interactively browses the traffic running on a computer network. Wireshark helps in diagnosing issues in the communication between different systems by providing detailed packet-level data.	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor (System)	Triggering event	Pre-condition	Post-condition
1	Initiate Simulation	Starting a time-domain steady-state simulation using PowerFactory Physical System.	PowerFactory Physical System	Researcher initiates simulation command.	PowerFactory is configured and connected to OPC UA Server.	Simulation data is generated and sent to OPC UA Server.
2	OPC UA Server Access	Accessing OPC UA Server to retrieve and process data	OPC UA Server	Data is available on OPC UA Server	OPC UA Server has received data from PowerFactory	Data is processed and ready for access by other systems.
3	SCADA Data Access	Accessing and visualizing processed data from OPC UA Server	SCADA System	Processed data is available on OPC UA Server.	SCADA is connected to OPC UA Server	SCADA displays real-time data.
4	Digital Twin Simulation	Running RMS simulation for detailed analysis using PowerFactory Digital Twin	PowerFactory Digital Twin	Processed data is available on OPC UA Server	PowerFactory Digital Twin is configured and connected to OPC UA Server.	Detailed RMS simulation data is generated and sent to OPC UA Server.
5	SCADA Command Response	SCADA retrieves RMS simulation results to determine necessary commands and setpoints for the physical system	SCADA System	RMS simulation results are available on OPC UA Server	SCADA is monitoring RMS simulation data	SCADA sends commands and setpoints back to PowerFactory Physical System through OPC UA Server.
6	Mininet Integration	Integrating network simulation with Mininet and accessing data from OPC UA Server	Mininet	Processed data is available on OPC UA Server	Mininet is set up and connected to OPC UA Server	Mininet utilizes data for network simulation and launching different attacks.
7	Network Monitoring	Capturing and analyzing network traffic using Wireshark	Wireshark	Network traffic starts	Wireshark is set up and monitoring the network	Network data is captured, filtered and saved.

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
I-01	Simulation Data	Data generated by the PowerFactory Physical System during the time-domain steady-state simulation, including active power, reactive power, current, voltage, frequency, and circuit breaker status.	

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
I-02	RMS Simulation Results	Detailed results generated by the PowerFactory Digital Twin during the RMS simulation, including detailed voltage and current waveforms, system stability indices, and other performance metrics.	
I-03	OPC UA Server Data	Simulation data that has been processed by the OPC UA Server, making it ready for access by SCADA, PowerFactory Digital Twin, and Mininet.	
I-04	SCADA Commands and Setpoints	Commands and setpoints determined by SCADA based on the RMS simulation results to optimize and control the physical power system operations.	
I-05	Network Traffic Data	Data captured and analyzed by Wireshark, including packet information, protocols, etc.	

6 Requirements (optional)

7 Common terms and definitions

RMS – Root Mean Square

SCADA – Supervisory Control and Data Acquisition System

OPC UA – Open Platform Communication Unified Architecture

TSO – Transmission System Operator

DSO – Distribution System Operator

OT – Operational Technology

IT – Information Technology

CRoF – Control Room of Future

MV – Medium Voltage

LV – Low Voltage

8 Custom information (optional)

B.2.2 DT-based dynamic stability assessment under active power flow changing events [NL02]

1 Description of the use case

1.1. Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
NL02	Transmission/Distribution	DT-based dynamic stability assessment under active power flow changing events.

1.2. Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	24.05.2024	José Rueda Jonathan Avilés	/ N.A.	
0.2	23.07.2024	José Rueda Jonathan Avilés	/ Added KPIs and use case conditions	
0.3	29.07.2024	José Rueda Jonathan Avilés	/ Added Diagrams, Technical Details, Information Exchanged, Common Terms and Definitions	
0.4	27.09.2024	José Rueda Jonathan Avilés	/ Added step-by-step analysis	

1.3. Scope and objectives of use case

Scope and objectives of use case	
Scope	This use case aims to develop and implement a Digital Twin (DT) to assess and enhance the stability of power systems under various active power flow disturbances. The DT will model and simulate the real-time dynamics of the power grid, including interactions between Distribution System Operators (DSOs) and Transmission System Operators (TSOs). The study will focus on understanding the impact of events such as generation tripping, load shedding, transmission line faults, large-scale renewable integration fluctuations, and demand response events on system stability.
Objective(s)	1. Develop a Digital Twin (DT) capable of simulating the dynamic behaviour of power systems during active power flow disturbances. 2. Calibrate the DT using generated signal records from simulations, accessible published databases, and parameter estimation techniques to obtain a numerically acceptable representation of real-time system dynamics. 3. Analyze the impact of various disturbance scenarios on system stability, focusing on frequency deviations, voltage stability, and power oscillations. 4. Evaluate and propose control and mitigation strategies that enhance the coordination between DSOs and TSOs during disturbance events.
Related business case(s)	

1.4. Narrative of Use Case

Narrative of use case	
Short description	
Development and utilization of a Digital Twin (DT) to evaluate and enhance the stability of the power system under various active and reactive power flow disturbance scenarios, emphasizing the critical interaction between Distribution System Operators (DSOs) and Transmission System Operators (TSOs). The DT will simulate system responses to identify potential stability issues and propose solutions.	
Complete description	
Modern power systems' increasing complexity, with the high integration of renewable energy sources and dynamic loads, necessitates advanced tools for stability assessment. This use case focuses on developing a Digital Twin (DT) to assess and improve the stability of power systems in scenarios where active and reactive power flow is disrupted. These disruptions could be due to sudden generation losses, significant load changes, or faults in the transmission network. Properly managing active and reactive power flows is crucial for the seamless interaction between the distribution and transmission networks. Effective coordination between Distribution System Operators (DSOs) and Transmission System Operators (TSOs) ensures the reliability and stability of the entire power system, especially during disturbance events. The DT will be calibrated to reflect the real-time dynamics of the power system using signals generated from simulations, accessible published databases, and parameter estimation techniques. Initially, it will simulate various types of active and reactive power flow disturbances, such as generation tripping, load shedding, transmission line faults, large-scale renewable integration fluctuations, and demand response events. The model parameters will be refined by comparing the DT's response with signals representative of the actual system data by using adequate metrics that ensure a close numerical representation. Critical aspects of the study include: Calibration: Using signals generated from simulations and accessible published databases to tune the DT model parameters, ensuring it represents the system's dynamic behaviour. Scenario Analysis: Simulating various disturbance scenarios to study their impact on system stability, including frequency deviations, voltage stability, and power oscillations, focusing on the coordination between DSOs and TSOs. Control and Mitigation Strategies: Evaluating the effectiveness of various control strategies, such as automatic generation control (AGC), load shedding schemes, and the incorporation of virtual inertia from renewable sources, to mitigate the effects of disturbances. Predictive Maintenance: Utilizing the DT to predict potential stability issues and proactively address them through maintenance or system upgrades, ensuring that both DSOs and TSOs are equipped to handle future challenges. Active-power-changing events considered in this study include: • Generation Tripping: sudden disconnection of power generation units. • Load Shedding: intentional reduction of load to maintain balance. • Transmission Line Faults: failures or interruptions in transmission lines. • Large-Scale Renewable Integration Fluctuations: variability in renewable energy sources like wind or solar power. • Demand Response Events: changes in demand due to response programs or unplanned consumption spikes. Reactive-power-changing events considered in this study include: • Capacitor Bank Switching: installed to manage voltage levels and power factor. • Inductive Load Variation: changes in the operation of loads such as motors, transformers, or reactors. • Voltage Regulation by Transformers: adjustments in transformer tap settings. • Synchronous Condenser Operation: used to manage reactive power and voltage stability. • Static VAR Compensator (SVC): activation or deactivation to provide dynamic Q support. • STATCOM Operations: activation or deactivation to provide dynamic Q support. The ultimate goal is to develop a robust DT that not only reflects the current state of the power system but can also predict and mitigate stability issues arising from active and reactive power flow disturbances.	

1.5. Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to the mentioned use case objectives

KPI-01	Frequency Deviation Index	Maximum frequency deviation (in Hz) recorded during active power flow disturbances.	Aligns with Objective 3: Analyzing the impact of disturbance scenarios on frequency stability.
KPI-02	Voltage Deviation Index	Maximum voltage deviation (in per unit, p.u.) during different disturbance events.	Aligns with Objective 3: Studying voltage stability under various scenarios.
KPI-03	Scenario Analysis Coverage Index	Number of different disturbance scenarios successfully simulated and analyzed.	Directly related to Objectives 1 and 3: Simulating and analyzing various disturbance scenarios.
KPI-04	Stability Restoration Time	Average time (in seconds) taken to restore system stability after a disturbance event.	Relates to Objective 4: Effectiveness of implemented control strategies.
KPI-05	Predictive Maintenance Accuracy Index	Percentage of correctly predicted stability issues that were proactively addressed.	Supports Objective 3 and Objective 4: Ensuring proactive maintenance and effective mitigation strategies.

1.6. Use case conditions

Use case conditions	
Assumptions	
1	TSO and DSOs will verify that PowerFactory's steady-state and time-domain simulations provide acceptable numerical approximations of the real physical power system since confidentiality aspects protect data from the actual infrastructure. The Digital Twin (DT) will use an alternative PowerFactory model for active power balance and frequency stability simulations and RTDS/RSCAD for fast stability scenarios.
2	Available data (generated signal records from simulations or accessible published databases) for calibrating the DT is available and representative of past disturbance events.
3	The Dutch integrated electricity grid model includes the transmission system model and an equivalent representation of the distribution system at important connection points. The DT will reflect the interactions between transmission and distribution networks at those connection points.
4	Communication channels between different components of the DT are assumed to be stable and reliable, ensuring uninterrupted data flow and close numerical simulation of power system dynamics.
Prerequisites	
1	Secure access to the Dutch transmission and distribution models within PowerFactory and RSCAD, ensuring proper configuration and licensing for both steady-state and time-domain simulations.
2	Properly set up and configuration of all the necessary tools and technologies to model the DT's environment. This includes simulation tools such as PowerFactory, RTDS/RSCAD, SCADA systems, and communication networks.
3	The physical and digital infrastructure of the Control Room of the Future (CRoF) at TU Delft is fully operational. This includes high-performance computing resources and the necessary virtual machines and servers for complex simulations.
4	Availability of required datasets for calibrating the DT. These datasets should be derived from historical data and real-time measurements generated from simulations and actual grid operations.

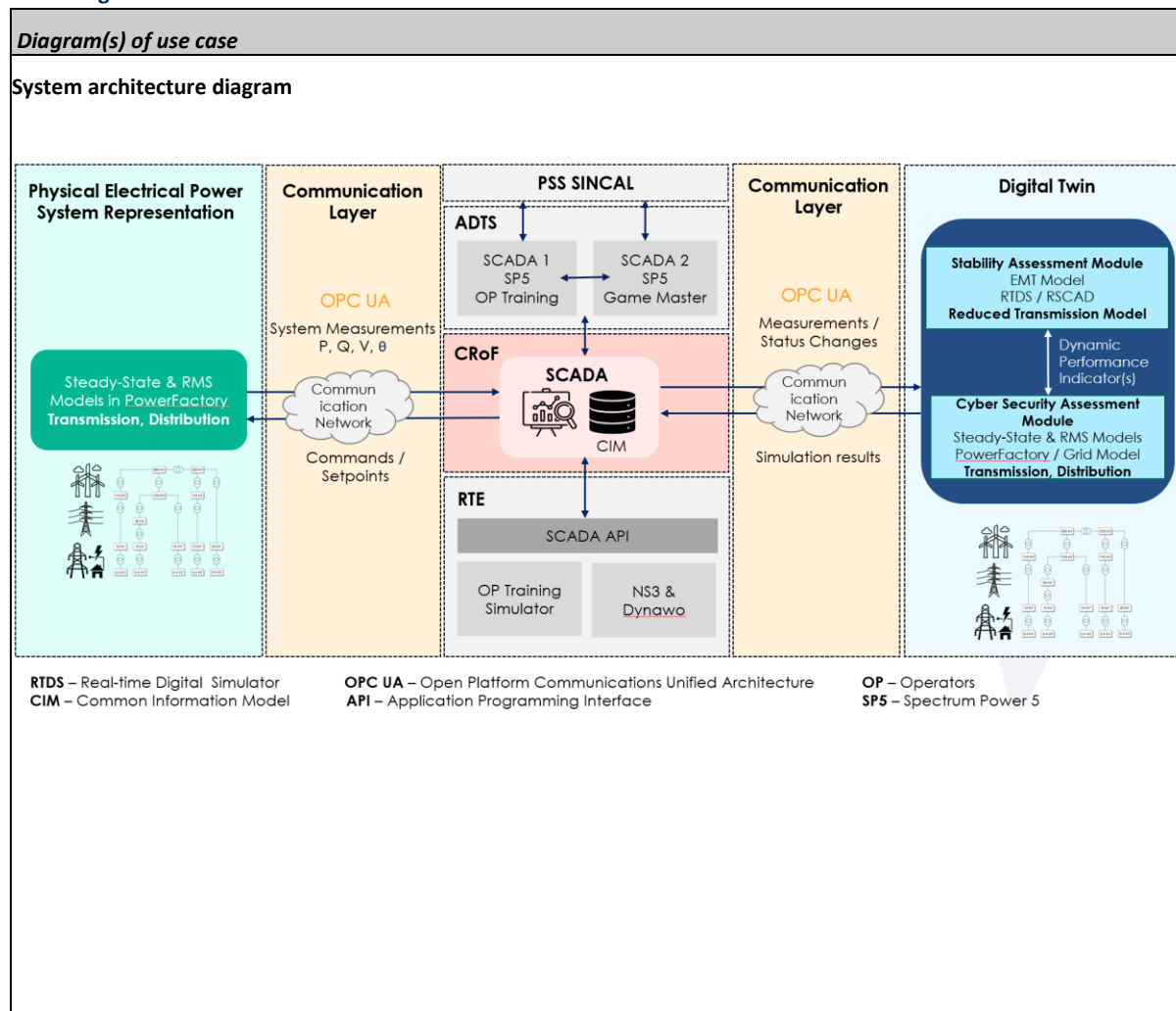
1.7. Further information to the use case for classification/mapping

Classification information
Relation to other use cases
NL01
Level of depth

The use case involves detailed scenario analysis and real-time simulations, providing deep insights into the effects of active and reactive power flow disturbances on power grid stability. It covers both theoretical aspects (modeling and simulation) and practical applications (real-time monitoring and processing).
Prioritization
Primary Focus: Simulating different types of active and reactive power flow disturbances, performing impact analysis, and studying system stability issues such as frequency deviations, voltage stability, and power oscillations. Secondary Focus: Evaluating and proposing control and mitigation strategies to enhance coordination between DSOs and TSOs during disturbance events. While still important, these activities are considered less critical in the initial stages of the use case.
Generic, regional, or national relation
This use case is specifically relevant to regional power grids, particularly the Dutch transmission grid and parts of the Dutch distribution grid in specific regions.
Nature of the use case
Demonstrative, Analytical, and Methodological
Further keywords for classification
Digital Twin, Power System Stability, Active Power Flow Disturbances, Modeling and Simulation, Control Strategies, DSO-TSO Coordination, Renewable Integration, Demand Response, Predictive Maintenance

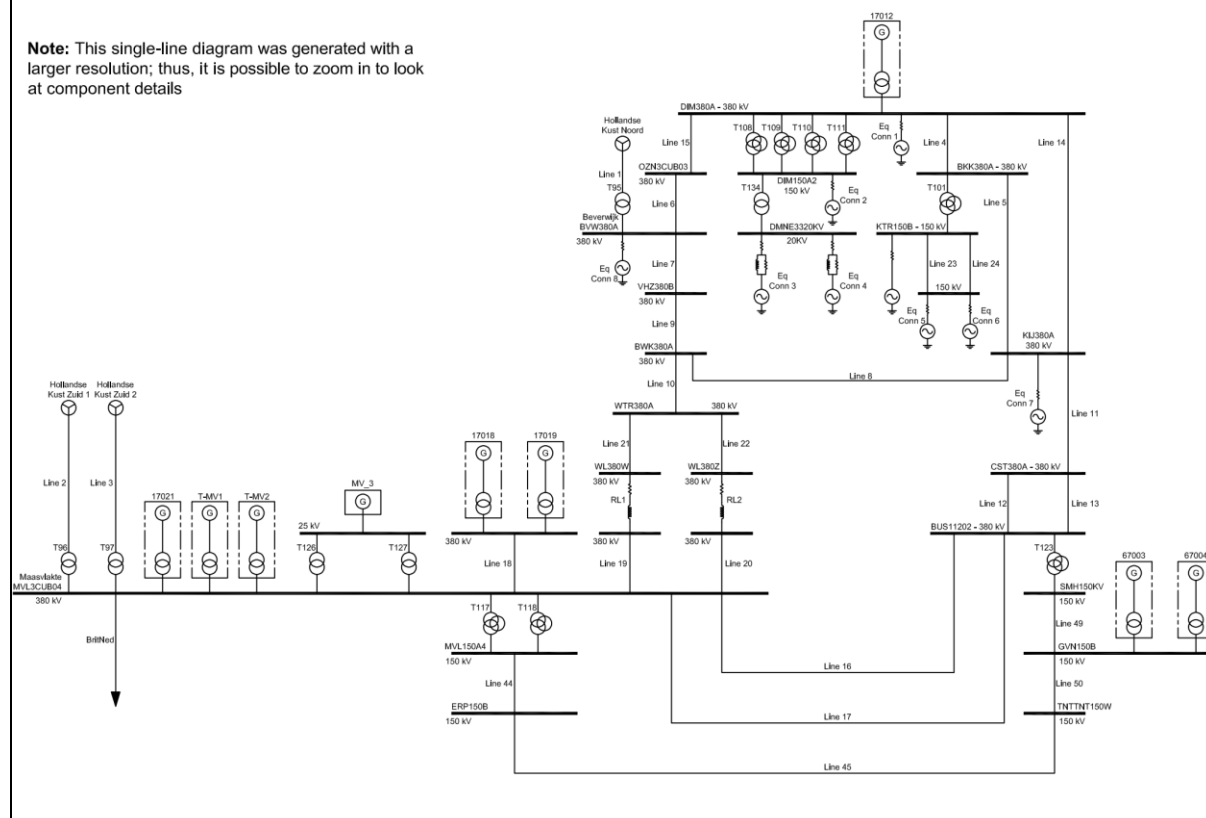
1.8. General remarks

2 Diagrams of use case



Randstad region's transmission network single-line diagram (SLD)

Note: This single-line diagram was generated with a larger resolution; thus, it is possible to zoom in to look at component details



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Zones of the transmission network		This case is executed at the transmission level. The specific zones are to be defined once the models are complete.	
Actor name	Actor type	Actor description	Further information specific to this business use case
Transmission System Operator (TSO)		This actor is responsible for maintaining and operating the transmission network.	TSO will be responsible for providing records and historical data for adequate system modeling. Since direct connection to the system is not feasible, a digital model to generate synthetic data is created and shall be verified by this actor.
Delft University of Technology		This actor owns the Control Room of the Future (CRoF), where the real-time simulator (RTDS) and additional hardware are located.	The demonstration of the Dutch digital twin pilot for stability assessment will be performed at TU Delft.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
PF_PhysicalSystem	Academic Institute	It is used for performing time-domain steady-state simulations of the power system. It allows for generating power flows, voltage profiles, parametric sensitivity analysis, etc., under different operating conditions.	
PF_DigitalTwin	Academic Institute	It serves as a digital twin for the power system, enabling RMS simulations. It is used for detailed dynamic analysis, including attack impact analysis, and cascading failures analysis. The digital twin helps investigate the behaviour of the power system under different scenarios and facilitates optimization or control strategies.	
RSCAD_DigitalTwin	Academic Institute	It serves as a digital twin for the power system, enabling EMT simulations. It is used for detailed dynamic analysis and fast stability issues. The digital twin helps investigate the power system's behaviour under different scenarios and facilitates optimization or control strategies.	
OPCUA_Server	Academic Institute	It facilitates secure and reliable data exchange between the power simulation tools (PowerFactory), SCADA system, and Mininet. It acts as a central communication hub, ensuring interoperability and data consistency. The server supports real-time data monitoring, historical data access, and event-driven communications.	
SCADA	Academic Institute	This system monitors and controls the power system in real-time. It collects data from various sensors and devices, allowing the operator to make informed decisions. It also responds to system events, such as providing commands and setpoints.	

3.3. References

Step-by-step analysis of the use case

4.1. Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Generation Tripping Event	Sudden disconnection of a power generation unit, affecting grid stability.	TSO	Sudden tripping of a large generation unit.	The DT has baseline data on system	The DT simulates system response, analyzes stability

					operation before the trip.	impacts, and suggests mitigation.
2	Load Shedding Activation	Intentional reduction of load to prevent grid instability.	TSO, DSO	Frequency falls below a critical threshold.	DT detects frequency drop and models load shedding requirement.	Stability is restored, and the DT provides analysis of the impact and recovery process.
3	Transmission Line Fault	Failure or disconnection of a key transmission line affecting power flow.	TSO	Transmission line fault or failure due to external conditions.	DT has data on the grid configuration and current power flow before the fault.	DT simulates the fault, proposes rerouting of power, and evaluates system performance post-fault.
4	Renewable Integration Event	Variability in renewable generation (e.g., wind or solar fluctuations).	DSO, TSO	Sudden reduction in renewable output due to weather changes.	DT monitors renewable generation and weather forecasts.	DT simulates the fluctuation and suggests compensatory strategies to ensure grid stability.
5	Demand Response Event	Sudden change in load due to demand response signals.	DSO, TSO	Triggered by demand response programs or unplanned spikes.	DT monitors load profiles and is ready to simulate demand changes.	DT analyzes load impact and response effectiveness in maintaining system stability.

4 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
I-01	Simulation Data	Data generated by the PowerFactory Physical System during the time-domain steady-state simulation, including active power, reactive power, current, voltage, frequency, and circuit breaker status.	
I-02	RMS Simulation Results	Detailed results generated by the PowerFactory Digital Twin during the RMS simulation, including detailed voltage and current waveforms, system stability indices, and other performance metrics.	
I-03	EMT Simulation Results	Detailed results generated by the RSCAD Digital Twin during the EMT simulation, including detailed voltage and current waveforms, system stability indices, and other performance metrics.	

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I-04	OPC UA Server Data	Simulation data that has been processed by the OPC UA Server, making it ready for access by SCADA, PowerFactory Digital Twin, and Mininet.	
I-05	SCADA Commands and Setpoints	Commands and setpoints determined by SCADA based on the RMS simulation results to optimize and control the physical power system operations.	

5 Requirements (optional)

6 Common terms and definitions

RMS	–	Root Mean Square
EMT	–	Electromagnetic Transient
SCADA	–	Supervisory Control and Data Acquisition System
OPC UA	–	Open Platform Communication Unified Architecture
TSO	–	Transmission System Operator
DSO	–	Distribution System Operator
OT	–	Operational Technology
IT	–	Information Technology
CRoF	–	Control Room of Future
EHV	–	Extra-High Voltage
HV	–	High Voltage
MV	–	Medium Voltage
LV	–	Low Voltage

7 Custom information (optional)

B.2.3 Power system training simulator for complex and critical situations [FR01]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
FR01	Transmission	Power system training simulator for complex and critical situations

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	22.10.2024	Thibaut Vermeulen, Oliver Bretteville	Scope, objectives, description	
0.2	20.11.2024	Thibaut Vermeulen, Olivier Bretteville	Filled sections 2, 3, 4, 5	
0.3	09.01.2025	Geethu Joseph	Add UML Use case diagram, edited section 4	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this use case concerns: - Cooperative training sessions for system operators. - Testbed for software or hardware modules.
Objective(s)	The objective of this use case is to improve the training of system operators on realistic network scenarios, involving power network as well as communication network events. The DT should be able to play scenarios and to record the results for debrief with trainees.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
The digital twin is meant for training system operators on stability-critical scenarios and for testing of new components (automata, software decision modules, ...). It will include several modules within a co-simulator interfaced through an orchestrator module :

- Cyber-physical simulators to represent physical and cyber networks.
- SCADA that will display network state to operators and send orders from the operators to the cyber-physical simulators.
- A game master will supervise all the modules and will have the ability to run training scenarios.

The twin provides input/output interfaces for interfacing software or hardware modules.

Complete description

The aim is to develop a kind of twin of the control room that can be used both to train our operators and to test under real conditions the new decision-support assistants that we are developing in R&D division. For this we want to model cyber-physical aspects, including the new range of automatic controllers that we are designing, we want to model telecoms networks, and of course all this will be scenarized to be able to simulate events on both physical and telecom networks.

It will be an innovative educational tool specifically calibrated to analyze stability-critical scenarios, providing a comprehensive platform for operator readiness and response optimization. The integration of SCADA interfaces and a communication system simulator into the DT will enhance the training experience, offering a realistic and immersive environment for operators to hone their skills and adapt to dynamic grid conditions effectively.

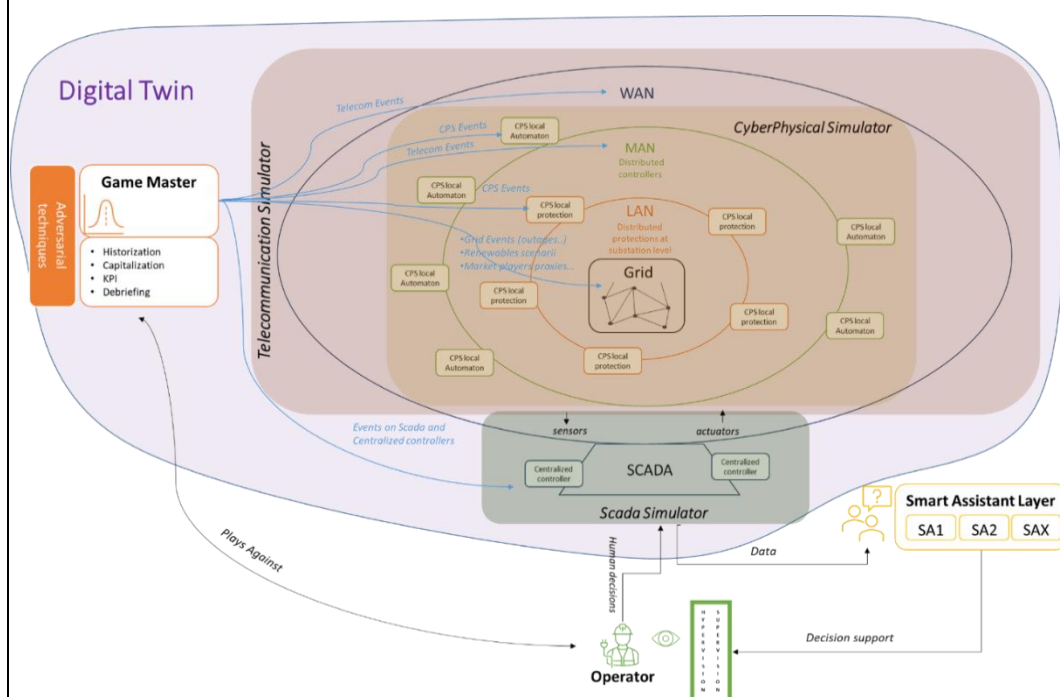


Figure 1: French Digital Twin Framework

This framework is made of:

- **Cyber-physical simulators** that can be like training simulators. They use real time data and scenario inputs and simulate the real-world physics and cyber layers (LAN and MAN layers). This simulator must give accurate results over time as the training session may last a while (hours) but should also run fast as the operator shouldn't experience any lagging or freezing effects. In other words, it must deal with all the time-domain simulation complexities (digital controllers, various automatons, etc.) while respecting short timing (less than 1 sec computation time for 1 sec simulated scenario). Co-simulation can be considered between the asset simulator (including telecommunication components) and the cyber-physical simulator.
- **SCADA** as the interface between the operator, the game master and the cyber-physical simulators. This SCADA displays the information (GUI) and receives the operators' orders as they would be sent/received as in the real world. Different levels of details are possible: a proxy of the real SCADA and WAN systems, a micro-WAN and an opensource SCADA simulator or replicas using the same protocols for sensors and actuators.
- **Game Master** that generates scenarios for the game (Training session) such as: wind scenarios – PV variations – classical generation outages, events affecting the data acquisition - delays, cyber-attacks, events that impact the automata on the field, electrical grid failures (faults, overloads). Creates contrasted and "queue distribution" while realistic scenarios to stress the operators during the game. Historizes and capitalizes on the game and on decision

making. It enables ex-post comparison of the various decision support modules. It gives the opportunity to debrief the sessions and enabling efficient comparison between the different modules tested. Game master is also responsible for configuring the system modules (grid model, mapping of grid assets with their telecommunication correspondents, ...). • Smart assistant layer is an independent module from the digital twin. Any proven convenient solution could be plugged into the framework. Live demos will demonstrate the tool's ability to perform advanced training sessions, including the various features of each module.

1.5 Key performance indicators (KPI)

<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
FR01-KPI1	Real-time physical simulation	Physical simulation should take less than simulated time considering a 1s time step.	Module performance for real-time simulation.
FR01-KPI2	Training simulator events	The cyber-physical simulator manages pre-scanarized events and events sent by other modules (SCADA emulator, game master, smart assistants) , at the rate of 1 event per second while keeping real-time synchronization. Complex events can be queued and sent to the simulator over multiple time steps.	Realistic network actions.
FR01-3	Event failure rate	The event success rate when played by the trainees should be more than 95%.	To reflect a realistic network, actions can be sent through SCADA interface.
FR01-KPI4	SCADA emulator	SCADA emulator displays update of points and measurements within 1 second.	Real-time interactions with trainees.
F01-KPI5	Real-time performance	Training simulator should be able to handle 1 non-critical event per second, with a time step of 1s for the French network (6000 voltage levels).	Realistic network simulation.

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	Physical simulator Dynawo can represent suitable dynamic phenomena within the time frame allocated by the real-time training simulator.
2	Realistic operation conditions can be represented in real time to system operator under training through physical and cyber simulations.
<i>Prerequisites</i>	

1	Training scenarios derived from current training classes and operations observation.
2	Data for French power grid and telecommunication network, used to build training scenarios.

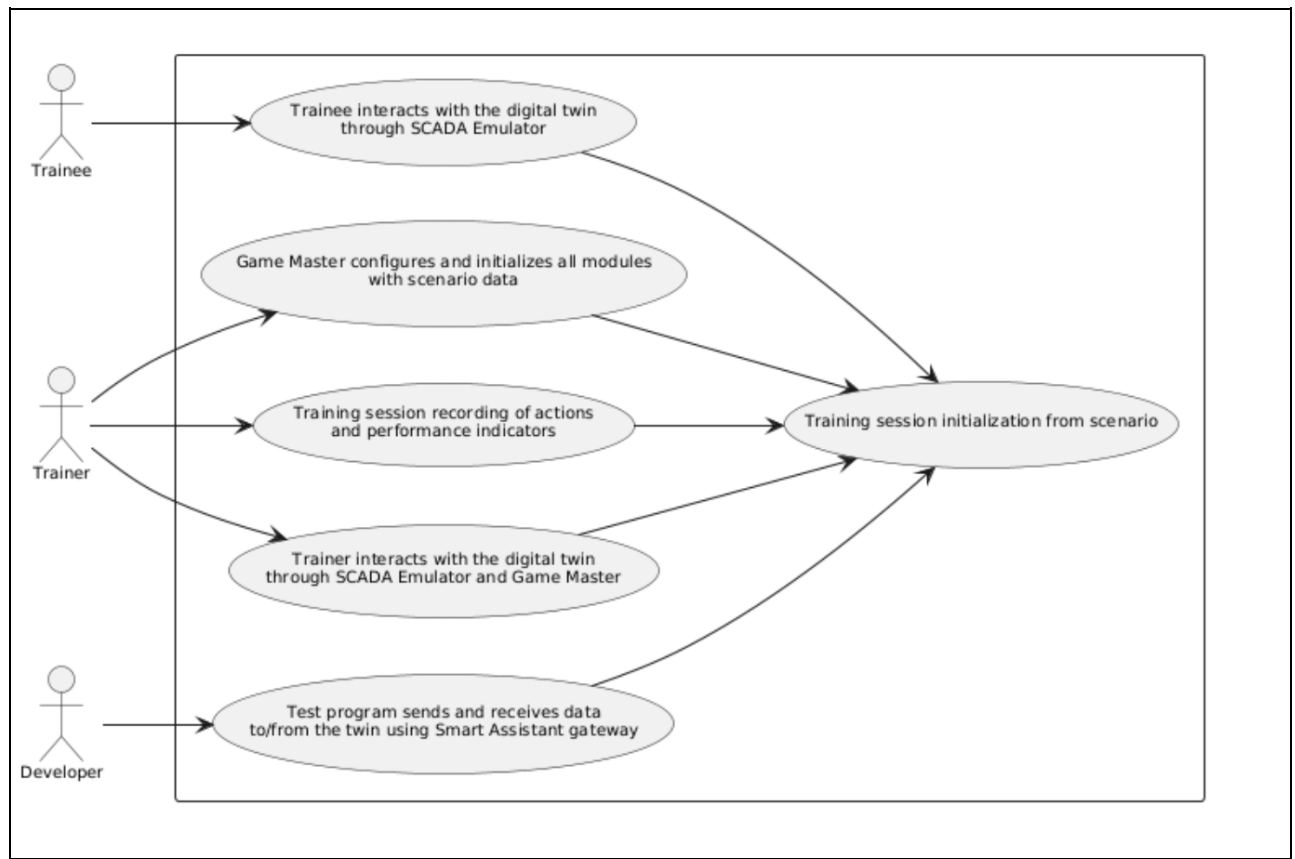
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Level of depth
Prioritisation
High level
Generic, regional or national relation
National relation
Nature of the use case
Further keywords for classification

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Trainer	Human trainer	Builds the scenarios. Runs the training session. Debriefs results of the session.	
Trainee	System Operator	Attend the training session.	
Smart assistant developer	Developer or tester	Responsible for external software module development.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Dynawo physical simulator	Open source	Module responsible of the physical representation of the network	
PowSyBI , Grid management framework	Open source	Module responsible of electric grid modelling in several modules (IIDM data format) as well as imagery handling in SCADA emulator GUI	
Cyber Asset simulator	RTE/Open source	Asset simulator (including telecommunication assets)	
SCADA emulator	RTE/Open source	SCADA interface with power grid states, values, alarms, controls.	
Orchestrator	RTE/Open source	Orchestrates data flows between modules	
Game Master	RTE/Open source	Entry point of the training simulator. Manages scenarios, and recording of the training sessions	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition

1	Initialization	Game master configure all modules and initializes all modules with scenario data	Trainer/developer	Training session initialization from scenario		
2	Training session – trainee	During training session, the trainee interacts with the digital twin through SCADA emulator	Trainee	Initialized training session start	Initialisation	
3	Training session – trainer	During the training session, the trainer interacts with the digital twin through SCADA emulator and Game master	Trainer	Initialized training session started	Initialisation	
4	Training session debrief	Training session recording of actions and performance indicators can be used	Trainer	Initialized training session terminated	Training session	
5	Smart assistant testing	The test program can send and receive data to/from the twin using smart assistant gateway	Developer	Initialized training session start	Initialization	

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1	Telecommands/setpoints	SCADA -> Orchestrator	
2	Statuses/measurements	Orchestrator -> SCADA	
3	Statuses/measurements	CPS-CAS -> Orchestrator	
4	Telecommands/setpoints	Orchestrator -> CPS-CAS	
5	Dynawo scenario	Orchestrator -> CPS-GS	
6	Events/measurements	CPS-GS -> Orchestrator	
7	Initial grid model,	Game master -> Orchestrator	

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
	Grid model modification		
8	Grid model update	Orchestrator -> Game master	
9	Statuses/measurements	Orchestrator -> Smart assistant layer	
10	Telecommands/setpoints	Smart assistant layer -> Orchestrator	

6 Requirements (optional)

7 Common terms and definitions

CPS	Cyber-Physical Simulator
CPS-GS	Cyber-Physical Simulator - Grid simulator
CPS-CAS	Cyber-Physical Simulator – Cyber assets simulator
SCADA	Supervisory Control and Data Acquisition System
TS, TM	Teleindication, Measurements
TC, TVC	Commands and Setpoints
DT	Digital Twin
RTE	French TSO (Réseau de Transport d'Electricité)
LAN	Local Area Network
MAN	Metropolitan Area Network
WAN	Wide Area Network
GUI	Graphical User Interface

8 Custom information (optional)

B.3 EAST-MED Pilot Site UCs

B.3.1 Congestion management in distribution grids through ancillary services [EM-CY-01]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
EM-CY-01	Local distribution grid	Congestion management in distribution grids through ancillary services

1.2 Version management

Version management				
Version No.	Date	Name of author(s)	Changes	Approval status
1	13/05/2024	Markos Asprou and Lenos Hadjidemetriou	Initial scope, objectives, and narrative	
2	12/06/2024	Markos Asprou and Lenos Hadjidemetriou	KPIs, Use case conditions, further information on the use case	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Coordination of flexible resources to manage congestion and avoid thermal limit violations in local distribution grids to maximize the utilization of existing grid capacity. This will be achieved by online coordinating distribution energy resources (DERs) for providing ancillary services (i.e., active and reactive power regulation) according to flexibility services availability, cleared through a local market. The procured flexibility will be calculated considering various what if scenarios in a digital twin framework.
Objective(s)	- Avoid thermal limit violation in local distribution grids, - Reduce of grid energy losses - Reduce investments for grid reinforcement, - Effective utilization of existing grid capacity - Active participation of DERs in the grid management process with potential economic benefits - Showcase the cyberattack in active distribution grid management
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description

Cyprus power system favors the massive installation of PV due to the climate conditions (abundant of sun) in order to achieve the national environmental target. The high penetration of renewables in specific feeders causes local congestion problems (voltage and thermal limit violations) in the distribution grid. Active and reactive power flexibilities provided by DERs will be coordinated by the DSO to relieve congestion and increase grid efficiency with the help of a digital twin framework. The management of flexibility services will be governed through a local ancillary services market.

Complete description

In this use case, DSO monitors the distribution grid state in real time and online coordinates DERs flexibility for avoiding congestion phenomena. A high-level description of the use case is provided below based on market and real-time operation processes:

- *Market level procedures:*
 - DSO procures congestion management availability products (i.e., active and reactive power flexibility) to the local ancillary service market by investigating several what-if scenarios in a digital twin environment utilizing historical and forecasting operating data,
 - Flexibility Service Providers (FSPs) bids to the local ancillary services market their availability,
 - Local ancillary service market clears flexibility every 3 hours.
- *Real-time operations:*
 - DSO receives measurements from the distribution grid and analyze the grid operating conditions,
 - In case of congestion, DSO coordinates in real-time the activation of flexibility services by DERs (awarded FSPs) in order to relieve overloading condition in a cost-effective manner (with minimum activation cost),
 - DERs receive the coordination signal and adjust the active and reactive power injection accordingly to relieve congestion,
 - The real-time operations can be demonstrated either in the actual distribution grid or in the real-time digital twin of the Cyprus power grid (running in a real time simulator). Potential cyber-attacks scenarios can also be demonstrated and analyzed through the digital twin environment.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Volume of available active and reactive power deviation, procured by DSO, offered by FSPs, and cleared by the Market operator.	This indicator contains the procured, offered and cleared ΔP and ΔQ availability service (in kW and kVar) for the time period under examination.	Congestion management
2	Reduction of Overloading condition	This indicator will provide information for the duration and the intensity of the overloading conditions occurs at the distribution grid as a percentage of the nominal thermal capacity of the distribution lines/substations. This will be compared with the base case where no ancillary services for congestion management are provided by the flexibility resources of the distribution grid.	Congestion management

1.6 Use case conditions

Use case conditions

Assumptions	
1	The use case will be developed and demonstrated in a non-invasive environment using the real time digital twin representing realistically current and future states of a part of the Cypriot distribution grid.
2	The DSO, FSPs, and ancillary services market will be emulated in the demo digital twin environment considering different realistic scenarios.
3	Bi-directional communication between DSO and FSPs in the distribution grid.
Prerequisites	
1	Distribution system data and characteristics from the Cypriot power system.
2	Data from operating conditions for the Cypriot distribution grid.

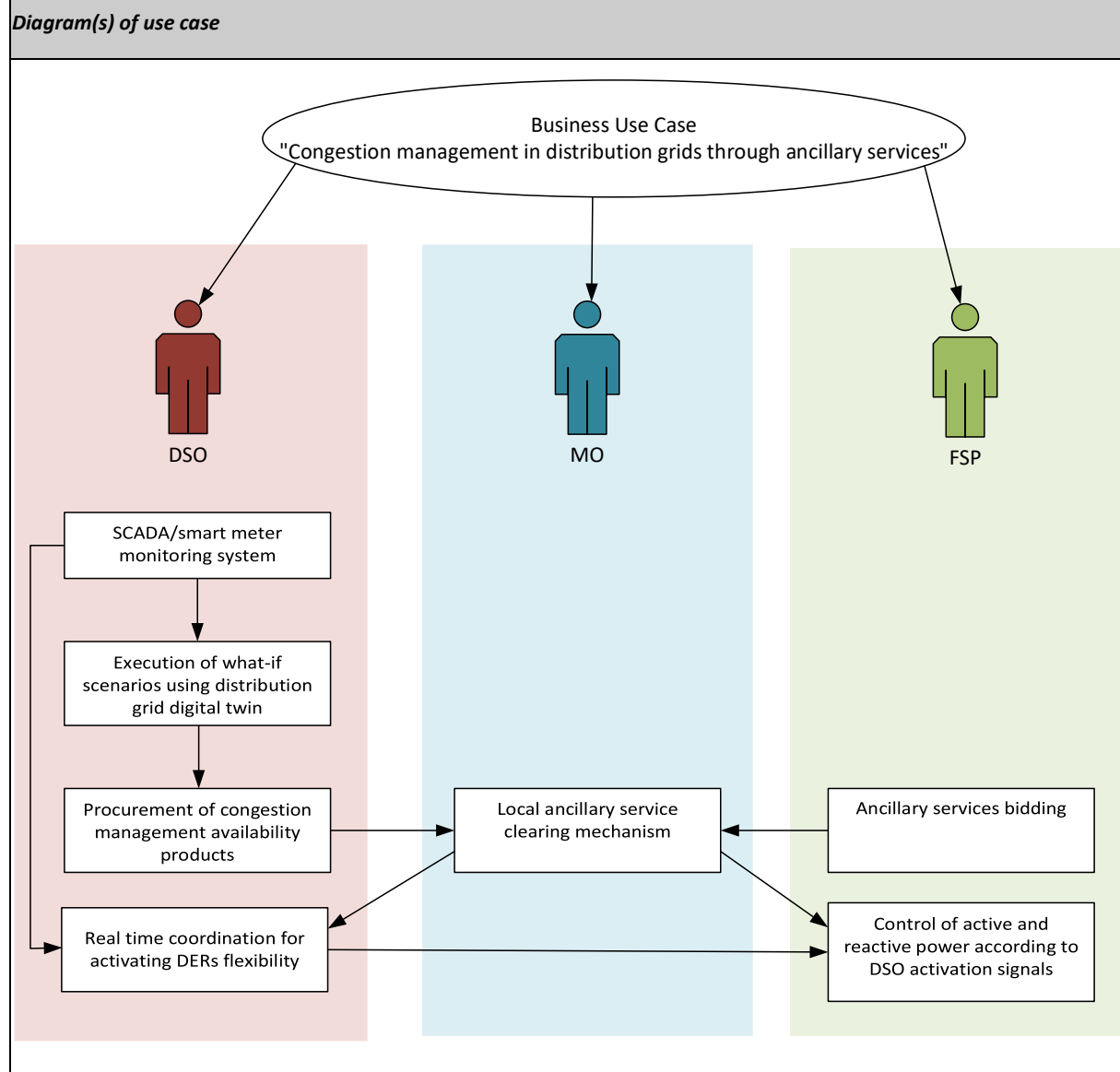
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
This use case is related to “EM-CY-02: Frequency support management of HVDC-interconnected systems in a regional level” since the operating condition of the Cypriot transmission grid can slightly affect the operation of the distribution grid
Level of depth
Distribution level
Prioritisation
High
Generic, regional or national relation
National and local area
Nature of the use case
BUC
Further keywords for classification
Active and reactive power flexibility, congestion management, FSP coordination for active distribution management.

1.8 General remarks

There are no general remarks.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A party responsible for operating, ensuring the maintenance of and, if necessary, developing the system in a given area and, for ensuring the long-term ability of the distribution grid to meet reasonable demands for the distribution of electricity.	DSO operator will be responsible for the proper operation of the distribution grid to avoid congestion through a cost-effective manner by coordinating DERs flexibility.

Market Operator (MO)	Business	A market operator is a party that provides a service whereby the offers to sell electricity or electricity flexibility are matched with bids to buy electricity or electricity flexibility.	The market operator will award market products related to congestion management services.
Flexibility Service Provider (FSP)	Business	A party providing flexibility services to energy stakeholders via bilateral agreements or flexibility markets.	FSP will participate to flexibility market and will provide congestion management services according to the activation signals of the FSPs

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
SCADA/Smart meter monitoring system	DSO	System responsible for receiving, processing and displaying grid measurements. SCADA outputs will be used for the execution of the what-if scenarios in the digital twin of the distribution grid as well as to the real time coordination of the DERs for avoiding congestion events .	
Digital twin of the distribution grid	DSO	Digital twin of the distribution grid that can emulate in high accuracy the distribution grid response. The digital twin will be used for executing what-if scenarios in order to determine the congestion management requirements that will be procured in the ancillary service market.	
Procurement of congestion management availability products	DSO	The DSO will calculate 3 hours ahead the flexibility requirements for overcoming potential congestion problems in the distribution grid with the minimum availability cost. The flexibility requirements will be procured as products to the ancillary service market.	
Real time coordination for activating DERs flexibility	DSO	Real time coordination of DERs according to the congestion problems that might occur in the system. The DSO will calculate the active and reactive setpoints that will serve to the congestion relief with the minimum activation cost.	
Local ancillary service clearing mechanism	MO	Market clearing mechanism responsible to match the procured flexibility services, bid by DSO, with the flexibility availability, offered by FSP, in a way to maximize social welfare.	
Ancillary services bidding	FSP	The ancillary services bidding tool of each FSP is responsible for evaluating the FSP available flexibility considering short-term forecasting in order to offer services reliably to the market for maximizing its profitability.	
Control of active and reactive power according to DSO activation signals	FSP	Local controller in FSP facilities will be responsible to regulate the active and reactive power injection of distributed resources in order to track the activation signals (set-points) sent by DSO while ensuring that the activation request is within the availability awarded by the flexibility market.	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Market level operation for congestion management	In this scenario, a DSO utilizes a digital twin of the power grid to procure congestion management products—specifically, active and reactive power flexibility from FSPs. The DSO investigates several what-if scenarios by leveraging historical and forecasted operational data to ensure the grid's stability under various conditions. FSPs submit bids for their available flexibility to a local ancillary services market, which clears every three hours. This process enables the DSO to secure the necessary resources for congestion management in a timely and efficient manner, mitigating potential risks to grid stability.	-FSP -DSO -MO	Periodic event	Established communication between DSO and Market and FSP and Market	The market will be cleared according to DSO products procurement and the FSPs offers.
2	Real time relief of congestion in distribution grid	During real-time operations, the DSO analyzes grid conditions using measurements from the distribution grid. If congestion occurs, the DSO coordinates the activation of flexibility services by DERs (awarded FSPs) to relieve overloading in a cost-effective way. DERs then adjust their power output accordingly. These operations will be demonstrated through a real-time digital twin of the Cyprus power grid, where potential cyber-attack scenarios can also be simulated and analyzed.	-FSP -DSO	Congestion detection through periodic grid measurements	- Conventional measurements from distribution substations are connected to the DSO SCADA -DERs associated with the awarded FSPs are connected to the DSO SCADA for monitoring and control purposes.	DERs will increase or decrease their active power output according to DSO requests to successfully relieve congestion in the distribution grid.

4.2 Steps – Scenarios for flexibility market not organised

Scenario name #1: Market level operation for congestion management

Scenario #1 description

In this scenario, the DSO uses a digital twin of the power grid to manage congestion by procuring active and reactive power flexibility from FSPs through a local ancillary services market. The DSO leverages both historical and forecasted operational data to explore several what-if scenarios, ensuring grid stability under various conditions. FSPs participate by submitting bids of their available flexibility to the market, which is cleared every three hours by the Market Operator (MO). This process

allows the DSO to acquire the necessary resources in a timely manner to prevent congestion and maintain the reliability of the power grid.

The digital twin technology enables the DSO to simulate potential grid issues and react proactively, while the structured market interaction with FSPs ensures an efficient allocation of flexibility resources. The periodic clearing of the market aligns procurement with real-time grid needs, improving responsiveness to congestion challenges.

Scenario name #2: Real time relief of congestion in distribution grid

Scenario #2 description

The scenario focuses on real-time relief of congestion in the distribution grid using advanced monitoring and control measures. The DSO continuously monitors grid conditions through conventional measurements from distribution substations linked to the DSO SCADA system. If congestion is detected, the DSO immediately coordinates the activation of flexibility services by DERs, managed by the awarded FSPs. These DERs adjust their power output based on the DSO's instructions to alleviate grid overloading in the most cost-effective manner.

The entire process will be demonstrated using the real-time digital twin of the Cyprus power grid, which also allows for testing and analysis of potential cyber-attack scenarios.

Scenario step by step analysis

Scenario								
Scenario name		Market level operation for congestion management						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1	-	Forecast & Analyze Grid Needs	The DSO uses the digital twin to simulate grid operations, analysing historical and forecasted data to identify potential congestion issues.		DSO			
1.2		Trigger Market Operation	A periodic event or anticipated grid congestion triggers the need for congestion management. The DSO determines the required active and reactive power flexibility.		DSO	MO	ID1-1	
1.3		FSPs Submit Bids	Flexibility Service Providers (FSPs) prepare and submit bids of their available active and reactive power flexibility to the local ancillary services market		FSP	MO	ID1-2	
1.4		Market Clearing	Every three hours, the Market Operator (MO) clears the market by matching the DSO's congestion management needs with the FSPs' flexibility bids. The cleared orders are sent to the awarded FSPs and the DSO		MO	FSP, DSO	ID1-3	

Scenario								
Scenario name		Real time relief of congestion in distribution grid						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1	-	Grid Monitoring and Detection of Congestion	The DSO continuously monitors the distribution grid using real-time data from substations connected to the SCADA system. Data includes power flows, voltage levels, and other critical parameters. The DSO analyzes these measurements to detect congestion when operational thresholds are exceeded.	-	DSO	-	-	-
2.2	-	Coordinate DERs for flexibility services activation	Upon detecting congestion, the DSO identifies available DERs managed by awarded FSPs that can provide flexibility services. The coordination is performed ensuring a minimum activation cost. The DSO sends coordination signals to the selected DERs, instructing them to adjust their active and reactive power output to alleviate the overloading.	-	DSO	FSP	ID2-1	-
2.3	-	DERs adjust their power output	FSP/DERs receive the instructions from the DSO and promptly adjust their power output to the specified levels, modifying both active and reactive power injections. This adjustment helps to relieve the congestion in the grid in real-time, ensuring stability. Measurement for the DERs operation are sent back to the DSO control centre.	-	FSP/DER	DSO	ID2-2	-

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1-1	Product procurement	Required active and reactive power flexibility sent by DSO to the MO	-
ID1-2	FSP bids submission	FSP bids their availability to the market for provision of congestion management services	-
ID1-3	Market clearing results	After the market clearing (every 3 hours) the MO informs the participated FSPs for their awarded flexibility products	-
ID2-1	Coordination signals for activating flexibility services	Active and reactive power deviation set-points are sent from the DSO to the FSPs/DERs to adjust their power output and relieve congestion	-
ID2-2	Measurements from DERs	Real-time measurements regarding the DERs operation are received by the DSO in order to allow the grid-level coordination of a flexibility services and to validate that the DERs has responded properly to the DSO coordination signals.	-

6 Requirements (optional)

7 Common terms and definitions

DERs-Distributed Energy Resources

PV-Photovoltaics

DSO-Distribution System Operator

FSP-Flexible Service Provider

SCADA-Supervisory Control and Data Acquisition

MO-Market Operator

8 Custom information (optional)

B.3.2 Frequency support management of HVDC-interconnected systems in a regional level [EM-CY-02]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
EM-CY-02	Regional/Transmission grid	Frequency support management of HVDC-interconnected systems in a regional level

1.2 Version management

Version management				
Version No.	Date	Name of author(s)	Changes	Approval status
1	13/05/2024	Markos Asprou and Lenos Hadjidemetriou	Initial scope, objectives, and narrative	
2	12/06/2024	Markos Asprou and Lenos Hadjidemetriou	KPIs, Use case conditions, further information on the use case	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Regional level coordination for the frequency support services of an HVDC link to enhance the stability of two interconnected systems (countries). A regional coordination framework will be established to manage the frequency support provision by considering the stability requirements and constraints at each side of the HVDC link. During an intense power imbalance disturbance, the stability of each country will be analysed through an interconnected digital twin environment.
Objective(s)	- Enhance frequency stability at each interconnected country, - Minimize cascading effect between countries during an intense power imbalance and showcase the potential impact of a cyber-attack in an HVDC link, - Effective regional coordination of an HVDC interconnection to support high RES penetration in low-inertia systems.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
Cyprus power system prioritize the massive installation of PVs to achieve the national climate targets. The high penetration of renewable energy sources (RES) in combination with the islanded nature of the system creates critical challenges related

to frequency stability and balancing due to the unpredicted nature of RES and the low-inertia characteristics of the system. There is an ongoing project (i.e., Great Sea Interconnector) of great importance to interconnect the Cyprus and Greece power systems. In this context, a digital twin environment replicating the interconnected power systems will be developed, allowing different investigations and enabling the implementation of a regional coordination framework to enhance both systems' stability.

Complete description

In this use case, the Regional Security Coordinator (RSC) in collaboration with the TSO of each country manage the HVDC interconnector to enhance both countries stability. A high-level description of the use case is provided below based on regional coordination and real-time operation processes:

- *Regional coordination process:*

- Energy market operators at each country (e.g., Cyprus, Greece) clears the day-ahead energy market, determining the power exchange in an hourly basis through the HVDC interconnector,
- Each country TSO procures Frequency Containment Reserve (FCR) service in the ancillary services market (in MW/Hz) and informs Regional Security Coordinator (RSC) about the country's FCR requirement from the interconnection and its constraints, by utilizing the country-level power system digital twin,
- Flexibility Services Providers (FSPs) submit their bids for FCR service,
- RSC provides the maximum FCR limits for each HVDC side,
- Ancillary services market clears the FCR availability for the FSPs and for each side of the HVDC connector, every 3 hours, according to TSO procurement, FSP bids, and RSC constraints.

- *Real-time operations:*

- The cleared FCR availability for each FSP and for each side of the HVDC link, as decided by the ancillary services market operators (satisfying RSC regional constraints), are utilized to determine the frequency support parameters of the flexible actuators during the real-time system operation for the next 3-hour time window,
- HVDC converters, operating according to a $P&Q$ control mode (either under grid-forming or grid-following mode), regulate in real-time the frequency and voltage support during a disturbance based on real-time local measurements at the point of common coupling,
- HVDC converters, operating according to a $V_{dc}&Q$ control mode (under grid-following mode), regulate the provision of frequency support services through a signal created by a regional wide area controller considering communication between each side of the HVDC interconnection,
- The flexible DERs operated by the FSPs are configured to provide an adequate frequency support services during disturbances according to the ancillary services market clearing decisions,
- A digital twin environment replicating the interconnected power systems will be utilized to investigate the stability response at a regional level under different extreme scenarios and to analyze the impact in both power systems by possible cyber-attacks on the HVDC interconnector.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Volume of available power, procured by TSO, offered by FSPs, and cleared by the Market operator, for FCR services.	This indicator contains the procured, offered and cleared FCR availability service (in MW/Hz) for the time period under examination.	Frequency Stability

2	Volume of power provided by HVDC link during frequency events	This indicator will provide the amount of power provided by the HVDC link to the interconnected systems during a frequency event.	Frequency Stability
3	Rate of Change of Frequency (ROCOF)	This indicator considers the maximum rate of change of frequency (in Hz/s) after an intense disturbance on system balancing	Frequency Stability
4	Frequency Nadir	This indicator considers the minimum frequency (in Hz) observed after an intense disturbance on system balancing	Frequency Stability

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The use case will be developed and demonstrated in a non-invasive environment using the real time digital twin representing realistically current and future states of the Cypriot and Greek power system, including their upcoming HVDC interconnection.
2	The TSO, FSPs, market and RSC will be emulated in the demo digital twin environment considering different realistic scenarios.
3	Wide area communication between the two sides of the HVDC interconnection.
4	HVDC converters with different control modes.
Prerequisites	
1	Transmission system data and characteristics from the Cypriot and the Greek power systems
2	Data from operating conditions for the Cypriot and Greek systems

1.7 Further information to the use case for classification/mapping

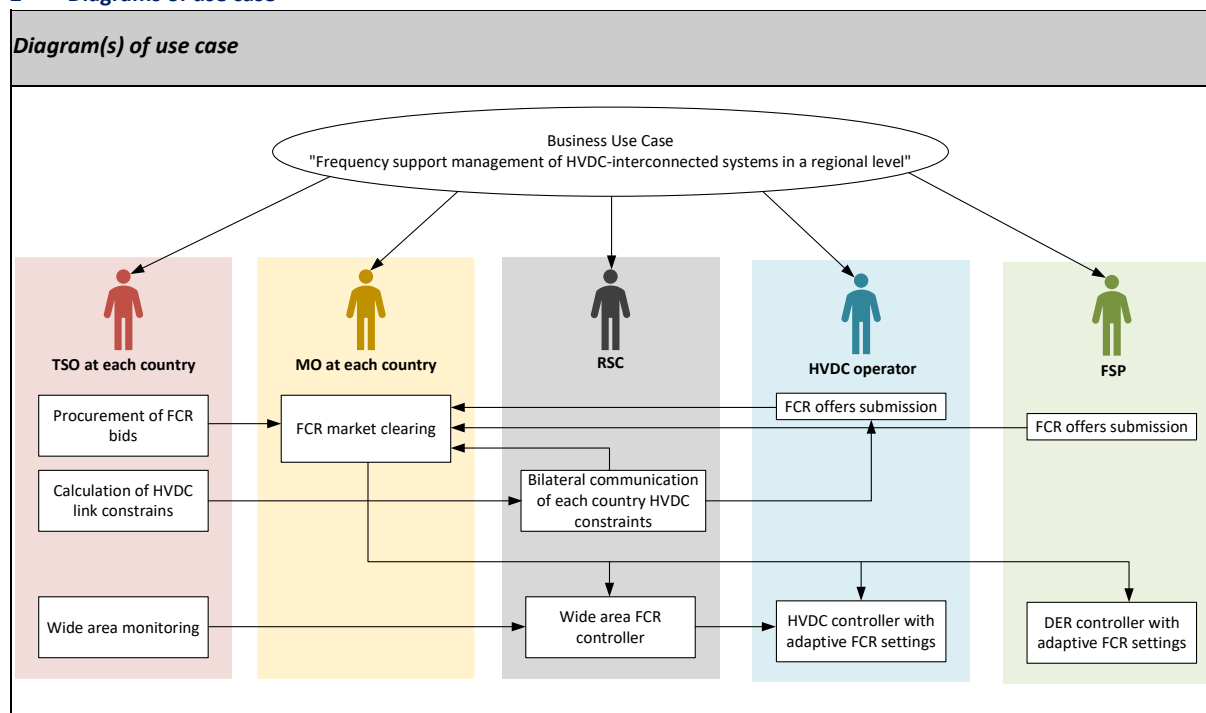
Classification information
Relation to other use cases
This use case is related to “EM-CY-01: Congestion management in distribution grids through ancillary services” since the operating condition of the Cypriot transmission grid can slightly affect the operation of the distribution grid
Level of depth
Transmission level
Prioritisation
High

Generic, regional or national relation
National and regional (cross-national)
Nature of the use case
BUC
Further keywords for classification
Active power, flexibility, frequency stability, regional coordination, HVDC frequency support, FCR

1.8 General remarks

There are no general remarks.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
TSO	Business	A party responsible for operating, ensuring the maintenance of and, if necessary, developing the system in a given area and, where applicable, its	Transmission system Operator will procure products related to FCR to the flexibility market for ensuring the frequency stability of the

		interconnections with other systems, and for ensuring the long-term ability of the transmission grid to meet reasonable demands for the transmission of electricity. It is also responsible to maintain the frequency and voltage stability of the transmission grid.	system. In addition, TSO will provide constraints for the operation of the HVDC link (considering the maximum power disturbance through the HVDC link during a critical event in an interconnected country) to regulate the cascading phenomena through the interconnection.
Market Operator (MO)	Business	A market operator is a party that provides a service whereby the offers to sell electricity or electricity flexibility are matched with bids to buy electricity or electricity flexibility.	In this use case, the market operator will clear and award market products related to FCR in a country, while considering the TSO procured bids, the local (country-level) FSP offers, the HVDC offers and the constraints of the interconnected countries (through HVDC) that will be communicated through the RSC.
Regional Security Coordinator (RSC)	Business	RSC is responsible for maintaining the security and reliability of the electrical grid within a specific geographical area through real time monitoring of the cross-border interconnection of power systems, coordination of cross-border electricity flows. RSC ensures the compliance with grid codes and regulations as well as interconnection constraints (imposed by the individual TSOs). RSC also facilitates communication and collaboration among transmission system operators (TSOs) and other stakeholders and play a crucial role in maintaining the continuous and secure supply of electricity across regions.	In this use case RSC will receive the constraints of each interconnected power system from the TSOs. The constraints will be related to the available power that can be offered from the two interconnected systems through the HVDC link for frequency support. RSC will ensure that the HVDC interconnection constraints are satisfied in order to maintain the stability of the interconnected regions.
HVDC operator	Business	HVDC operator is responsible for the operation and maintenance of HVDC links, which are used to transfer large amounts of electricity between interconnected countries/regions. HVDC operator is also responsible for monitoring and controlling the HVDC equipment, ensuring the reliability and stability of power transmission, and the compliance with the constraints imposed by the interconnected power systems. The HVDC operator can participate to the electricity markets of the interconnected systems for the provisions of grid support services	In this use case HVDC operator will be responsible for submitting offers to the markets of the interconnected systems for FCR services of the HVDC link. Further, he will control the HVDC link in order to provide the cleared FCR services (according to the market) to the interconnected systems in case of frequency events.
FSP	Business	A party providing flexibility services to energy stakeholders via bilateral agreements or flexibility markets.	FSP will participate to FCR market and will provide FCR services according to the cleared FCR services by the market. The provision of the FCR services will be automatically activated by measuring locally the system frequency.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information

			<i>specific to this system use case</i>
Procurement of FCR bids	TSO	The TSO (at each country) will calculate 3 hours ahead the flexibility requirements for FCR product to ensure the frequency stability of the transmission grid. The flexibility calculation will be enabled through a what-if digital twin based analysis considering possible scenarios for the expected operating conditions. The calculated FCR bids will be procured to the flexibility market.	
Calculation of HVDC link constraints	TSO	The TSO (at each country) will calculate 3 hours ahead the maximum allowable power disturbance that can undertake from the HVDC link interconnection during a severe event in an interconnected country without risking its own stability. These constraints will be calculated for a set of possible expected scenarios/conditions through a digital twin approach. The HVDC constraints will be considered for the interconnected country's MO, through the RSC, when clearing the FCR market.	
Bilateral communication of each country HVDC constraints	RSC	A bilateral communication via a data-exchange framework is managed by RSC and is responsible to exchange critical information regarding each country stability that needs to be considered during the market clearing of the interconnected country.	
FCR submission offers (by HVDC operator)	HVDC operator	The FCR offers submission tool of the HVDC operator is responsible for evaluating the available flexibility of HVDC link in a short-term horizon ahead in order to generate FCR offers reliably to be submitted to the flexibility market for maximizing its profitability.	
FCR submission offers (by DERs)	FSP	The FCR offers submission tool of each FSP is responsible for evaluating the available flexibility of DERs in a short-term horizon ahead in order to generate FCR offers reliably to be submitted to the flexibility market for maximizing its profitability.	
FCR market clearing	MO	Market clearing mechanism for FCR services responsible to match the procured flexibility services, bid by TSO, with the flexibility availability, offered by FSP, in a way to maximize social welfare, while ensuring HVDC interconnection limitations.	
Wide Area Monitoring	TSO	By receiving Phasor Measurement Units measurements from the interconnection points, the wide area monitoring system will provide in real time the frequency and ROCOF of the system to the TSO, which will be also reported to the RSC.	
Wide Area FCR controller	RSC	The Wide Area FCR Controller is responsible for calculating in real time the necessary power in MW needed from the "sink" system in case of a disturbance in the "source" system. The Controller will then communicate the calculate set-points to the HVDC operator and in particular to the HVDC controller.	
HVDC Controller with adaptive FCR settings	HVDC operator	The HVDC controller will adapt the settings of the HVDC link to provide the necessary FCR support according to frequency and ROCOF measurements. The HVDC controller will also consider both the inputs from the wide area FCR controller as well as the cleared FCR products in order to ensure the compliance to both the constraint limits of the two systems as well to clearing decisions of the markets	
DER controller with adaptive FCR settings	FSP	Local controller in FSP facilities will be responsible to regulate the active power provided by the DER during a frequency event, according to the local frequency and ROCOF measurements. The DER controller will	

		automatically activate the FCR support, while will ensure that FCR provision by the DER is within the awarded FCR by the market.	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Regional coordination between interconnected systems	In this scenario, energy market operators in each country (e.g., Cyprus, Greece) clear the day-ahead energy market to determine power exchanges through an HVDC interconnector on an hourly basis. Each country's TSOs procure Frequency Containment Reserve (FCR) services via an ancillary services market while also submit system constraints to the RSC to ensure system stability, using a digital twin of the power system. FSPs and HVDC operator submit bids for FCR services. The RSC sets the maximum FCR limits for both sides of the HVDC interconnector. The FCR market clears every three hours, aligning FCR procurement with FSP and HVDC operators bids and RSC constraints.	TSOs, MO, RSC FSPs, and HVDC operator	Periodical event for FCR procurement and FCR	Established communication between TSOs, RSC, MO, and HVDC operator	FCR Market clearing results announced to FSPs and HVDC operator.
2	Real-time operation for frequency stability enhancement of interconnected systems	This scenario focuses in real-time operation processes for frequency stability enhancement of interconnected systems. The frequency support parameters for flexible actuators are set based on cleared FCR availability for each FSP and each side of the HVDC link, as determined by ancillary services market operators of each country. HVDC converters, operating in P&Q or Vdc&Q control modes, adjust frequency and voltage in real-time during disturbances using local measurements or signals from a regional wide area controller. Flexible DERs (operated by FSPs) provide	HVDC operator, FSPs, RSC, TSO, MO	Frequency disturbance event	FSPs, HVDC operator, and RSC are able to receive the market clearing results and adjust their frequency supporting settings	After an intense frequency disturbance, the HVDC converter and the FSPs in each country respond to provide supporting services and enhance the frequency stability of the system.

		frequency support as per market clearing decisions. A digital twin environment emulates the interconnected systems to study regional stability responses and assess impacts from potential cyber-attacks on the HVDC interconnector.				

4.2 Steps – Scenarios for flexibility market not organised

Scenario name #1 Regional coordination between interconnected systems

Scenario #1 description

In this scenario, energy market operators in each country, such as Cyprus and Greece, clear the day-ahead energy market to determine power exchanges through an HVDC interconnector on an hourly basis. Each country's TSO procures FCR services via an ancillary services market. The TSOs use a digital twin of their power systems to assess real-time constraints and calculate the FCR requirements. The constraints for each system are submitted to the Regional Security Coordinator (RSC) to ensure system stability. FSPs and the HVDC operator participate in this process by submitting bids for FCR services, offering their flexibility to help manage grid frequency across the interconnected regions when needed.

The RSC plays a critical role by setting the maximum FCR limits for both sides of the HVDC interconnector, taking into account each country's constraints and system needs. The FCR market clears every three hours, matching TSOs procurement with the bids from FSPs and the HVDC operator, while the MO announces the cleared FCR services to the FSPs and the HVDC operator. This coordination ensures that frequency containment services are available on both sides of the interconnector while maintaining grid stability and optimizing cross-border energy exchange.

Scenario name #2: Real-time operation for frequency stability enhancement of interconnected systems

Scenario #2 description

This scenario centres on real-time operations aimed at enhancing frequency stability in interconnected power systems. The process involves setting frequency support parameters for flexible actuators based on the cleared Frequency Containment Reserve (FCR) availability for each FSP and each side of the HVDC link, as determined by the ancillary services market operators in each country. During disturbances, HVDC converters, operate in either P&Q or Vdc&Q control modes, are able to regulate frequency and voltage support provision in real-time, utilizing local measurements at the point of common coupling or signals from a regional wide area controller. Flexible DERs operated by FSPs are configured to provide frequency support services according to market clearing decisions, ensuring coordinated responses across the interconnected systems.

A digital twin environment will be developed to be able to replicate the interconnected power systems, allowing for the investigation of regional stability responses under various extreme scenarios. This simulation environment plays a crucial role in analyzing the dynamic behaviour of the systems and the impact of potential cyber-attacks on the HVDC interconnector. By testing these scenarios, operators can better understand the vulnerabilities and enhance the resilience of the system to disturbances. Following intense frequency disturbances, HVDC converters and FSPs in each country quickly adjust their settings to provide timely support, enhancing the overall frequency stability of the interconnected power systems.

Scenario step by step analysis

Scenario	
Scenario name	Regional coordination between interconnected systems

Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1		Day-Ahead Market Clearing	Energy market operators in each country (e.g., Cyprus, Greece) clear the day-ahead market, determining hourly power exchanges through the HVDC interconnector.		MO	TSO	ID1-1	
1.2		TSO requirements submission	Each country's TSO uses a digital twin to determine the need for Frequency Containment Reserve (FCR) services and submit the FCR procurement to the FCR market of each country		TSOs	MOs	ID1-2	
1.3		TSO Assessment & Constraints Submission	Each country's TSO uses a digital twin to assess grid constraints. TSOs submit their FCR constraints and to the Regional Security Coordinator (RSC).		TSOs	RSC	ID1-3	
1.4		Bid Submission by FSPs & HVDC Operator	FSPs and the HVDC operator submit their bids to provide FCR services to the FCR market of each country.		FSP, HVDC operator	MO	ID1-4	
1.5		RSC Determines FCR Limits	The RSC reviews systems constraints and sets the maximum FCR limits for each side of the HVDC interconnector to ensure systems frequency stability. The limits are sent to the MOs and to the HVDC operator		RSC	MO and HVDC operator	ID1-5	
1.6		FCR Market Clearing and market results sharing with the market participants	Every three hours, the FCR services market clears, aligning FCR procurement with TSO needs, FSP and HVDC operator bids, and the RSC's constraints. The market cleared results are shared with the market participants.		MOs	FSPs, HVD operator	ID1-6	

Scenario	
Scenario name	Real-time operation for frequency stability enhancement of interconnected systems

Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1		Setting frequency support parameters	The process begins with the ancillary services market operators of each country clearing the FCR availability for each FSP and each side of the HVDC link. Based on these clearing results, frequency support parameters are determined for the flexible actuators to be used during real-time operation for the next 3-hour time window. These parameters consider control setting for each FSP and HVDC converter to be configured in order to respond appropriately during a frequency disturbance event, aligning with regional stability requirements set by the RSC.		FSP (DER controller), HVDC operator (HVDC controller), RSC (wide area regional controller)			
2.2	Frequency disturbance event	Real-time operation of HVDC converters and activation of frequency supporting services	HVDC converters are configured to operate in different control modes (either P&Q or Vdc&Q) according to the HVDC architecture, and for each mode a different real time operation approach is needed to properly respond under a frequency disturbance event: 1. HVDC converter in P&Q mode: When operating in P&Q control mode, HVDC converters regulate frequency and voltage support based on real-time local measurements at the point of common coupling and the frequency support settings, either under grid-forming or grid-following mode.		HVDC operator (HVDC P&Q controller), RSC (wide area regional controller)	HVDC operator (HVDC Vdc&Q controller)	ID2-1	

			2. HVDC converter in Vdc&Q mode: When operating in Vdc&Q control mode, the converters provide frequency support services guided by a signal from a regional wide area controller, which considers communication between both sides of the HVDC interconnection and the cleared frequency support settings.					
2.3	Frequency disturbance event	Real-time operation of FSPs/DERs activation of frequency supporting services	Flexible DERs operated by the FSPs are set up to provide adequate frequency support services during a frequency disturbance, following the market clearing decisions. In response to frequency and deviations, these DERs adjust their output dynamically, enhancing the system's frequency stability. The FSPs continuously monitor the local grid conditions and adjust the DERs' performance to align with real-time operational needs for enhancing grid stability.	FSPs	-	-	-	-

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1-1	Day-Ahead market results	Day ahead market clearing results are sent to the TSOs of the two countries for knowing the HVDC interconnection support	
ID1-2	FCR products procurement	TSO procures FCR products to the FCR market operator	
ID1-3	System constraint submission	TSO submits system constraints to the RSC to ensure system stability in case of a frequency event in the interconnected region	
ID1-4	Bids submission to FCR markets	FSPs at the two countries as well HVDC operators submit their bids to the market of the countries	

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1-5	Submission of the two system constraints	RSC sends the constraints of the two countries for FCR services that will be provided by the HVDC interconnection to the market operators and the HVDC operator	
ID1-6	Information on Market clearing results	Market clearing results are announced to the FSPs of the two countries and the HVDC operator	
ID2-1	RSC wide area coordination signals	The RSC wide area controller monitors the grid frequency conditions in country 1 (where the HVDC controller is configured in P&Q mode), and then according to the market results for FCR is able to send a wide area coordination signal (ΔP) to control the HVDC converter in country 2 (where HVDC is configured in Vdc&Q mode) in order to timely provide adequate frequency support from country 1 to country 2.	

6 Requirements (optional)

7 Common terms and definitions

DERs-Distributed Energy Resources

PV-Photovoltaics

TSO-Transmission System Operator

FSP-Flexible Service Provider

MO-Market Operator

HVDC-High Voltage Direct Current

FCR-Frequency Containment Reserve

RSC-Regional Service Coordinator

ROCOF-Rate of Change of Frequency

RES-Renewable Energy Sources

8 Custom information (optional)

B.3.3 Congestion management in transmission and distribution grids through TSO-DSO coordination [EM-GR-01]

1 Description of the use case

1.1 Name of use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
EM-GR-01	Transmission and distribution grids	Congestion management in transmission and distribution grids through TSO-DSO coordination

1.2 Version management

<i>Version management</i>				
<i>Version No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
1	28/05/2024	Nikolaos Koltsaklis (UPRC), Konstantinos Plakas (IPTO), Efstratia Sarafoglou (HEDNO), Vasilios Boglou (HEDNO), Vasiliki Markaki (HENEX), Aikaterini Forouli (HENEX)	Initial scope, objectives, and narrative	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	This use case focuses on utilizing Distributed Energy Resources (DERs) and Industrial Demand Response to mitigate congestion in both local distribution and transmission grids. This involves analysing how DERs, such as solar panels, wind turbines, energy storage systems and electric vehicles, can be integrated and managed to alleviate grid stress during peak demand periods. This will be achieved by online coordinating DERs for upward energy balancing according to flexibility services availability. Additionally, the scope includes optimising industrial demand response to dynamically adjust and reduce energy consumption during peak periods, thereby enhancing grid stability and efficiency.
<i>Objective(s)</i>	Active participation of DERs in the grid management process with potential economic benefits • Avoid voltage and thermal limits violations in distribution grids • Avoid congestion in distribution lines • Reduce grid energy losses • Reduce investments for grid reinforcement • Effective utilization of existing grid capacity • Enhance grid stability and efficiency through coordinated industrial energy management.

	Integrate industrial demand response mechanisms to balance energy supply and demand dynamically.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
The integration of Distributed Energy Resources (DERs) into the electrical grid presents a transformative opportunity for enhancing grid flexibility, resilience, and efficiency. The high penetration of renewable energy resources in specific feeders causes local congestion problems (voltage and thermal limit violations) in the distribution grid. In this use case, we explore how DERs can play a crucial role in congestion management at the Distribution System Operator (DSO) level, leveraging a digital twin framework for the balancing market. DERs encompass a diverse range of distributed energy assets, including solar photovoltaics (PV), wind turbines, energy storage systems (ESS), demand response resources, and Electric Vehicles (EVs). These assets have the inherent capability to adjust their operation in response to grid conditions, providing valuable flexibility that can be harnessed for balancing supply and demand and alleviating congestion in the distribution grid. In terms of the HV grid, industrial demand response can significantly alleviate congestion in the high voltage (HV) grid by adjusting the electricity consumption patterns of large industrial consumers. During peak demand periods or times of grid stress, industrial facilities can reduce or shift their electricity usage, thereby easing the strain on the HV grid. This flexible adjustment helps to balance supply and demand in real-time, reduces the need for costly grid upgrades, and minimizes the risk of blackouts. By participating in demand response programs, industries not only contribute to grid stability but also benefit from potential cost savings and incentives, enhancing overall grid efficiency and reliability.
Complete description
Distributed generation sources like rooftop solar panels can help mitigate grid congestion by reducing the need for electricity imports from the transmission grid during peak demand periods. Solar PV systems generate electricity locally, thereby reducing the load on distribution feeders and alleviating congestion. ESS can be strategically deployed at critical locations on the distribution grid to alleviate congestion and enhance grid stability. They can be used to optimize the utilization of existing grid infrastructure and improve the reliability of electricity supply in congested areas. Furthermore, ESS can also provide ancillary services like frequency regulation and voltage support, further enhancing their value for congestion management. Finally, by coordinating EV charging schedules, DSOs can encourage EV owners to charge their vehicles during off-peak hours or times of low grid congestion. Additionally, EV batteries can serve as mobile energy storage units, allowing DSOs to leverage vehicle-to-grid (V2G) technology to store excess energy or provide grid services during peak demand periods. V2G capabilities can help balance supply and demand on the distribution grid and alleviate congestion in targeted areas. Traditionally, grid operators have relied on centralized generation and transmission infrastructure for grid balancing. However, the increasing penetration of DERs introduces new challenges and opportunities. DERs can be dynamically controlled to respond to grid signals, offering localized solutions for congestion management and grid optimization. The Digital Twinning (DT) platform is split into three different modules, namely the Day-Ahead Market (DAM) model, the Balancing Market (BM) model, and the electricity network tools (transmission and distribution networks). The following Figure 1 depicts the interlinkage of the developed methodological framework.

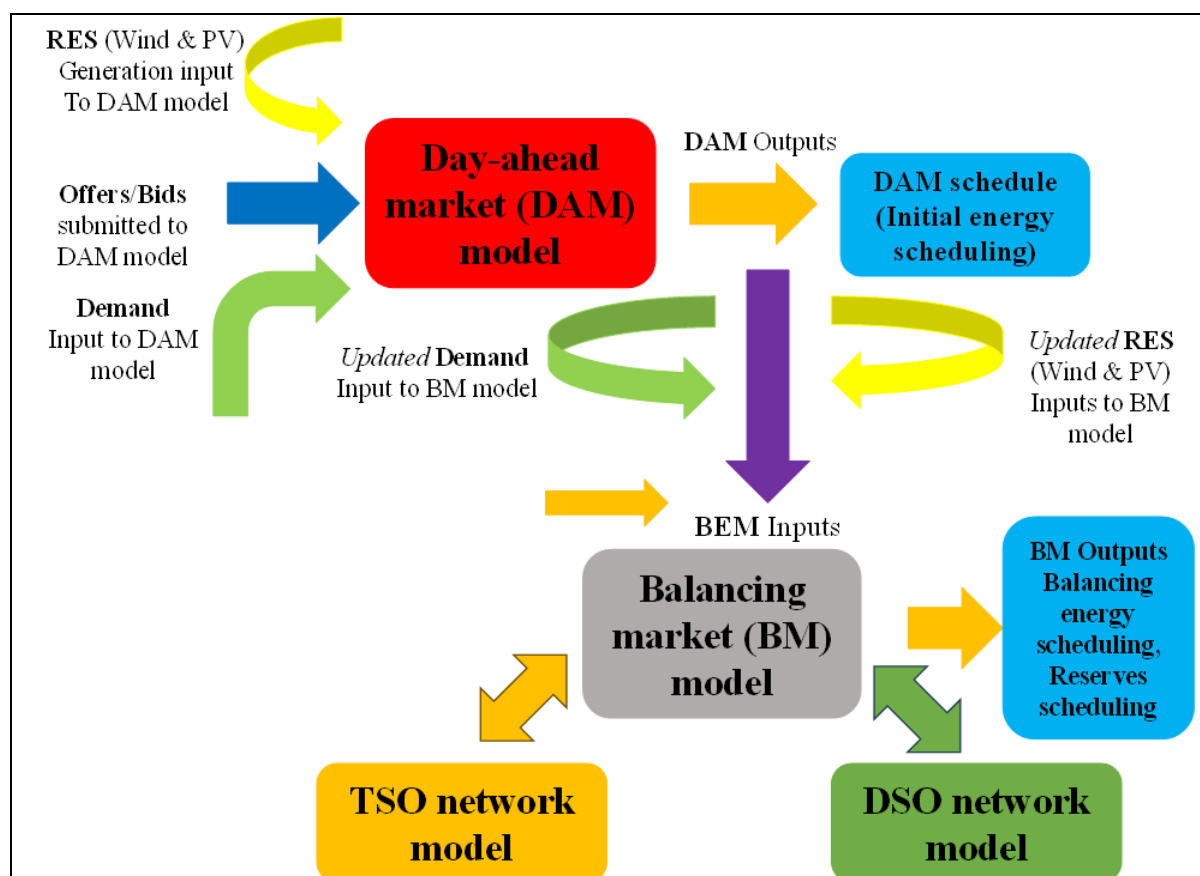


Figure 1: Integration of the Day-Ahead Market (DAM) model with the Balancing Market (BM) model and the electricity network tools

Two (2) market design options are examined:

Market design A: No TSO-DSO coordination

For the needs of the Greek Demo, there is no TSO-DSO coordination in the first Market Design. Figure 2 depicts the structure of the full market operation. This diagram depicts each stakeholder's different subprocesses/functions in the flexibility lifecycle. Under that formulation, the process may involve all the relevant stakeholders in the flexibility market. The participants in both day-ahead and balancing markets include conventional power producers (e.g., thermal power units), large industrial consumers (high voltage), as well as Service Providers (e.g. Aggregators), accounting for the grouping of various Distributed Energy Resources (DERs) such as rooftop solar panels, energy storage and electric vehicles.

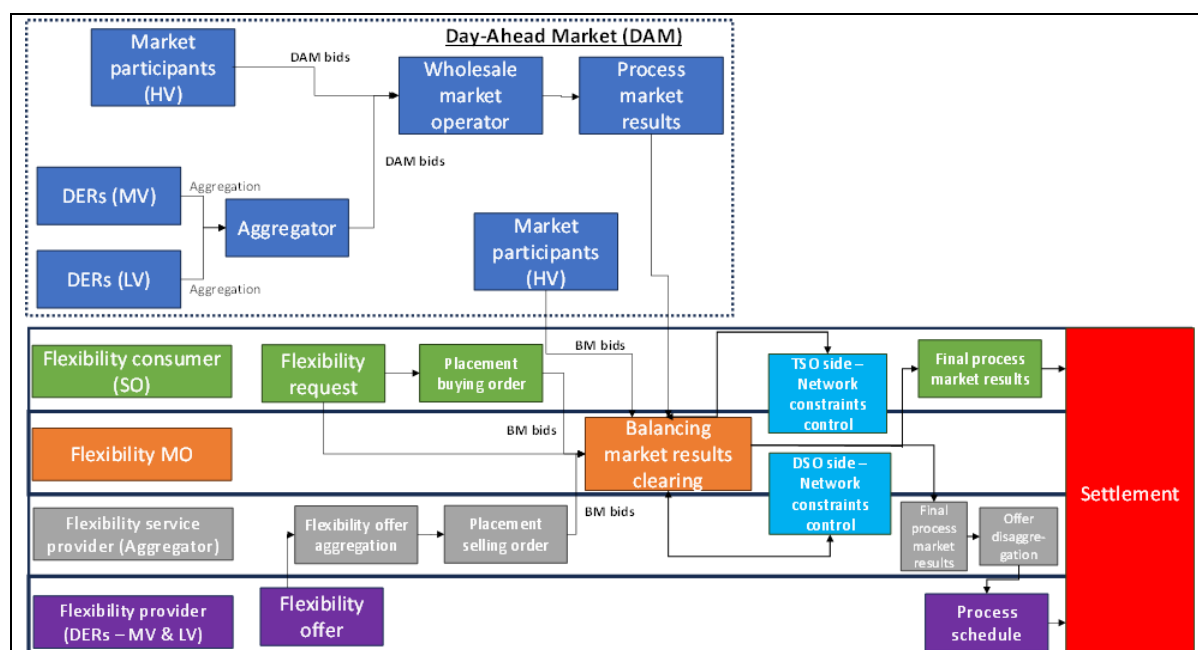


Figure 2: No TSO-DSO coordination market design

The Nominated Electricity Market Operator (NEMO) is mandated to operate the Day-ahead electricity Market (DAM), which runs as a pan-European auction where electricity is bought and sold for delivery the following day in hourly/sub hourly blocks, allowing electricity producers and consumers, such as utilities, industrial facilities, and traders, to plan their energy purchases and sales in advance. Submitted orders are matched utilizing an optimization algorithm called PCR Euphemia, aiming to maximize social welfare while considering price limits of orders and network constraints. DAM input data include network capacities and constraints provided by the TSOs, as well as bids and offers from market participants, including renewable energy sources (RES) generation (wind and photovoltaics) and demand response assets. After the DAM model's successful execution, the model determines the initial energy market schedule, the cross-border electricity flows, and the resulting electricity price in the bidding area of the Greek power system.

In response to anticipated market changes and regulatory mandates up to 2030, Hellenic Energy Exchange (HENEX) is developing a Day-Ahead market simulation tool tailored for the Greek electricity market. The simulator will integrate updates in market topology, including the introduction of new interconnectors, and enhance time resolution with 15-minute products. Moreover, as the energy landscape shifts towards a greater reliance on renewable energy sources (RES), storage solutions, and demand response (DR) mechanisms, the simulator will accurately model the evolving generation mix. Additionally, new market design elements will be investigated such as asset-based participation. The DAM simulator outputs, including market clearing prices and asset market schedules, will be forwarded to the Balancing Market.

The Transmission System Operator (TSO) and Distribution System Operator (DSO), as Flexibility Consumers, aim to optimize the operation of their grid by using flexibility to be deployed. Both System Operators (SOs) initiate the flexibility activation lifecycle process, assess the flexibility offered by the market, and handle the settlement process. Since there is no coordination among them, each one of them has distinct requirements for its own services, and the resources that are connected to each system are solely responsible for covering the required services.

Taking into consideration the nominated DAM schedules, each DER aggregator calculates and submits a daily schedule outlining the available flexibility and balancing services they can provide to the grid. This schedule includes parameters such as available capacity, response time, and cost. The BM model receives these schedules from DER aggregators to form a comprehensive pool of available resources. The DT platform utilizes advanced optimization algorithms to match supply and demand, considering factors such as grid constraints, market prices, and system reliability requirements. Upon receiving the optimized schedule from the BM model, the DSO performs a prequalification process to assess potential limitations and congestion in the distribution grid. This assessment takes into account factors such as voltage constraints, line capacity, and network topology. Based on the DSO's prequalification, the balancing market digital twin refines the schedule for DERs, adjusting their dispatch profiles to mitigate identified congestion and ensure grid stability. The updated schedule is then communicated back to the DER operators for implementation.

From IPTO perspective, by integrating industrial demand response (IDR) into these markets, industrial facilities can offer their adjustable load capacities as a resource to the grid, providing valuable flexibility that can be deployed during times of high demand or grid stress. Industrial consumers can bid their demand response capabilities into IPTO's flexibility markets, similar to how power generators bid their electricity production. These bids can include commitments to reduce

or shift consumption during specific periods, which helps balance the supply and demand on the HV grid. They can participate in both the Day-Ahead Market (DAM) and the Balancing Market (BM). In the DAM, they can submit bids to reduce their load the following day, providing advance notice of their availability to respond to anticipated congestion. In the BM, they can offer real-time adjustments to their electricity usage, responding to immediate grid needs.

The Balancing Market Operator (BMO) enables flexibility trading by operating the balancing market. Based on the updated inputs (demand and RES generation), the newly submitted bids of the market participants (centralized power stations, large consumers, aggregators) for the balancing market and the thermal power units' techno-economic data (technical minimums/maximums, synchronization, soak, desynchronization times, minimum uptimes and downtimes, reserve capability provision per reserve type, ramp-up and down limits, CO₂ emissions factor, etc.) the balancing market (BM) model determines the optimal balancing energy and reserves scheduling.

The balancing market products include: (i) upward and downward balancing energy, and (b) several types of reserve capacity, including:

- FCR with upward direction (TSO level),
- FCR with a downward direction (TSO level),
- aFRR with upward direction (TSO level),
- aFRR with a downward direction (TSO level),
- mFRR with upward direction (TSO level),
- mFRR with a downward direction (TSO level),
- Operational congestion management at a TSO level with an upward direction (TSO level),
- Operational congestion management at a TSO level with a downward direction (TSO level),
- Operational congestion management at a DSO level with an upward direction (DSO level) and
- Operational congestion management at a DSO level with a downward direction (DSO level).

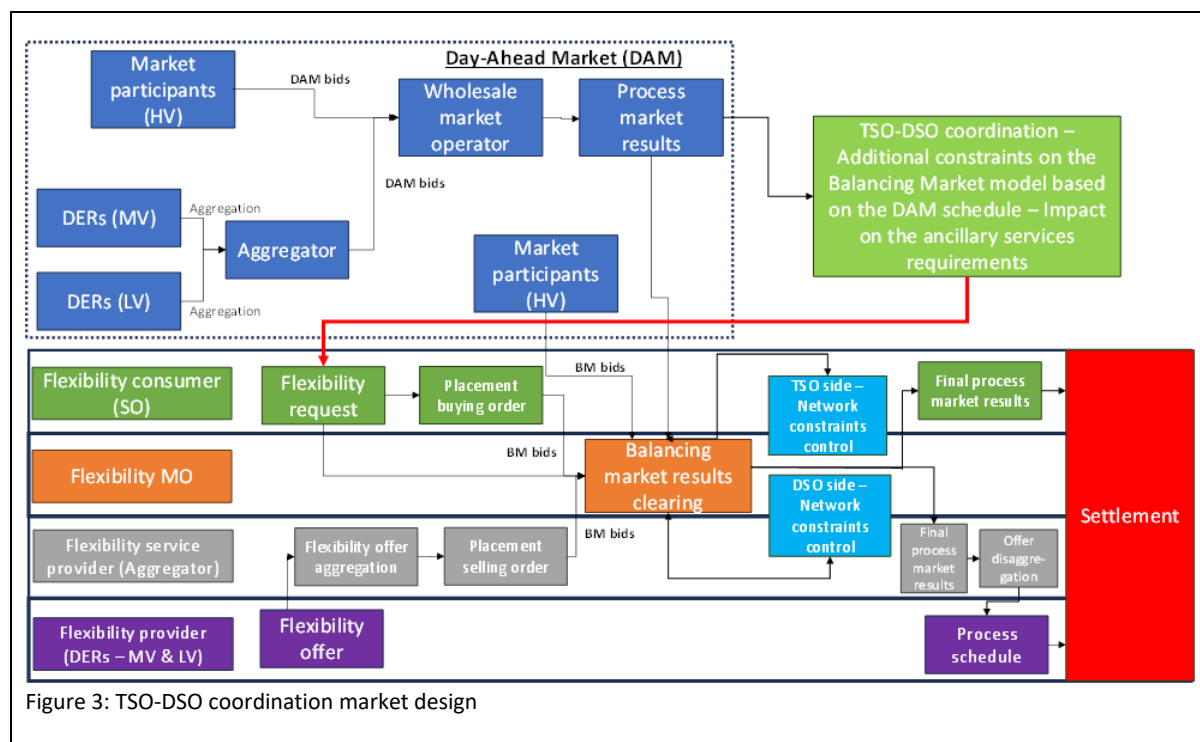
After the initial execution of the BM model and the determination of the optimal scheduling, that market schedule is checked to identify if there is any network constraint violation by the specific electricity network (transmission and distribution) tools. If the resulting schedule is not feasible, they provide feedback (regarding energy and/or power constraints), and the balancing market clearing is implemented again with the updated technical information. This iterative procedure continues until the resulting BM schedule is technically feasible and guarantees the reliability of both transmission and distribution systems.

By leveraging digital twin technology and market mechanisms, DERs can provide valuable grid services while enhancing system reliability and efficiency. This use case demonstrates the potential of DERs to play a pivotal role in the transition towards a more flexible and resilient electrical grid. In the same context, IDR can provide valuable grid services while enhancing system reliability and efficiency. This use case can be exploited in coordination with the respective one from HEDNO in order to maximize the benefits in the network level (both distribution and transmission).

Market design B: TSO-DSO coordination – Integrated Operational congestion management services

The key difference between Market Design B (TSO-DSO coordination) and A (No TSO-DSO coordination) is that after the determination of the DAM schedule, coordination is established between the system operators (TSO and DSO). During that process, the TSO and the DSO have a common objective: to decrease costs and satisfy both the need for resources by the TSO and the DSO. The joint operation of a common market (centralized variant) could realize this shared objective. Both resources connected at the transmission level and resources connected at the distribution level participate in the same marketplace. There is no priority a priori for the TSO or DSO. The choice of which resources to be used by the DSO to solve local constraints will depend on the combined optimization of both the needs for flexibility at the distribution level and the requirements for flexibility at the transmission level. The resources are allocated based on the minimization of total system costs, leading to increased social welfare. Within that context, TSO and DSO constraints are integrated into the BM's market-clearing process by including relevant constraints and their impacts on the dimensioning of ancillary services. Consequently, the operational congestion management service is integrated into a shared requirement and can be covered by resources connected at both levels.

The remaining market sequence operation is identical to the one of Market Design A, as depicted in Figure 3.



1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
	Thermal Limit Violation (Both TSO+DSO)	This KPI measures the number or percentage of transmission and distribution lines that exceed their thermal capacity limits.	Congestion Management
	Transformers' overloading	The present KPI aims to quantify the percentage of transformers' overloading due to the selection of the residential assets by the balancing market	Congestion Management
	Activation of assets from the side of the distribution network	The present KPI quantifies the contribution of the distribution network assets in terms of their participation in the market scheme	Congestion Management
	Facilitating DERs Transactions in the DAM	This KPI quantifies the volume of MWh successfully transacted using new trading products for renewable energy sources (RES) and energy	Active participation of DERs in the grid management process with potential economic benefits

		storage systems within DAM.	
	Social Welfare Increase from DERs Participation in DAM	This KPI measures the impact of integrating new energy sources into the DAM on overall social welfare by comparing current metrics against a baseline established prior to their integration.	Active participation of DERs in the grid management process with potential economic benefits
	Participation rate of Industrial facilities in the DR program	This KPI measures the percentage of eligible industrial facilities participating in DR programs.	Congestion Management
	Frequency of industrial DR events (events/year)	This KPI measures the number of DR events called within a specific time period, typically a year.	Congestion Management
	Increase in mFRR activation signals from industrial DR (both up and down)	This KPI measures the mFRR volume, offered in the balancing market, from industrial DR	Congestion Management
	Redispatch Volumes	This KPI measures the volume of generation that must be adjusted (redispatch) to manage grid congestion at both the transmission and distribution levels. Importance: Minimizing redispatch volumes can indicate effective congestion management and optimized use of grid resources through TSO-DSO coordination.	Congestion Management
	Utilization Rate of Flexibility Resources	This KPI measures the percentage of available flexibility resources (like distributed energy resources, storage, demand response) utilized to manage congestion. Importance: Higher utilization rates indicate better coordination between TSO and DSO in activating flexible assets to manage congestion.	Congestion Management

1.6 Use case conditions

Use case conditions

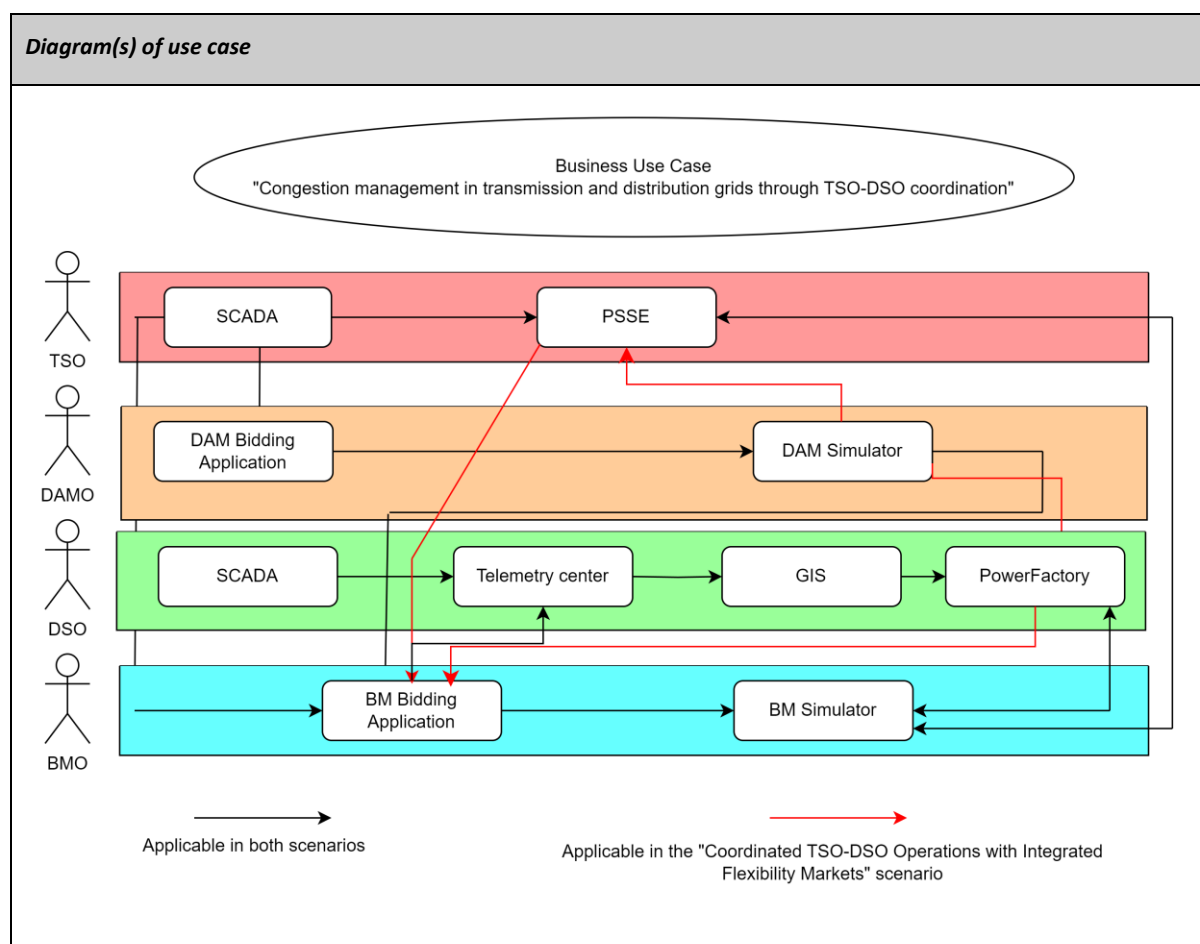
Assumptions	
	The use case will be developed and demonstrated in a non-invasive environment, using data from specific parts of the Greek Distribution System.
	The use case will be developed and demonstrated in a non-invasive environment, using data from specific parts of the Greek Transmission System.
	The balancing market will be emulated in the demo digital twin environment considering different realistic scenarios.
Prerequisites	
	Data from operating conditions for the Greek distribution grid.
	Data from operating conditions for the Greek transmission grid.
	Distribution Characteristics for the Greek Power System Data from the NECP (2030) for the priorities and policy measures in the framework of the strategy to be developed for energy efficiency (both IPTO+HEDNO)

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
None
Level of depth
Transmission+ Distribution
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification

1.8 General remarks

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
HEDNO	Distribution System Operator (DSO) - Business	A party responsible for managing and maintaining the local electricity distribution network, ensuring safety, reliability and efficiency, regarding the delivery of power from transmission systems to end users. DSOs play a crucial role in balancing supply and demand, integrating distributed energy resources (such as renewable energy and storage), and ensuring grid stability. They also oversee the	DSO will procure products related to Congestion Management to the balancing market, leveraging Distributed Energy Resources of Medium and Low Voltage. The DSO will perform a prequalification process to assess potential limitations

		operation, maintenance, and development of distribution infrastructure while coordinating with various market participants to facilitate energy transition and support the shift towards decentralized, low-carbon energy systems.	and congestion in the distribution grid, so that the balancing market DT completes the balancing process.
IPTO	Independent Transmission Operator (TSO)	The mission of IPTO is the operation, control, maintenance and development of the Hellenic Electricity Transmission System, to ensure the country's supply with electricity in an adequate, safe, efficient and reliable manner, as well as the operation of the electricity market for transactions outside the Day Ahead Scheduling, pursuant to the principles of transparency, equality and free competition.	
HENEX (DAMO)	Day Ahead Market Operator - Business	A party responsible for operating the Day-Ahead Market (DAM). DAM is performed as a pan-European auction where electricity is traded for delivery the following day in time blocks. The DAM clearing process is based on the principles of social welfare optimization.	HENEX will model and implement all necessary changes to integrate Distributed Energy Resources (DERs) technologies into the DAM.
UPRC	Balancing Market Operator (BMO) - Business	The role of the BMO is central to the reliable and efficient operation of the electricity grid. The BMO coordinates with various market participants—such as generators, retailers, consumers, transmission and distribution system operators, and is responsible for maintaining the balance of supply and demand in real-time, managing reserves and ancillary services, ensuring market transparency, and enabling the integration of renewable energy and DERs.	UPRC will model and implement the balancing market by integrating Distributed Energy Resources (DERs) as well as some novel ancillary services such as congestion management service
RAAEY	Regulatory Authority for Energy, Waste and Water - Regulator	The energy regulatory body responsible for overseeing and enforcing rules on grid operations, tariffs, and system reliability.	Ensures compliance with congestion management protocols and sets policies for TSO-DSO coordination. May also oversee grid

			connection standards and flexibility markets.
Distributed Energy Resources (DER) Owners	Prosumers/Stakeholders	Owners of decentralized energy assets, such as rooftop solar, energy storage, electric vehicles, and demand response systems.	Provide flexibility services to DSOs and TSOs by adjusting generation or consumption during congestion events, either directly or via aggregators.
Flexibility Service Providers	Third-Party Provider	Aggregators or operators that pool flexibility services from DERs to offer congestion management services to DSOs and TSOs.	Play a crucial role in mitigating grid congestion by offering demand-side flexibility or generation curtailment, typically through contractual agreements with DSOs and TSOs.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
SCADA	DSO	System responsible for receiving, processing and displaying grid measurements.	SCADA outputs will be used for the execution of the scenarios in the digital twin of the balancing market and for DSO's prequalification process.
Geographic Information System (GIS)	DSO	A Geographic Information System (GIS) is a technology used to visualize, analyze, and manage spatial data related to the electrical distribution network. It enables DSOs to map infrastructure, monitor asset conditions, and optimize network performance. The GIS provides immediate information on issues such as new RES requests, charging stations, execution of projects near the network, etc.	

		Through GIS, HEDNO collects data and obtains the exact location of the visible elements of the network, using digital tools. In this way, it has the possibility for better preparation in terms of prevention and maintenance, as well as for the coordination of its actions in cases of crises.	
Telemetry Centre	DSO	HEDNO's telemetering centre is integral to the monitoring and management of electricity consumption across the country. It involves the collection of real-time data from smart meters installed throughout Greece, which allows efficient tracking of electricity usage and enhances customer service. HEDNO is currently engaged in a significant project to install approximately 3.12 million smart electricity meters by 2026. The organization has also initiated a program for monthly meter readings and employs advanced IT systems to manage metering data effectively.	
PowerFactory	DSO	PowerFactory is a leading power system analysis software application for use in analysing generation, transmission, distribution and industrial systems.	For the purposes of the Eastern Mediterranean Pilot, PowerFactory will be used for the modelling of several zones of the distribution system and the simulation of RES integration according the NECP 2030, using data from GIS. Thus, the simulated scenarios will be used for the implementation of the balancing process.
SCADA (HIS)	TSO	It allows operators to gather real-time data, control infrastructure, and ensure the reliable and secure operation of high-voltage power transmission networks across Greece.	

		The system helps in monitoring equipment, detecting faults, and optimizing power flow.	
PSSE	TSO	PSSE allows you to perform a wide variety of analysis functions, including power flow, dynamics, short circuit, contingency analysis, optimal power flow, voltage stability, transient stability simulation, harmonics, time series power flow and much more.	
DAM Bidding Application	HENEX (DAMO)	Application that performs the bidding strategies of participants in the DAM, based on projected scenarios driven by expected changes in the generation mix up to 2030.	The outputs of the Bidding Application serve as inputs to the DAM Simulator.
DAM Simulator	HENEX (DAMO)	The DAM Simulator is the first module of the Greek Electricity Market Digital Twin. It is designed to replicate and forecast the operation of the Greek Day-Ahead electricity market. The DAM Simulator uses input data from multiple sources, such as network capacities and constraints provided by the TSO, along with bids and offers from market participants as produced by the Bidding Application. It then performs the matching of bids and offers. Outputs generated by the DAM Simulator include market prices for the Greek bidding zone for each Market Time Unit (MTU) and asset market schedules.	DAM Simulator outputs will be utilized as an input data pool for the Balancing Market (BM) module, supporting the effective coordination and management of electricity supply and demand, particularly with the DERs integration.
BM Bidding Application	BM-MO	Application that performs the bidding strategies of participants in the BM, based on projected scenarios driven by expected changes in the generation mix up to 2030. It must be in line with the goals of maintaining grid stability, ensuring a	The outputs of the BM Bidding Application serve as inputs to the BM Simulator.

		competitive market environment, and optimizing system efficiency.	
BM Simulator	BM-MO	The BM Simulator is the second module of the Greek Electricity Market Digital Twin. It is designed to replicate and forecast the operation of the Greek balancing electricity market. The BM Simulator uses input data from multiple sources, such as DAM schedule, demand and renewable energy forecasts, transmission and distribution grid constraints, TSO-DSO coordination information, along with bids and offers from market participants as produced by the BM Bidding Application. It then performs the matching of bids and offers. Outputs generated by the DAM Simulator include the balancing market clearing prices for the Greek power system for each Market Time Unit (MTU), total upward and downward balancing energy activated to resolve imbalances, and ancillary services schedule per reserve type.	Depending on the examined scenario reflecting different TSO-DSO coordination levels, BM Simulator outputs will be utilized as an input data pool for transmission and distribution network tools, ensuring the safe and reliable operation of the grid, by managing the flow of electricity, maintain system stability, and preventing issues like blackouts, equipment damage, or power quality degradation.

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Independent TSO-DSO Operations	In the first scenario, TSO and DSO provide grid information to the balancing market operator only after the initial market clearing has taken place. This represents a traditional, reactive approach where both operators handle their respective grids independently,	-TSO -DSO	The balancing market clears, and the TSO and DSO identify potential grid congestion.	The balancing market operator has cleared the market based on economic bids without considering real-time	After the initial market clearing, the TSO and DSO provide grid status and congestion information

		and grid congestion is addressed after market results are known. Before market clearing, the balancing market operator clears bids based solely on economic considerations without accounting for real-time grid constraints. Once the market has cleared, the TSO and DSO review the results, identify any potential congestion in their networks, and then share this information with the balancing market operator. At this point, congestion management measures are implemented, which may include re-dispatching generation, curtailing renewable energy, or activating local flexibility resources. This reactive approach has several limitations. Since grid data is only provided after the market clearing, congestion is often mitigated using last-minute, costly measures. The market-clearing process does not fully reflect the real-time capabilities and constraints of the grid, leading to suboptimal resource dispatch and higher levels of renewable energy curtailment. Additionally, distributed energy resources (DERs) such as solar PV, energy storage, and demand-response systems are underutilized, as they are not fully integrated into the congestion management framework. Consequently, grid reinforcement costs tend to be higher, as both TSOs and DSOs must rely on more traditional solutions, such as grid upgrades or load shedding, to address congestion.		Example: After the balancing market clears, the TSO notices congestion on a key transmission line due to high volumes of renewable generation. The DSO simultaneously detects local congestion in the distribution network from excess rooftop solar production. Only after the market clearing do the TSO and DSO notify the balancing market operator of these issues, triggering curtailment of distributed solar PV and re-dispatch of centralized generation.	transmission or distribution grid conditions.	to the balancing market operator. Congestion management measures are implemented, possibly requiring re-dispatch, curtailment, or local flexibility resources.
2	Coordinated TSO-DSO Operations with Integrated Flexibility Markets	The second scenario represents an advanced model, where TSO and DSO provide grid information to the balancing market operator both before and after the market clearing. This proactive approach ensures that grid constraints are taken into account during the initial	-TSO -DSO	The balancing market prepares to clear bids, and grid information from the TSO and DSO is incorporated	The balancing market operator receives real-time grid data from the TSO and DSO before clearing the	After market clearing, grid data is continuously updated and sent to the balancing market operator,

		market-clearing process, leading to more efficient and optimized congestion management. Before market clearing, the TSO and DSO share real-time data with the balancing market operator, including grid constraints, congestion forecasts, and available flexibility resources. This ensures that the market clears bids in a way that reflects the true operational capacity of both the transmission and distribution grids. Following market clearing, the TSO and DSO continue to provide real-time updates on grid conditions, enabling dynamic adjustments to the dispatch of flexibility services, demand-response programs, or other grid-balancing actions. This proactive, coordinated approach offers significant advantages. By sharing grid data before market clearing, the market results are aligned with actual grid conditions, reducing the need for post-clearing adjustments and last-minute interventions. Distributed energy resources, such as DERs, energy storage, and demand-side response mechanisms, are actively integrated into congestion management strategies through joint flexibility markets. Flexibility providers can offer services to both the TSO and DSO, optimizing the use of available resources to mitigate congestion at both the transmission and distribution levels. Moreover, predictive analytics and real-time data exchange allow the TSO and DSO to anticipate and prevent congestion before it occurs, further minimizing the need for grid reinforcements and curtailments. As a result, operating costs are reduced, as the reliance on costly re-dispatch or		into the process both before and after market clearing. Example: Before the balancing market clears, the TSO provides data indicating potential congestion on a transmission line due to high wind generation, and the DSO alerts the market operator of local congestion in areas with high rooftop solar production. The market clears bids considering these constraints, ensuring that flexibility resources (e.g., energy storage, demand-response) are dispatched proactively. After market clearing, the TSO and DSO continue to provide real-time grid updates, allowing fine-tuning of dispatch to address any unexpected issues that arise.	market. This data includes congestion forecasts, available grid capacity, and flexibility resources.	allowing for fine-tuning of flexibility services, demand response, and re-dispatch, minimizing congestion and improving overall grid efficiency.

		curtailment of renewable generation is minimized. Grid efficiency is enhanced, as DERs are effectively utilized, contributing to more resilient and flexible grid operations. This approach ensures that the grid operates in a more sustainable and cost-effective manner, with increased renewable integration and lower overall system stress.				

4.2 Steps – Scenarios for flexibility market not organised

Scenario name #1: Independent TSO-DSO Operations

Scenario #1 description

In a scenario where the Transmission System Operator (TSO) and the Distribution System Operator (DSO) operate independently with minimal coordination, grid management becomes fragmented, leading to inefficiencies in handling congestion and integrating distributed energy resources (DERs). Each system operator manages congestion based solely on the conditions within their respective networks, without real-time data exchange or joint problem-solving. This independent approach is characterized by a lack of cooperation, limited data sharing, and traditional methods of congestion management.

The TSO focuses on managing transmission grid congestion by re-dispatching large, centralized generation units such as gas, coal, or nuclear plants. Meanwhile, the DSO addresses congestion at the distribution level by relying on local measures like manual load shedding or activating localized backup generation. However, there is no real-time data exchange or collaborative efforts between the TSO and DSO to optimize overall system performance. Data flow between the two operators is restricted to periodic reports, and there is no real-time exchange of grid status, forecasts, or congestion alerts. This results in both operators working in isolation, without access to crucial information about each other's networks.

Without a coordinated flexibility market, each system operator handles demand response and flexibility independently. This isolation leads to an underutilization of DERs such as solar PV, energy storage, and electric vehicles. DERs, which could otherwise provide valuable flexibility to both the transmission and distribution grids, remain largely untapped due to the lack of a framework that fully integrates them into congestion management strategies. As a result, the flexibility potential of these resources is wasted, leading to inefficiencies in grid operations.

This fragmented approach forces both the TSO and DSO to invest more in grid infrastructure reinforcement to handle peak loads and congestion. Since each operator manages their network independently, they often have to resort to expensive and less efficient methods, such as curtailing renewable energy, shedding loads, or activating costly backup generation. These traditional solutions increase operating costs for both operators, as they miss out on the cost-saving benefits that could come from leveraging demand response or DERs for grid flexibility.

The lack of coordination also hampers the integration of renewable energy into the system. Without using DERs for flexibility, the TSO and DSO frequently curtail renewable energy during periods of high generation. This not only reduces system efficiency but also prevents renewable energy from reaching its full potential, as the grid struggles to accommodate fluctuating generation levels. The result is suboptimal renewable energy integration, leading to higher reliance on conventional energy sources during times of congestion.

An example of this scenario might occur on a hot summer day, when high demand causes congestion on both the transmission and distribution grids. In response, the TSO re-dispatches gas turbines to alleviate transmission-level congestion, while the DSO disconnects local distributed generation to prevent overload on the distribution network. However, without coordination between the two operators, these actions are not optimized, and the overall congestion could have been resolved more efficiently by leveraging flexibility from DERs across both grids. This lack of coordination results in higher costs, underutilization of renewable energy, and missed opportunities for grid optimization.

Scenario name #2: Coordinated TSO-DSO Operations with Integrated Flexibility Markets

Scenario #2 description

In a scenario where the Transmission System Operator (TSO) and the Distribution System Operator (DSO) coordinate closely to manage congestion, the grid operates with a high degree of efficiency and flexibility. This integrated approach involves

real-time data exchange and joint use of distributed energy resources (DERs) and demand-response mechanisms, enabling both operators to address congestion dynamically across both transmission and distribution networks. The TSO and DSO share real-time grid status, forecasts, and congestion data, allowing for a more comprehensive understanding of potential issues and a proactive approach to congestion management.

A key feature of this coordinated model is the joint congestion management strategy. Rather than acting independently, the TSO and DSO collaborate to resolve congestion by leveraging flexibility from DERs, such as energy storage, solar PV, and demand-response resources. When congestion is detected or forecasted, flexibility providers across both networks are activated to address the issue. This real-time coordination prevents congestion from escalating and ensures grid stability.

Additionally, an integrated flexibility market allows DERs and other flexibility providers (such as aggregators) to offer services that benefit both the transmission and distribution grids. This market optimizes the dispatch of flexible resources by considering locational needs and pricing signals, ensuring that congestion is managed effectively at both levels. The flexibility market dynamically allocates resources to the areas experiencing the highest congestion, improving the overall efficiency of the grid.

One of the significant advantages of this approach is proactive congestion prevention. With access to predictive analytics and real-time forecasting, the TSO and DSO can anticipate where congestion is likely to occur and take pre-emptive actions, such as adjusting generation or load profiles or activating DERs before grid issues materialize. This allows for congestion management that is not only reactive but also forward-looking, reducing the need for emergency interventions.

The optimized use of DERs is another key benefit. Renewable energy sources, energy storage, and electric vehicles are fully integrated into the congestion management strategy, offering their flexibility to both the TSO and DSO. These resources are critical during peak periods, helping to reduce stress on the grid by providing additional flexibility where needed. As a result, DERs play a pivotal role in enhancing the overall resilience and efficiency of the grid.

The outcomes of this coordinated approach are highly beneficial. First, there is a significant reduction in the need for grid reinforcements. By dynamically managing congestion through demand-response, energy storage, and joint flexibility markets, the TSO and DSO can avoid costly infrastructure upgrades that would otherwise be required to handle peak loads. Second, operating costs are minimized, as flexibility services are far more cost-effective than relying on last-minute re-dispatch or curtailing renewable energy generation. The wide range of flexibility providers accessible to both the TSO and DSO further reduces the need for expensive, reactive measures.

Finally, this coordinated strategy maximizes the integration of renewable energy. Renewable integration is optimized, as DERs are used to their full potential, reducing the need for curtailment during periods of high generation. This ensures that the system operates with a higher share of clean energy, improving both sustainability and efficiency.

An example of this coordinated approach can be seen during a winter evening peak, where both the transmission and distribution grids experience high demand, leading to potential congestion. Thanks to real-time data exchange, the TSO and DSO quickly identify critical areas of the grid at risk of congestion. Through the joint flexibility market, they activate a range of flexibility providers, including energy storage units, solar PV curtailment, and industrial demand-response, to relieve stress on both the transmission and distribution networks. This coordinated effort prevents costly grid reinforcements, reduces operating costs, and ensures full use of renewable energy generation, demonstrating the effectiveness of a fully integrated and flexible grid management strategy.

Scenario step by step analysis

Scenario								
Scenario name		Independent TSO-DSO Operations						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1	-	DAM Input Data Generation	The Day-Ahead Market (DAM) auction takes place at 12:00 CET (Central European	Bid Management and Submission	HENEX (DAMO)	HENEX (DAMO)	ID1-1	Interconnector capacities and market participant orders must be submitted prior to

			Time) for deliveries scheduled the following day, referred to as Delivery Day (D). The DAM order submission window opens at 10:00 CET, D-2, and remains available until 12:00 CET, D-1. During this timeframe, the order generation process takes place by the Bidding Application, simulating the order submission process conducted by market participants. Around 10:45 CET, D-1, the network capacities and constraints are generated by the Bidding Application, simulating the data provision process typically carried out by the TSO.					market gate closure.
1.2	-	DAM Market Clearing	After the market gate closes at 12:00 CET, D-1, the DAM Simulator processes the orderbook and interconnector capacities and performs the market clearing. By 14:00 CET, D-1, the DAM Simulator outputs are published to the BM Simulator, including market clearing prices for the Greek bidding zone and assets market schedules per Market Time Unit (MTU), encompassing imports and	Market Clearing	HENEX (DAMO)	TSO, DSO, BMO	ID1-2	DAM Market Clearing outputs must be published by 14:00 CET, D-1.

			exports per Interconnection.					
1.3		Submission of Bids/Offers to the BM	Market participants (generators, aggregators, DERs) submit bids/offers to the balancing market operator based on their ability to generate or consume electricity and provide flexibility.	Energy/flexibility offers	Market participants (generators, aggregators, DERs)	Balancing market operator	Market bids, flexibility offers	Participants must submit their bids before the market closing time. Bids must comply with regulatory and market rules regarding prices and volumes.
1.4		Initial Balancing Market Execution	The balancing market operator executes the balancing market model and determines the optimal schedule based on economic criteria and market rules.	Initial market schedule determination	Balancing market operator	TSO, DSO	Optimal scheduling results	Initial schedule is determined without detailed grid constraint validation
1.5		Network Constraint Validation	After the initial BM schedule is determined, the TSO and DSO check the resulting schedule against the transmission and distribution grid constraints using specific network analysis tools.	Feasibility check for grid operation	TSO, DSO	Balancing market operator	Feedback on power and energy constraints	The schedule must be validated for technical feasibility on both transmission and distribution networks
1.6		Feedback on Grid Violations	If the initial schedule violates network constraints, the TSO and DSO provide detailed feedback to the balancing market operator regarding the violated power and energy constraints.	Grid status feedback	TSO, DSO	Balancing market operator	Information on congestion or power limitations, required adjustments	Grid violations must be corrected before final scheduling. Feedback must include exact location and type of violation.
1.7		Iterative Market Re-Execution	Based on the feedback from the TSO and DSO, the balancing market operator updates the BM model with	Updated market schedule determination	Balancing market operator	TSO, DSO, market participants	Revised scheduling results	The balancing market is cleared iteratively until the resulting schedule is technically feasible

			the new technical constraints and re-executes the market clearing process.				updated bids/offers	
1.8		Continuous Monitoring and Updates	After each iteration of the market clearing, the TSO and DSO continue to monitor grid status in real-time and provide further feedback if necessary. The iterative process continues until no constraint violations remain.	Grid status monitoring and feedback	TSO, DSO	Balancing market operator	Real-time monitoring updates, grid status	Continuous feedback is provided until grid conditions are stable and reliable. Technical feasibility must be guaranteed across both transmission and distribution systems.
1.9		Final BM Schedule	Once the BM schedule is technically feasible and free from grid constraint violations, the final schedule is sent to all market participants, and operational dispatch begins.	Final market schedule	Balancing market operator	Market participants (generators, DERs, aggregators)	Final scheduling results	The final BM schedule must guarantee reliable operation of the grid and optimal economic dispatch. No grid violations should remain before operational dispatch.

Scenario								
Scenario name		Coordinated TSO-DSO Operations with Integrated Flexibility Markets						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1	-	DAM Input Data Generation	The Bidding Application replicates market participants' order submissions (including DER aggregators) and generates network capacities and constraints, emulating standard TSO data provision processes.	Bid Management and Submission	HENEX (DAMO)	HENEX (DAMO)	ID1-1	Interconnector capacities and market participant orders must be submitted prior to market gate closure.

2.2	-	DAM Market Clearing	The DAM clearing process, based on social welfare optimization principles, outputs Greek bidding zone market clearing prices, asset market schedules per MTU, and interconnection flows.	Market Clearing	HENEX (DAMO)	TSO, DSO, BMO	ID1-2	DAM Market Clearing outputs must be published by 14:00 CET, D-1.
2.3	-	TSO-DSO Coordination Established (Post-DAM)	After the DAM is cleared, coordination between the TSO and DSO begins to address both local (distribution) and system-level (transmission) needs.	Joint flexibility requirement optimization	TSO and DSO	Balancing Market (BM) Operator	TSO and DSO grid constraints and flexibility needs	TSO-DSO coordination is required to minimize overall system costs while satisfying grid constraints.
2.4	-	Integration of Constraints into Market Clearing	TSO and DSO constraints (e.g., congestion, voltage control) are integrated into the BM clearing process to manage operational issues and ancillary services.	Congestion management	TSO and DSO	Balancing Market Operator (BMO)	Updated TSO and DSO grid status and constraints	Constraints from both TSO and DSO networks are included to ensure a balanced market clearing
2.5	-	Common Market Clearing Process (BM)	BMO clears the BM, incorporating flexibility needs from both transmission and distribution levels without prioritizing either system.	Flexibility allocation and market-clearing	Balancing Market (BM) Operator	TSO, DSO, Market participants	Market clearing results, flexibility dispatch	The market clearing process must optimize flexibility across both TSO and DSO levels to reduce total system costs.
2.6	-	Allocation of Resources for Congestion Management	Resources (DERs, storage, flexible generation) connected at both transmission and distribution levels are allocated to meet the system needs for congestion management.	Resource dispatch for congestion management	BMO	Market participants (DERs, generators)	Dispatch orders for flexibility providers	DERs and other resources are allocated based on a combined optimization of TSO and DSO needs.
2.7	-	Iterative Monitoring and Market Clearing	After the initial BM clearing, the TSO and DSO monitor the grid status and	Real-time grid optimization	TSO and DSO	BMO	Real-time grid updates, flexibility	The market re-clears iteratively to ensure that both TSO and

			continuously update constraints. The BM is iteratively re-cleared until a robust operational status is achieved.				resource adjustments	DSO constraints are met dynamically
2.8	-	Finalized System Operation	Once the BM has been iteratively cleared and the grid is operating within the required constraints, the system operates robustly, providing congestion-free transmission and distribution services.	Balanced grid operation	TSO and DSO	BMO	Final dispatch instructions and system status	System operates in a stable, congestion-free manner with balanced dispatch across transmission and distribution

ISP General Details

The ISP is executed as a Mixed Integer Linear Programming model and is solved as a co-optimization problem taking into account the Balancing Energy and Balancing Capacity Offers of the BSEs as well as their respective constraints, the HETS constraints and the HETS Operator needs, in order to minimize the cost of Balancing Energy and Balancing Capacity procurement. The ISP execution produces:

- the commitment status (synchronization or de-synchronization) of each Balancing Service Entity,
- the awarded upward and downward Balancing Capacity products per Balancing Service Entity for each Dispatch Period of the Dispatch Day, and
- the inter-zonal flows.

IPTO defines the zonal and systemic upward and downward HETS needs per Dispatch Period (30-min) of the Dispatch Day, for the following Balancing Capacity products:

- Upward and downward Frequency Containment Reserve (FCR),
- Upward and downward automatic Frequency Restoration Reserve (aFRR),
- Upward and downward manual Frequency Restoration Reserve (mFRR).

Apart from the above-mentioned Balancing capacity offers, BSPs submit to the ISP upwards/downwards Balancing Energy offers.

For the transitional period before commencement of the coupled operation of the Intra-Day Market of Law 4425/2016, the ISP is executed at three scheduled times for each Dispatch Day D as follows.

ISP1	It is executed at 16:45 EET on calendar day D-1 and concerns all Dispatch Periods (48 Dispatch Periods) of Dispatch Day D.
ISP2	It is executed at 00:00 EET on calendar day D, taking into account the updated input data, and concerns all Dispatch Periods (48 Dispatch Periods) of Dispatch Day D.
ISP3	It is executed at 12:00 EET on calendar day D, taking into account the updated input data. The time interval taken into account is from 13:00 EET until the end of Dispatch Day D (24 Dispatch Periods).

IPTO may execute the ISP at any time for all or for certain Dispatch Periods ("ad-hoc ISP"), in case of an event which significantly affects the scheduling of the Units and the dispatch of the Balancing Capacity. Such events may include but are not limited to significant changes in the zonal Load Forecast, or zonal RES Units Forecast, or the availability of resources, or the HETS conditions.

The analytical timetable of the ISP can be found at the Technical Decision ISP.

BSPs submit Balancing Capacity and Energy offers for Dispatch Day D, from 14:00 to 16:45 EET of the calendar day D-1 per Dispatch Period (30-min). The awarded amount of capacity per Balancing Service Entity is binding and participants are required to have the corresponding capacity available in order to maintain a safe margin for the balancing of the System in real-time through the aFRR and mFRR procedures.

Bids Submission BSPs

BSPs submit Balancing Capacity and Energy offers for Dispatch Day D, from 14:00 to 16:45 EET of the calendar day D-1 per Dispatch Period (30-min). The awarded amount of capacity per Balancing Service Entity is binding and participants are required to have the corresponding capacity available in order to maintain a safe margin for the balancing of the System in real-time through the aFRR and mFRR procedures.

Requirements of FCR, aFRR and mFRR in ISP

In the framework of the ISP, the HETS Operator prepares and then publishes on its website until 09:30 EET of calendar day D-1 the following forecasts for each Dispatch Period of the Dispatch Day:

- a) the zonal Load Forecast,
- b) the zonal RES Units Forecast, which includes the non-Dispatchable RES Units Portfolios forecast and the Dispatchable Intermittent RES Units Portfolios forecast.
- c) the zonal and system upward and downward HETS Operator needs in FCR, aFRR, and mFRR,

Furthermore, it publishes the current availability of Dispatchable Generating Units and the maximum forecast availability of Generating Units for Dispatch Day D, on the basis of their non-Availability Declarations at 09:30 EET of calendar day D-1 and whenever an important modification of availability occurs.

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
ID1-1	DAM Input Data	Capacities of interconnectors and market participants' orders (supply/demand bids) submitted to the DAM Simulator.	Interconnector capacities and market participant orders must be submitted before DAM clearing begins.
ID1-2	DAM Clearing results	Market clearing prices for the Greek bidding zone, assets market schedules per Market Time Unit (MTU), interconnection flows generated by the DAM Simulator and sent to the BMO.	The DAM schedule must be finalized before the TSO-DSO coordination process begins.
ID1-3	Congestion Data	Data about real-time and forecasted transmission and distribution grid congestion. This includes information on congestion points and severity.	The TSO and DSO must share congestion data to facilitate joint congestion management in the BM process.
ID1-4	Flexibility Bids and Availability	Flexibility offers from market participants (including DER aggregators and generators) that include load shedding, demand response, and generation curtailment.	Flexibility bids should be considered during market clearing for both TSO and DSO needs.
ID1-5	Market Clearing Results	The results of the balancing market clearing process, detailing which	The market clearing results must incorporate TSO and

		flexibility resources are dispatched and their schedules.	DSO grid constraints, optimizing for system cost minimization.
ID1-6	Real-Time Grid Updates	Updates on real-time grid status, including voltage levels, congestion relief status, and system imbalances.	Real-time updates from the TSO and DSO must be exchanged to allow for iterative re-clearing of the BM.
ID1-7	System Operational Status	Final information on the operational state of the transmission and distribution grids after iterative market clearing and flexibility dispatch.	After the BM iterative process, the grid must operate robustly, and the system must remain within operational limits.

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.3.4 Fast Frequency Response for Effective Frequency Control through TSO-DSO coordination [EM-GR-02]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
EM-GR-02	Transmission grid	Fast Frequency Response for Effective Frequency Control through TSO-DSO coordination

1.2 Version management

Version management				
Version No.	Date	Name of author(s)	Changes	Approval status
1	28/05/2024	Nikolaos Koltsaklis (UPRC), Konstantinos Plakas (IPTO), Efstratia Sarafoglou (HEDNO), Vasilios Boglou (HEDNO), Vasiliki Markaki (HENEX), Aikaterini Forouli (HENEX)	Initial scope, objectives, and narrative	
2	24/10/2024	Nikolaos Koltsaklis (UPRC), Konstantinos Plakas (IPTO), Efstratia Sarafoglou (HEDNO), Vasilios Boglou (HEDNO), Vasiliki Markaki (HENEX), Aikaterini Forouli (HENEX)	KPIs, Use case conditions, further information on the use case	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this use case includes the essential role of Fast Frequency Response (FFR) in maintaining grid stability by rapidly addressing frequency deviations, the comparative advantages of FFR over Frequency Containment Reserves (FCR), the various technologies capable of providing FFR, and the modeling and optimization of FFR within the balancing market. It also covers the participation of different entities in providing FFR services and the regulatory considerations necessary to ensure reliable grid operation.
Objective(s)	Ensure rapid and effective response to frequency deviations to maintain grid stability.

	• Provide faster primary reserves compared to traditional Frequency Containment Reserves (FCR). • Integrate various technologies, (mainly batteries) to deliver Fast Frequency Response (FFR). • Optimize the deployment of FFR resources using sophisticated algorithms to balance system requirements, grid conditions, and economic considerations. • Facilitate participation in the balancing market through accurate modeling of FFR capabilities and characteristics.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description The increasing penetration of renewables in power systems introduces new challenges for their control and operation. Conventional synchronous generators provide system inertia by storing or discharging kinetic energy with minimal changes in rotational speed. However, as these rotating generation units are increasingly replaced by wind and solar units, system inertia decreases, leading to a reduction in Frequency Containment Reserves (FCR), which are closely linked to inertia. Additionally, the rapid dynamics of energy storage systems and inverters necessitate new solutions to ensure effective system control within security and reliability constraints. Fast Frequency Response (FFR) offers a potential solution to these challenges. FFR can play a critical role in maintaining grid stability in modern power systems with high renewable energy integration and evolving demand patterns. Designed to quickly counteract frequency deviations caused by sudden changes in supply or demand, FFR helps to keep grid frequency within acceptable limits, thereby supporting overall system stability. Complete description The activation of FFR is essential for maintaining grid stability by rapidly responding to frequency deviations caused by events such as sudden generator trips, load fluctuations, or disturbances in the transmission network. It acts as a primary means of frequency regulation, ensuring that grid frequency remains within a narrow range around its nominal value, which is critical for the reliable operation of electrical equipment and appliances. Since the FFR is even faster than FCR, it is indeed an option for the modern power system with reduced inertia. The main contributions of the FRR to the system are: • The ability to offer faster primary reserves compared to FCR, • The ability to reduce the inertial need of the system, especially in the context of reduced shares of inertia providers (conventional generators), • The ability to respond to the new and fast dynamics caused by power electronic components and batteries. The FFR is fully activated within 5s, instead of 30s needed by FCR. There are several technologies capable of providing FFR in different ways. Batteries, and other energy storage technologies are ideal for providing FFR due to their ability to charge and discharge electricity rapidly. They can inject or absorb power into the grid almost instantaneously to counteract frequency deviations. Apart from energy storage systems, gas turbines, hydroelectric plants with turbine governors, supercapacitors, and other fast-acting generators can also provide FFR by adjusting their output quickly in response to frequency changes. Regarding FFR modeling in the context of a Balancing Market, several aspects, such as the capacity and response time, the bidding strategies, the dispatching methodology and the regulatory framework, should be considered. FFR providers must specify their available capacity and response time characteristics, including the maximum amount of power they can inject or absorb and the ramp up- or down time in response to frequency deviations. TSOs use sophisticated optimization algorithms to determine the optimal allocation of FFR resources based on system requirements, grid conditions, and

economic considerations. This involves scheduling the activation and deactivation of FFR resources to maintain grid frequency within predefined limits while minimizing costs.

FFR providers submit bids to the balancing market operators, indicating the price at which they are willing to provide FFR services. These bids may vary based on factors such as the availability of alternative revenue streams (e.g., energy arbitrage for ESS) and operational costs.

In the context of the balancing market, the FFR products could include:

- up/down capacity offers (with minimum response time guarantee),
- up/down pairs of capacity – response time offers

The participating entities could be:

- Batteries,
- Hydroelectric plants / pumping units with turbine governors
- Supercapacitors
- Fast-acting generators

In summary, modeling FFR in the balancing market involves accurately representing the capabilities and characteristics of FFR resources, optimizing their deployment to address frequency deviations, and complying with regulatory requirements to ensure grid stability and reliability. They facilitate safe and reliable grid operation by providing faster primary reserves and mitigating the impact of diminishing system inertia.

This use case will utilize the market design B of the other Greek use case (“Congestion management in transmission and distribution grids through TSO-DSO coordination”) by incorporating the FFR as an additional reserve capacity and with the option that DERs can also participate its coverage.

1.5 Key performance indicators (KPI)

<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
1	Number of FFR activations	This KPI measures the number of DR events called within a specific time period, typically a year.	Frequency Control
2	Resource Utilization rate	This KPI measures how effectively the available FFR resources are being utilized, to the total FCR and FFR available capacity.	Frequency Control
3	Renewable Energy Curtailment Reduction	This KPI measures the reduction in renewable energy curtailment due to FFR actions.	Maximized renewable integration. Ensures that renewable energy is utilized rather than curtailed, by using it for frequency response and grid balancing.
4	DER Activation Rate	This KPI measures the percentage of DERs successfully activated to provide Fast Frequency Response within the required time frame.	Optimized use of DERs. Ensures that DERs such as energy storage, solar PV, and EVs contribute to frequency control and grid stability.

1.6 Use case conditions

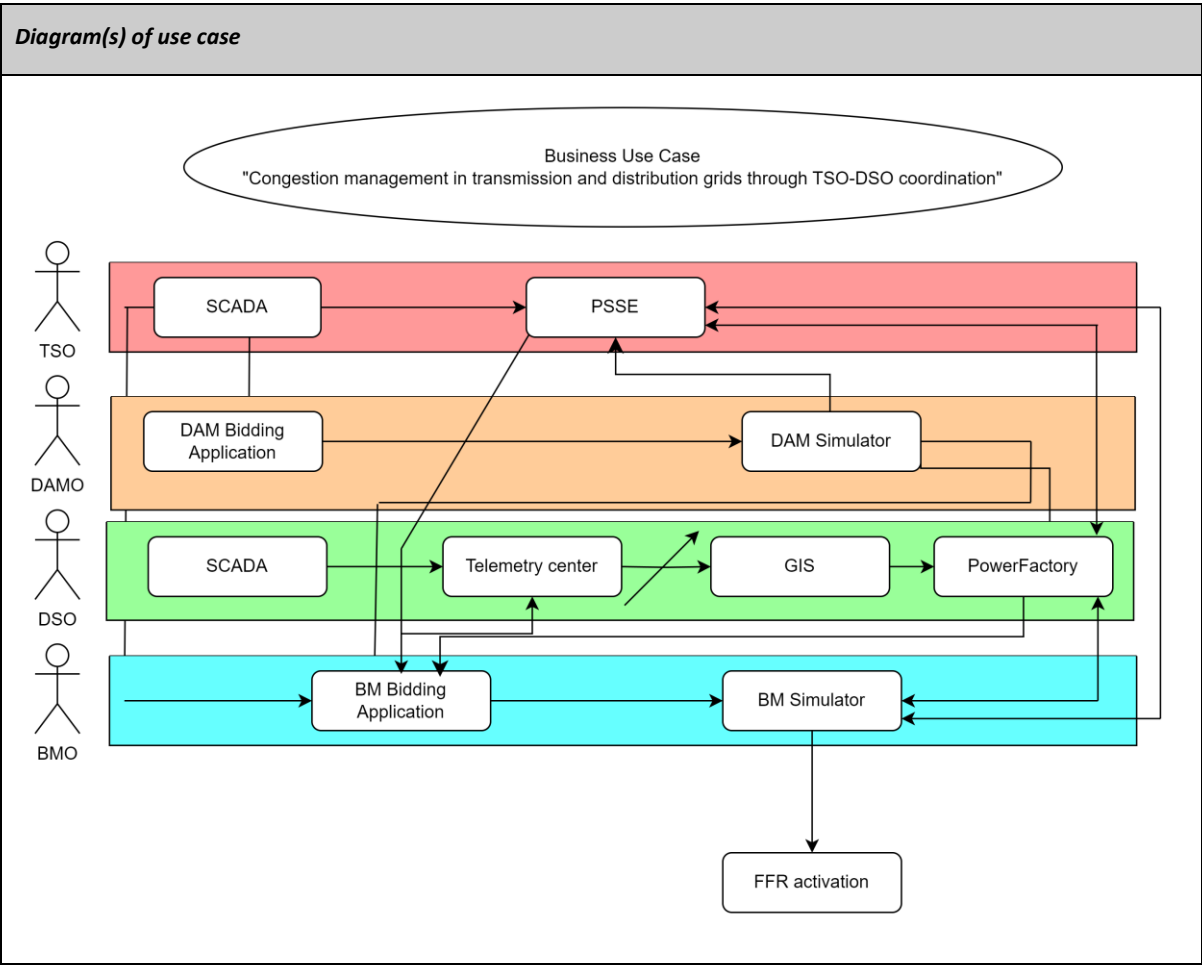
Use case conditions	
Assumptions	
The use case will be developed and demonstrated in a non-invasive environment, using data from specific parts of the Greek Transmission System.	
The balancing market will be emulated in the demo digital twin environment considering different realistic scenarios.	
Prerequisites	
Data from operating conditions for the Greek transmission grid.	
Distribution Characteristics for the Greek Power System Data from the NECP (2030) for the priorities and policy measures in the framework of the strategy to be developed for energy efficiency (IPTO)	

1.7 Further information to the use case for classification/mapping

Classification information	
Relation to other use cases	
The “EMD-GR-02: Fast Frequency Response (FFR) for Effective Frequency Control through TSO-DSO Coordination” use case is closely related to the “EMD-GR-01: Congestion management in transmission and distribution grids through TSO-DSO coordination” use case because it further enhances grid operation by incorporating an additional critical service—frequency control. While congestion management focuses on resolving and preventing grid overloads through coordinated use of flexibility resources, FFR adds another layer of system stability by addressing frequency deviations. This additional service strengthens the overall resilience of the grid by ensuring that both congestion and frequency issues are managed in a synchronized manner, leveraging the same flexibility providers and real-time data exchange between the TSO and DSO.	
Level of depth	
Transmission level	
Prioritisation	
High	
Generic, regional or national relation	
National	
Nature of the use case	
BUC	
Further keywords for classification	
Fast Frequency Response (FFR); Frequency Control; TSO-DSO Coordination; Distributed Energy Resources (DERs); Flexibility Markets.	

1.8 General remarks

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
IPTO	Independent Power Transmission Operator	The mission of IPTO is the operation, control, maintenance and development of the Hellenic Electricity Transmission System, to ensure the country's supply with electricity in an adequate, safe, efficient	

		and reliable manner, as well as the operation of the electricity market for transactions outside the Day Ahead Scheduling, pursuant to the principles of transparency, equality and free competition.	
HENEX (DAMO)	Day Ahead Market Operator - Business	A party responsible for operating the Day-Ahead Market (DAM). DAM is performed as a pan-European auction where electricity is traded for delivery the following day in time blocks. The DAM clearing process is based on the principles of social welfare optimization.	HENEX will model and implement all necessary changes to integrate Distributed Energy Resources (DERs) technologies into the DAM.
BMO	Balancing Market Operator	The balancing market operator (BMO) is responsible for maintaining the real-time balance between electricity supply and demand within a power grid. This involves managing reserves and dispatching power to ensure that electricity generation matches consumption on a minute-by-minute basis. The BMO coordinates with power generators, demand-side participants, and transmission system operators to adjust output or demand as needed, ensuring grid stability and preventing blackouts. They oversee the activation of balancing services, including frequency regulation and reserve activation, based on market mechanisms. The BMO plays a key role in facilitating a reliable, cost-effective energy system while integrating variable renewable energy sources.	

3.2 Systems

Actors

<i>Grouping (e.g. domains, zones)</i>		<i>Group description</i>	
<i>System name</i>	<i>System owner</i>	<i>System description</i>	<i>Further information specific to this system use case</i>
SCADA (HIS)	TSO	It allows operators to gather real-time data, control infrastructure, and ensure the reliable and secure operation of high-voltage power transmission networks across Greece. The system helps in monitoring equipment, detecting faults, and optimizing power flow.	
PSSE	TSO	PSSE allows you to perform a wide variety of analysis functions, including power flow, dynamics, short circuit, contingency analysis, optimal power flow, voltage stability, transient stability simulation, harmonics, time series power flow and much more.	
DAM Bidding Application	HENEX (DAMO)	Application that performs the bidding strategies of participants in the DAM, based on projected scenarios driven by expected changes in the generation mix up to 2030.	The outputs of the Bidding Application serve as inputs to the DAM Simulator.
DAM Simulator	HENEX (DAMO)	The DAM Simulator is the first module of the Greek Electricity Market Digital Twin. It is designed to replicate and forecast the operation of the Greek Day-Ahead electricity market. The DAM Simulator uses input data from multiple sources, such as network capacities and constraints provided by the TSO, along with orders from market participants as produced by the Bidding Application. It then performs the matching of orders. Outputs	DAM Simulator outputs will be utilized as an input data pool for the Balancing Market (BM) module, supporting the effective coordination and management of electricity supply and demand, particularly with the DERs integration.

		generated by the DAM Simulator include market prices for the Greek bidding zone for each Market Time Unit (MTU) and asset market schedules.	
Balancing Market bidding process	BMO	The balancing market bidding process involves energy suppliers, producers, and other market participants submitting bids to provide balancing energy and ancillary services to maintain grid stability. In this process, participants offer electricity or services like frequency control, voltage support, and reserves to balance supply and demand. Bids are typically submitted ahead of time, and the system operator selects the most cost-effective bids to meet real-time imbalances. Participants are compensated based on the accepted bid prices, which reflect the value of the services they provide. This process ensures a reliable and flexible energy system, critical for integrating variable renewable energy sources.	
Balancing Market clearing	BMO	The balancing market clearing process ensures that electricity supply and demand remain balanced in real-time. It involves matching bids and offers from market participants, including generators and consumers, to adjust energy imbalances that arise due to deviations from the scheduled dispatch in the day-ahead or intraday markets. System operators activate the least-cost balancing resources while maintaining grid stability, often considering constraints like transmission capacity and reserve requirements. The	

		market is typically cleared using marginal pricing, where the highest accepted bid sets the price, incentivizing efficient resource allocation and enhancing flexibility in power system operations.	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

<i>Scenario conditions</i>						
<i>No.</i>	<i>Scenario name</i>	<i>Scenario description</i>	<i>Primary actor</i>	<i>Triggering event</i>	<i>Pre-condition</i>	<i>Post-condition</i>
1	High Renewable Generation Scenario	The grid experiences high levels of renewable energy generation (from solar PV and wind), leading to potential frequency deviations and congestion in the network.	TSO, DSO	High renewable energy generation forecast	Real-time data exchange between TSO and DSO, high renewable energy bids submitted to the DAM	FFR services are successfully activated, frequency and grid stability are maintained, and renewables are fully utilized
2	Grid Stress During Peak Demand	The grid experiences high demand during peak periods (e.g., winter evenings), causing stress on both the transmission and distribution networks.	TSO, DSO	High demand during peak period, leading to grid stress	Real-time data exchange between TSO and DSO; high peak demand forecast and load profiles submitted	FFR and demand-response services are activated, grid stability is maintained, and costly grid reinforcements are avoided

4.2 Steps – Scenarios for flexibility market not organised

Scenario name #1 High Renewable Generation Scenario

Scenario #1 description

In this scenario, the grid experiences a significant increase in renewable energy generation, particularly from wind and solar power. During periods of high generation, the intermittent nature of these resources leads to frequency fluctuations, requiring rapid corrective actions. The TSO and DSO, working in coordination, use real-time data exchange to detect the

frequency deviations early. FFR services are activated within seconds from a combination of technologies such as battery energy storage systems, demand response from industrial loads, and fast-responding DERs. The joint flexibility market optimizes the dispatch of these resources, ensuring that both transmission and distribution grids remain stable without the need to curtail renewable energy generation. The speed of FFR, in this case, proves essential to preventing larger frequency deviations that would otherwise require the activation of slower, more expensive FCR. This scenario highlights the advantage of FFR in integrating higher shares of renewables into the grid while minimizing curtailment and reducing reliance on conventional generation.

Scenario name #2 Grid Stress During Peak Demand

Scenario #2 description

In this second scenario, the grid experiences peak demand during a cold winter evening, causing stress on both the transmission and distribution networks. As demand surges, frequency deviations occur due to the mismatch between supply and demand. The TSO and DSO, through close coordination, monitor grid conditions in real-time and identify areas where frequency support is needed. Instead of resorting to costly re-dispatch of centralized generation, FFR services are quickly activated, primarily through demand response mechanisms and distributed energy storage at the distribution level. Industrial consumers reduce their load, and energy storage units inject power into the grid, providing immediate frequency support. The ability of FFR to rapidly respond to these deviations prevents the need for load shedding or activating slower reserves. This scenario demonstrates how FFR can be used not only during renewable energy integration but also during peak demand periods to maintain frequency stability and avoid high operational costs.

Scenario step by step analysis

Scenario								
Scenario name		High Renewable Generation Scenario						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1	-	DAM Input Data Generation	The Bidding Application simulates market participants' order submissions (including RES aggregators) and generates network capacities and constraints, emulating standard TSO data provision processes.	Bid Management and Submission	HENEX (DAMO)	HENEX (DAMO)	ID-11	Interconnector capacities and market participant orders must be submitted prior to market gate closure.

1.2	-	DAM Market Clearing	The Day-Ahead Market Operator implements the market clearing process based on social welfare optimization, producing a generation market schedule that ensures the integration of high renewable resources.	Market Clearing	HENEX(DAMO)	TSO, DSO, BMO	ID-12	Market schedules are shared with TSO and DSO for grid stability assessment.
1.3	Assess potential grid issues	TSO-DSO Coordination	The TSO and DSO jointly assess potential grid issues, such as congestion and frequency deviations, due to high renewable penetration.	Congestion and Frequency Management	TSO, DSO	TSO, DSO	Grid stability assessment, congestion points, potential frequency deviations	TSO and DSO coordination for proactive grid stability assessment.
1.4	Communicate FFR requirements	Communication to Balancing Market Operator	The TSO and DSO jointly communicate the need for Fast Frequency Response (FFR) to the Balancing Market Operator (BMO) to ensure rapid frequency control.	FFR Requirement	TSO, DSO	Balancing Market Operator (BMO)	FFR requirement for grid stability	TSO and DSO must provide FFR requirements to BMO based on real-time grid assessments.
1.5	Balancing Market clearing	Balancing Market Clearing	The Balancing Market Operator clears the	Market Clearing	Balancing Market Operator (BMO)	TSO, DSO, Aggregators	FFR bids, selected resources	The balancing market clearing must

			market, selecting FFR providers based on bids submitted by flexibility providers (e.g., DERs, energy storage).					ensure optimal dispatch of FFR resources.
1.6	Check feasibility of balancing schedule	TSO-DSO Coordination and Iterative Feedback	The TSO and DSO check the balancing market schedule for potential transmission or distribution grid constraints and provide feedback to the BMO.	Feasibility Check	TSO, DSO	Balancing Market Operator (BMO)	Feasibility assessment, grid constraints, iterative adjustments	Iterative feedback loop between TSO, DSO, and BMO to ensure grid stability and schedule feasibility.
1.7	Activation of FFR	FFR Activation	The selected FFR providers (DERs, energy storage) are activated in real-time to respond to frequency deviations and stabilize the grid.	FFR Activation	Balancing Market Operator (BMO)	Aggregators, DERs, Energy Storage	Activation signals, frequency stabilization metrics	FFR activation should occur within seconds of a frequency deviation to prevent grid instability.

Scenario								
Scenario name		Grid Stress During Peak Demand						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchange (IDs)	Requirement, R-IDs
2.1	-	DAM Input Data	The Bidding Application replicates the	Bid Manager	HENEX(DAMO)	HENEX(DAMO)	ID-11	Interconnector capacities

		Generation	order submissions of market participants, including demand response providers and flexibility aggregators, reflecting anticipated demand and available flexibility while generating network capacities and constraints, thereby emulating standard TSO data provision processes.	nt and Submission				and market participant orders must be submitted prior to market gate closure.
2.2	-	DAM Market Clearing	The Day-Ahead Market Operator implements the market clearing process based on social welfare optimization, determining the generation schedule for energy and demand response resources. This schedule is communicated to the TSO and DSO for grid stability assessments.	Market Clearing	HENEX (DAMO)	TSO, DSO	ID-12	DAM schedule should be shared with TSO and DSO for grid assessments before activation of resources.
2.3	Assess grid stability	TSO-DSO Coordination	The TSO and DSO jointly assess the impact of the Day-Ahead schedule on their respective	Congestion and Frequency Management	TSO, DSO	TSO, DSO	Grid stability assessment, congestion forecast	Coordination between TSO and DSO to check the grid's ability to

			grids, identifying potential frequency deviations or congestion points due to the peak demand.					handle the scheduled demand during peak times.
2.4	FFR requirements identified	Communication to Balancing Market Operator for FFR	The TSO and DSO jointly determine the need for Fast Frequency Response (FFR) to mitigate potential frequency deviations during peak demand and communicate these requirements to the BMO.	FFR Requirement	TSO, DSO	Balancing Market Operator (BMO)	FFR requirements	FFR requirements should be communicated to the BMO to ensure real-time response readiness.
2.5	Balancing market clearing	Balancing Market Clearing	The BMO clears the balancing market, selecting FFR and demand-response providers based on the bids submitted. The clearing ensures optimal dispatch of flexibility.	Market Clearing	BMO	TSO, DSO, Aggregators	Balancing market schedule, selected FFR bids	The balancing market clearing process should optimize flexibility resource dispatch to match grid requirements.
2.6	Grid check and feedback loop	Check from Transmission and Distribution Operators	The TSO and DSO review the balancing market schedule to ensure that FFR dispatch aligns with grid conditions. If any issues are identified, feedback is sent to the	Feasibility Check	TSO, DSO	BMO	Feasibility assessment, grid constraints, iterative feedback	TSO and DSO must ensure that the balancing schedule will not overload the grid or cause frequency instabilities.

			BMO for adjustments.					
2.7	Activation of FFR	FFR Activation	Once the balancing market schedule is verified, FFR providers (e.g., energy storage, demand response) are activated in real-time to manage frequency deviations and maintain grid stability.	FFR Activation	BMO	Aggregators, DERs, Energy Storage	Activation signals, frequency stabilization metrics	FFR activation signals should be communicated instantly to flexibility providers to prevent grid instability.

ISP General Details

The ISP is executed as a Mixed Integer Linear Programming model and is solved as a co-optimization problem taking into account the Balancing Energy and Balancing Capacity Offers of the BSEs as well as their respective constraints, the HETS constraints and the HETS Operator needs, in order to minimize the cost of Balancing Energy and Balancing Capacity procurement. The ISP execution produces:

- the commitment status (synchronization or de-synchronization) of each Balancing Service Entity,
- the awarded upward and downward Balancing Capacity products per Balancing Service Entity for each Dispatch Period of the Dispatch Day, and
- the inter-zonal flows.

IPTO defines the zonal and systemic upward and downward HETS needs per Dispatch Period (30-min) of the Dispatch Day, for the following Balancing Capacity products:

- Upward and downward Frequency Containment Reserve (FCR),
- Upward and downward automatic Frequency Restoration Reserve (aFRR),
- Upward and downward manual Frequency Restoration Reserve (mFRR).

Apart from the above-mentioned Balancing capacity offers, BSPs submit to the ISP upwards/downwards Balancing Energy offers.

For the transitional period before commencement of the coupled operation of the Intra-Day Market of Law 4425/2016, the ISP is executed at three scheduled times for each Dispatch Day D as follows.

ISP1	It is executed at 16:45 EET on calendar day D-1 and concerns all Dispatch Periods (48 Dispatch Periods) of Dispatch Day D.
ISP2	It is executed at 00:00 EET on calendar day D, taking into account the updated input data, and concerns all Dispatch Periods (48 Dispatch Periods) of Dispatch Day D.
ISP3	It is executed at 12:00 EET on calendar day D, taking into account the updated input data. The time interval taken into account is from 13:00 EET until the end of Dispatch Day D (24 Dispatch Periods).

IPTO may execute the ISP at any time for all or for certain Dispatch Periods ("ad-hoc ISP"), in case of an event which significantly affects the scheduling of the Units and the dispatch of the Balancing Capacity. Such events may include but are not limited to significant changes in the zonal Load Forecast, or zonal RES Units Forecast, or the availability of resources, or the HETS conditions.

The analytical timetable of the ISP can be found at the [Technical Decision ISP](#).

BSPs submit Balancing Capacity and Energy offers for Dispatch Day D, from 14:00 to 16:45 EET of the calendar day D-1 per Dispatch Period (30-min). The awarded amount of capacity per Balancing Service Entity is binding and participants are required to have the corresponding capacity available in order to maintain a safe margin for the balancing of the System in real-time through the aFRR and mFRR procedures.

Bids Submission BSPs

BSPs submit Balancing Capacity and Energy offers for Dispatch Day D, from 14:00 to 16:45 EET of the calendar day D-1 per Dispatch Period (30-min). The awarded amount of capacity per Balancing Service Entity is binding and participants are required to have the corresponding capacity available in order to maintain a safe margin for the balancing of the System in real-time through the aFRR and mFRR procedures.

Requirements of FCR, aFRR and mFRR in ISP

In the framework of the ISP, the HETS Operator prepares and then publishes on its website until 09:30 EET of calendar day D-1 the following forecasts for each Dispatch Period of the Dispatch Day:

- the zonal Load Forecast,
- the zonal RES Units Forecast, which includes the non-Dispatchable RES Units Portfolios forecast and the Dispatchable Intermittent RES Units Portfolios forecast.
- the zonal and system upward and downward HETS Operator needs in FCR, aFRR, and mFRR,

Furthermore, it publishes the current availability of Dispatchable Generating Units and the maximum forecast availability of Generating Units for Dispatch Day D, on the basis of their non-Availability Declarations at 09:30 EET of calendar day D-1 and whenever an important modification of availability occurs.

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
ID-1	Demand Forecast	Peak demand forecasts shared between TSO, DSO, and Balancing Market Operator (BMO) to anticipate grid stress during high demand periods.	Real-time data exchange of demand forecasts to allow proactive congestion management.
ID-2	Load Profiles	Load profiles from distribution and transmission networks, outlining expected demand and consumption patterns for peak periods.	Load profiles must be updated and communicated regularly to reflect current grid conditions.
ID-3	Grid Status	Real-time grid status, including transmission and distribution system conditions, voltage levels, and frequency stability.	TSO and DSO must share real-time grid data to monitor stress points and prevent overload.
ID-4	Frequency Deviation	Alerts or real-time data on frequency deviations detected during peak demand, shared between TSO, DSO, and BMO to trigger FFR activation.	Frequency deviation data must be shared instantly to ensure rapid FFR response.
ID-5	FFR Requirement	Specification of Fast Frequency Response (FFR) service requirements (e.g., capacity, duration) communicated by TSO and	FFR requirements must be communicated to the Balancing Market for effective activation.

		DSO to BMO for activating FFR.	
ID-6	FFR Bids	Flexibility bids from DERs and aggregators submitted to the Balancing Market Operator for selection and dispatch during frequency deviations.	FFR bids must be optimized and selected based on grid needs for frequency stabilization.
ID-7	Balancing Market Schedule	Market clearing schedule for FFR services, provided by the BMO to TSO, DSO, and aggregators. It includes selected resources for FFR activation.	The balancing market schedule must reflect the real-time grid needs for frequency control.
ID-8	Feasibility Assessment	Joint assessment of balancing market schedule by TSO and DSO to ensure that FFR dispatch is feasible without causing transmission or distribution grid issues.	Iterative feasibility checks must be performed by TSO and DSO before FFR activation.
ID-9	Activation Signal	Real-time activation signals sent by the BMO to flexibility providers (DERs, storage, demand response) for FFR dispatch to correct frequency deviations.	Activation signals must be sent in real-time to ensure timely FFR response for grid stability.
ID-10	Frequency Stabilization Report	Post-activation report outlining the effectiveness of the FFR service in stabilizing frequency, shared between TSO, DSO, and BMO for validation.	Reports must be generated to evaluate the effectiveness of FFR actions in maintaining grid stability.
ID-11	DAM Input Data	Capacities of interconnectors and market participants' orders (supply/demand bids) submitted to the DAM Simulator.	Interconnector capacities and market participant orders must be submitted before DAM clearing begins.
ID-12	DAM Clearing results	Market clearing prices for the Greek bidding zone, assets market schedules per Market Time Unit (MTU), interconnection flows generated by the DAM Simulator and sent to the BMO.	The DAM schedule must be finalized prior to the TSO-DSO grid assessment process.

6 Requirements (optional)**7 Common terms and definitions****8 Custom information (optional)**

B.4 German Pilot Site UCs

B.4.1 Utilization monitoring on LV-/MV level [GE01]

1 Description of the use case

1.1 Name of use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ge01	Distribution	Utilization monitoring on LV-/MV-level

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	17.07.2024	Jessica Stephan		
0.3	18.07.2024	Ellen Jaenecke		
0.4	28.11.2024	Jessica Stephan		

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	Visualization of the distribution grid, integrating real-time measurements from Scada-like systems and intelligent meter measurements
<i>Objective(s)</i>	Have a measurement-based real-time monitoring of grid utilization in order to identify bottlenecks.
<i>Related business case(s)</i>	LV operation, enable congestion management

1.4 Narrative of Use Case

<i>Narrative of use case</i>
<i>Short description</i>
Use case 1 focuses on implementing the Intelligent Grid Platform (IGP) to digitally visualize the distribution grid, integrating real-time measurements from Scada-like systems and intelligent meter measurements. The platform enables online monitoring, visualization of measurement locations and values, and in-depth analysis of parameters like voltage, utilization, and symmetry, with notifications for threshold violations. The primary objective is to achieve measurement-based real-time monitoring to identify grid bottlenecks, benefiting the distribution system operator by providing comprehensive grid

visualization, statistics on utilization rates and voltage levels, and the ability to detect data inconsistencies for continuous improvement.

Complete description

Use case 1 focuses on the implementation of the Intelligent Grid Platform (IGP) to provide a detailed digital visualization of the distribution grid. This platform integrates real-time measurements sourced from SCADA-like systems and intelligent meter data, ensuring an accurate representation of grid conditions. The IGP facilitates online monitoring of the distribution grid, presenting visualization tools for measurement locations and their corresponding values. This functionality allows for an in-depth analysis of various parameters such as voltage levels, grid utilization, and symmetry.

The goal is to achieve measurement-based real-time monitoring to pinpoint and address grid bottlenecks. Therefore, a consistent Online Monitoring and the deriving state estimations are necessary. This capability to locate grid bottlenecks is crucial for the distribution system operator, who can leverage the platform to gain a comprehensive understanding of the grid's performance. This includes detailed statistics on utilization rates, voltage levels, and the ability to identify and rectify data inconsistencies, thereby facilitating continuous improvement of grid operations.

Additionally, the platform provides an overview of sensor penetration for each observed grid, categorized into customer measurements and feeder/substation monitoring. It employs state estimation algorithms to derive the complete grid state in medium and low voltage levels. The estimation of the grid state is based on the latest real-time data (including measurements and switching states) and other indicators such as generation and load types and capacities. The platform supports a maximum frequency for state estimation of 1/minute. It evaluates the grid state for every single asset, issuing warnings in case of limit violations.

The Use Cases will realize an overview of all monitored grids and key performance indicators (KPIs) for voltage levels and asset loading based on the results of the latest state estimation. It visualizes the results of the state estimation for each individual asset and documents and visualizes historical state estimation results.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	10% Increase in Grid Observability accuracy	Relevant variables for observability of the grid are valid: - voltage at (all) nodes of the grid - utilization of lines, - utilization of transformers etc. - count of measurements - quality of measurements	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	

2	
Prerequisites	
1	Availability of Real-Time Measurement Data
2	Sufficient grid size (>4 feeders, >40 connection objects)
3	High data availability and quality for static grid data
4	Sufficient space for monitoring devices in substation (if not there yet)

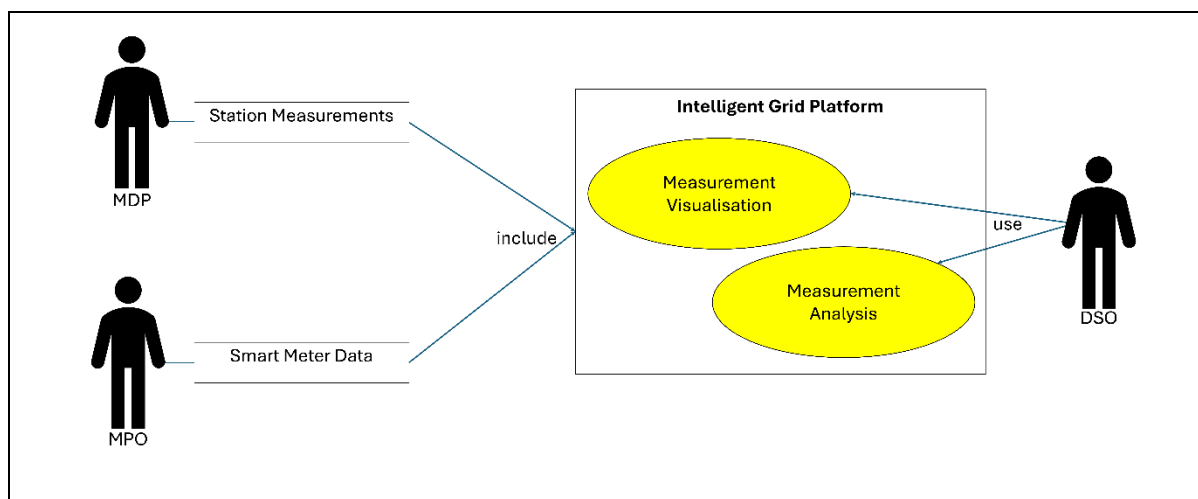
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Basis for Use Case 2 State Estimation
Level of depth
Distribution Level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification
Online monitoring, observability, measurements

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity. Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),	
Metering Point Operator (MPO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.	
Measuring Device Provider (MDP)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Measurement Devices in the Field like e.g. in LV/MV stations.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Digital Twin	DSO	Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelio.	The IGP visualises all data in a grid map.
Smart Meter Data Platform	MPO	A Platform where all Smart Meter Data is collected, mapped and prepared.	The IGP receives the smart meter measurements and visualises them.
Measurement Platform	MDP	A Platform where all Station Measurement Data is collected, mapped and prepared.	The IGP receives the station measurements and visualises them.

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Data collection	The IGP receives the needed data, like station measurements and smart meter data.	DSO			
2	Visualisation	The IGP visualises all measurements at the nodes in the grid in one grid map	DSO			
3	Analysis	In the IGP plots with time series and measured peaks are shown	DSO			

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
1	Smart Meter Data	Measured active power (and sometimes voltage and current) delivered by the MPO. This is time series, delivered in real-time.	
2	Station Measurements	Measured active power, voltage and current delivered by the MDP at the LV/MV station. This is time series, delivered in real-time.	
3	Measurement Analysis	Visualisation on Load Flow Results, Max./Min. Voltage, Max. Current,	
4	Topology Overview	Visualization of the Topology	

6 Requirements (optional)

7 Common terms and definitions

Distribution System Operator (DSO)

A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),

Metering Point Operator (MPO)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.

Measuring Device Provider (MDP)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Measurement Devices in the Field like e.g. in LV/MV stations.

8 Custom information (optional)

B.4.2 State estimation under changing topology on LV-level [GE02]

1 Description of the use case

1.1 Name of use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ge02	Distribution	State estimation under changing topology on LV-level

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	24.6.2024	Ellen Jaenecke (Envelio)		
0.3	28.11.2024	Jessica Stephan		

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	Expansion of utilization monitoring by integrating real-time topology measurements and developing state estimation algorithms.
<i>Objective(s)</i>	Extend the observability from the measurement locations to the full grid using digital twin information (asset attributes, topology, load/generation data,...) and computational methods, including changes to the topology and resulting changes in the grid state.
<i>Related business case(s)</i>	

1.4 Narrative of Use Case

<i>Narrative of use case</i>
<i>Short description</i>
Use case 2 expands upon utilization monitoring by integrating real-time topology measurements and developing state estimation algorithms. These algorithms analyze measurement data and topology changes to continuously update and visualize the grid state in real-time, including warnings for limit violations. The objective is to enhance observability across the entire grid using digital twin information and computational methods, enabling the distribution system operator to identify and respond to critical situations throughout the grid. By automatically considering topology changes, the system ensures accurate grid state estimation even after network reconfigurations, providing comprehensive grid monitoring and management capabilities.

Complete description	
Use Case 2 builds upon the foundation of utilization monitoring by incorporating real-time topology measurements and developing advanced state estimation algorithms. These algorithms analyze measurement data and topology changes to continuously update and visualize the grid state in real-time. This includes issuing warnings for limit violations, enabling the distribution system operator (DSO) to identify and respond to critical situations across the entire grid efficiently. Even though visualization and analysis of measurement data already provide the DSO with significant benefits, there remain many blind spots within the grid. In these areas, the DSO lacks knowledge about the grid state and may be unaware of threshold violations in terms of voltages and currents. Extending observability by estimating the grid state for all parts of the grid addresses this issue. It enables the DSO to analyze and monitor the entire grid comprehensively, allowing for timely reactions to critical situations in any part of the network. The integration of real-time topology measurements ensures that the system can automatically account for topology changes. While these changes are not very frequent at the low voltage level, they must be considered to maintain accurate grid state estimation. By doing so, the system guarantees that even after network reconfigurations, the correct topology is used to estimate the grid state. This automatic consideration of topology changes ensures that the grid monitoring and management capabilities remain accurate and reliable.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	20% decrease in the deviation error	The higher the standard deviation, the higher the inaccuracy and the greater its influence on the result of the state estimation → target: small deviation	
2	5% Increase in number of monitored switches	Number of monitored switches (most of the switches are not monitored from remote yet)	
3	Percentage of State Estimation (SE) runs that did not converge	- The current solver for the SE optimization problem is not intrinsically guaranteeing a feasible solution - The calculation may be interrupted by a crash - ... → Key is a continuous monitoring of the grids with as few interruptions as possible	
4	Relative deviations between SE input and output	- High deviations (relative, normalized to e.g. the nominal power of the asset) are often an indicator for data quality problems, faulty measurement inputs, ... → Disproportionately high deviations are not a strict metric, much rather a hint towards one of a selection of potential problems.	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Measurement devices are assumed to be calibrated and providing accurate data

2	Switching state synchronization number: manually updated switching states are correct
Prerequisites	
1	Threshold values/limits for voltage, utilization, symmetry, and failure should be predefined and set up in the monitoring system.
2	Continuous and stable network connectivity between the measurement devices and the IGP platform
3	Good quality of topology information (equipment data etc.)

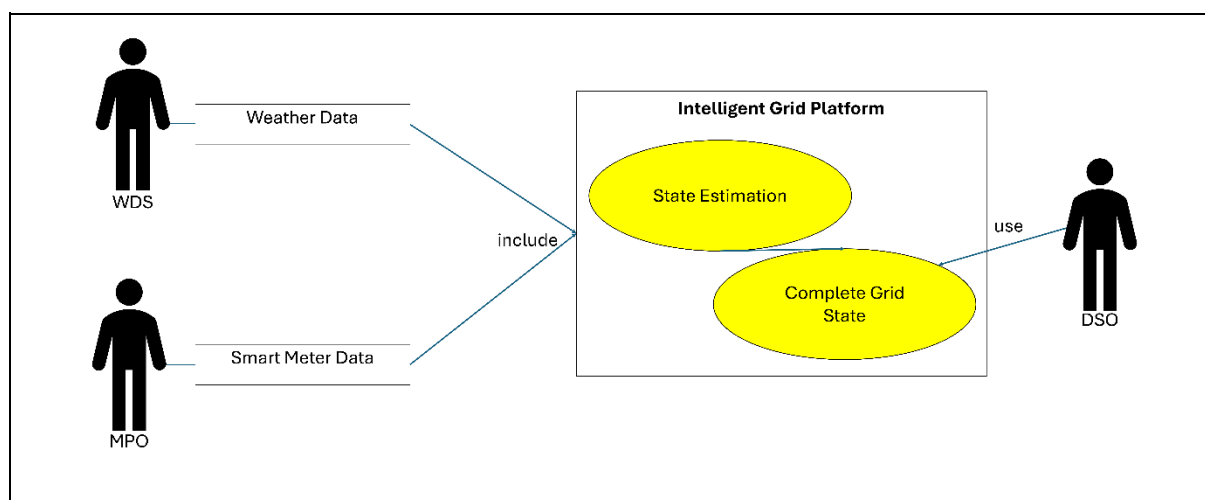
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Basis for use case 3 congestion management
Level of depth
Distribution Level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification
State estimation, LV switching,

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity. Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),	
Metering Point Operator (MPO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.	
Measuring device provider (MDP)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Measurement Devices in the Field like e.g. in LV/MV stations.	
Weather Data Supplier (WDS)	Business	A natural or legal person who is selling weather data via API.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Digital Twin	DSO	Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelopio.	The IGP visualises all data in a grid map.
Smart Meter Data Platform	MPO	A Platform where all Smart Meter Data is collected, mapped and prepared.	The IGP receives the smart meter measurements and visualises them.
Station Measurement Platform	MDP	A Platform where all Station Measurement Data is collected, mapped and prepared.	The IGP receives the station measurements and visualises them.
Weather Data Platform	WDS	A Platform that provides weather data via API	The IGP needs solar and wind data to estimate the power generation.

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Data collection	The IGP receives the needed data, like weather data and smart meter data.	DSO	cyclic	Data are available from WDS & MPO	gathered/generated data are processed to the IGP
2	Generating pseudo measurements	All nodes that are not measured get synthetic profiles (load or generation) to enable a state estimation	DSO	data received are assessed, indicating the missing points/nodes		
3	State estimation	Within the IGP a state estimation is calculated. The real measurements are weighted much more than the pseudo measurements. As output all currents and voltages for the whole grids are known.	DSO			

4	complete grid state	The IGP visualises the complete grid state with all calculated voltages and currents	DSO		State estimation converged	

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1	Smart Meter Data	Measured active power (and sometimes voltage and current) delivered by the MPO. This is time series, delivered in real-time.	
2	Station Measurements	Measured active power, voltage and current delivered by the MDP at the LV/MV station. This is time series, delivered in real-time.	
3	Weather Data	Wind and solar data delivered by the WDS. This is time series, delivered in real-time and advance.	
4	IGP internal commands	Synthesize not-measured nodes, Create complete grid state, etc.	

6 Requirements (optional)

7 Common terms and definitions

Distribution System Operator (DSO)

A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),

Metering Point Operator (MPO)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.

Measuring Device Provider (MDP)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Measurement Devices in the Field like e.g. in LV/MV stations.

Weather Data Supplier (WDS)

A natural or legal person who is selling weather data via API.

8 Custom information (optional)

B.4.3 Development of advanced monitoring & control tools for congestion management [GE03]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ge03	Distribution	Development of advanced monitoring & control tools for congestion management

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	24.6.2024	Ellen Jaenecke (Envelio)		
0.3	28.11.2024	Jessica Stephan		

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Implementation of curative control measures to address bottlenecks in the grid caused by the increasing adoption of electromobility and heat pumps.
Objective(s)	Curative control of congestions based on state estimations.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
Use case 3 utilizes a central network model continuously validated with sensor data integration to perform regular state estimations, identifying critical network states and areas. The objective is to implement curative control measures to address bottlenecks in the grid caused by the increasing adoption of electromobility and heat pumps. By analysing real-time grid status and historical data, the system generates schedules for grid operators to implement ad-hoc adjustments to alleviate congestion. This proactive approach enables the grid operator to manage electricity consumption spikes from electric vehicles and heat pumps, mitigating potential overload scenarios in the low-voltage grid and facilitating the transition to new energy business models.

Complete description

The surge in electromobility and the widespread adoption of heat pumps are creating significant bottlenecks in the low-voltage grid. As more electric vehicles and heat pumps consume electricity simultaneously and uncoordinatedly, the resulting power peaks can overload the grid. While new business models related to electromobility are accelerating the energy transition, they also increase the potential for congestion. This use case addresses these challenges by developing advanced monitoring and control tools that enable the grid operator to manage and mitigate these congestion risks effectively. Use Case 3 leverages a central grid model that is continuously validated with integrated sensor data to perform regular state estimations, identifying critical grid states and areas. The system analyses real-time grid status and historical data to generate schedules for grid operators, enabling ad-hoc adjustments to alleviate congestion. This proactive approach allows the grid operator to manage electricity consumption spikes from electric vehicles and heat pumps, mitigating potential overload scenarios in the low-voltage grid and facilitating the transition to new energy business models.

The central grid model forms the foundation of this use case, subject to continuous validation with up-to-date data. Sensors provided by measuring device providers are continuously integrated into the grid model, ensuring that it accurately reflects current conditions. Regular state estimations are conducted to assess the grid status, identifying critical states or areas that may require intervention.

The system identifies suitable and non-discriminatory control measures to manage these critical states. By analysing both real-time grid status and historical data from previous months or years, the system generates schedules and suggestions for the grid operator. These schedules can be activated on an ad-hoc basis to adjust the behaviour of affected individual systems accordingly.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	10% increase in Response Time	Time taken to identify and respond to potential congestion events	
2	20% increase of congestion events that are avoided.	Number solved congestions	
3	10% decrease of SE runs that did not converge	Just as in UC2, Online Monitoring, CM relies on a SE run every minute to observe the repercussions of the sent control commands. If these SEs cannot be carried out, the transparency of congestion resolution processes gets lost.	
4	Quota of failed regulator interventions	Regulator interventions are initiated with a fixed timeline in order to solve a congestion detected earlier, using parameters fitting to the given situation. Still, a regulator intervention may not resolve the congestion: A second (third, fourth, ...) intervention would be chained in this case. Reaching a 100% quota should not be the goal here (the volatility of the inputs would not allow for that), but a good steering algorithm takes eventualities into account and mitigates as many congestions as possible.	

1.6 Use case conditions

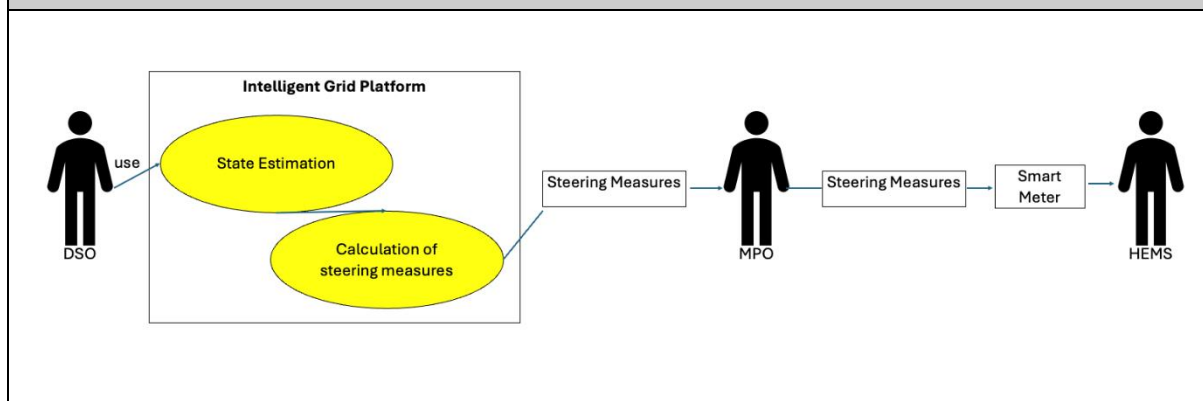
Use case conditions	
Assumptions	
1	Only transformer and feeders at ONS / electrical substation are in scope
2	Non-discriminatory selection of the steerable loads to be controlled: As far as technically feasible, equal proportional power reduction of all loads in the line.
3	Sufficient space for monitoring devices in substation available
Prerequisites	
1	High data availability and quality for static grid data
2	Availability of Controllable Assets
3	Availability of ImSys(where the MeLo = MaLo) (Smart Meters)
4	Once an iMS has been installed: provision of the technology required to connect the to the iMS by the MPO
5	Threshold values/limits should be predefined

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Bases on use case 1 and 2
Level of depth
Distribution Level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC

Further keywords for classification

Congestion management, steering measures,

1.8 General remarks**2 Diagrams of use case****Diagram(s) of use case****3 Technical details****3.1 Actors**

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity. Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),	
Metering Point Operator (MPO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.	
HEMS Provider	Business	Defined as any legal entity that aggregates and controls flexible assets behind the meter.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Digital Twin	DSO	Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelio.	The IGP calculates and sends the envelope curve to the FSPs.
Communication module	MPO	Receives load limits from the IGP and sends them to the HEMS.	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	State estimation	Within the IGP a state estimation is calculated. The real measurements are weighted much more than the pseudo measurements. As output all currents and voltages for the whole grids are known.	DSO			
2	Calculating steering measures	If a congestion is detected, the IGP calculates the needed load reduction for some nodes.	DSO			
3	Sending the steering measures to MPO	The IGP sends load limits for some nodes to the MPO	DSO			
4	Sending the load limits to the HEMS	The MPO sends the load limits to the Households.	MPO			
5	Load reduction	The household reduces its load	HEMS			
6	Grid without congestions	The grid congestion is solved and there is no more critical grid state	DSO			

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
1	Load limits	Maximum load for some nodes in the grids	
2	Commands to HEMS	Signals sent to the HEMS	

6 Requirements (optional)

7 Common terms and definitions

Distribution System Operator (DSO)

A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),

Metering Point Operator (MPO)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.

HEMS Provider

Defined as any legal entity that aggregates and controls flexible assets behind the meter.

ImSys

Intelligent Measurement System (Smart Meter)

8 Custom information (optional)

B.4.4 Development of a concept for a preventive congestion management [GE04]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ge04	Distribution	Development of a concept for a preventive congestion management

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	28.11.2024	Jessica Stephan		

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Development of a concept for preventive congestion management, focusing on the conceptual development of a congestion forecast and possible proactive control measures
Objective(s)	Development of a concept for preventive congestion management.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
Use case 4 aims to develop a concept for preventive congestion management, focusing on the conceptual development of a congestion forecast and possible proactive control measures. The objective is to identify efficient calculation logic for forecasting congestion, with emphasis on critical low-voltage grids. Through the analysis of user data, grid conditions, and various models, the system aims to devise proactive strategies to mitigate congestion. The implementation in the German demonstrator involves testing and evaluating these models to ensure effective preventive congestion management. Additionally, the use case involves identifying any required additional data and important calculation and control chains necessary for successful implementation.
Complete description

Use case 4 is centred around developing a comprehensive strategy for preventive congestion management. The primary focus is on designing a robust congestion forecast and implementing proactive control measures to address potential bottlenecks, particularly in critical low-voltage grids. The project aims to identify and develop efficient calculation logic for accurately forecasting congestion. This involves an in-depth analysis of user data, grid conditions, and various predictive models to devise effective strategies for mitigating congestion before it occurs. Additionally, this use case involves a thorough investigation to identify any supplementary data that might be required for more accurate forecasting and control. The project also aims to delineate essential calculation and control chains that are necessary for the successful implementation of preventive congestion management strategies. This holistic approach ensures that all aspects of congestion management are addressed, paving the way for a more resilient and efficient power grid. By leveraging detailed analyses and innovative modeling techniques, the system seeks to proactively manage congestion, thereby enhancing grid stability and reliability. The insights gained from this use case will not only improve current practices but also provide a foundation for future advancements in congestion management, highlighting the potential for ongoing innovation and collaboration in this field. The strong increase in electromobility and heat pumps is creating bottlenecks in the low-voltage grid. If too many electric vehicles and heat pumps increase their electricity consumption simultaneously and uncoordinated, the resulting power peaks overload the low-voltage grid. New business models with electromobility, in particular, are accelerating the energy transition but are increasing the potential for congestion in the low-voltage grid.

For the conceptual development of a congestion forecast, a "concept for proactive control" is being devised. This concept serves as a forecast scope of action for market-based aggregators. As part of the implementation in the German demonstrator, an efficient calculation logic for this forecast concept is to be identified. Various models will be developed, tested, and evaluated for this purpose. Only critical grids are considered and utilized for congestion management, with all congestion-relevant low-voltage grids being deemed critical. The forecast management relies on available user data, grid conditions, and resulting analyses. Analysis and listing of required additional data or important calculation and control chains will be conducted during this use case.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	30% increase in envelope curves implemented	Dependent on criticality, a certain number of envelope curves have been implemented	
2	Prediction Accuracy in %	The percentage accuracy of the congestion forecasts compared to actual congestion events	
3	False Positive Rate in %	The percentage of times a congestion event is forecasted but does not occur	
4	False Negative Rate in %	The percentage of times a congestion event occurs but is not forecasted	

1.6 Use case conditions

Use case conditions
Assumptions

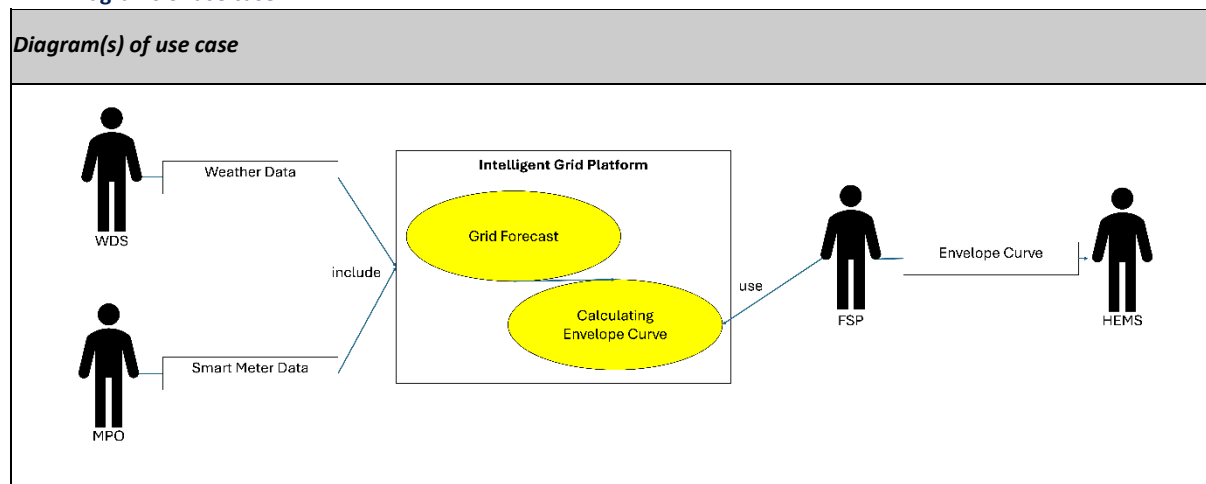
1	Only critical LV-grids are considered.
2	LV-grid restrictions in form of envelope curve are only described regarding substation capacity limits. Line ratings and voltage boundaries are out of scope of this project.
3	Grid Monitoring with available measurements is implemented, to make sure that state estimation is possible with the goal of forecasting grid state for the next day.
Prerequisites	
1	Availability of data and high quality for static grid data
2	Availability of controllable consumer assets
3	Availability of ImSys (where the MeLo = MaLo) (Smart Meters)
4	Sufficient space for monitoring devices in substation (if not there yet)

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Basis for use case 5 and 6
Level of depth
Distribution Level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification
Forecast, congestion management,

1.8 General remarks

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity. Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),	
Flexibility Service Provider (FSP)	Business	Defined as any legal entity that offers flexibility services in the market, based on acquired (aggregated) capabilities, usually from third parties.	
Metering Point Operator (MPO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.	

Measuring Device Provider (MDP)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Measurement Devices in the Field like e.g. in LV/MV stations.	
Weather Data Supplier (WDS)	Business	A natural or legal person who is selling weather data via API.	
HEMS Provider	Business	Defined as any legal entity that aggregates and controls flexible assets behind the meter.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Digital Twin	DSO	Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelope	The IGP calculates and sends the envelope curve to the FSPs.
Smart Meter Data Platform	MPO	A Platform where all Smart Meter Data is collected, mapped and prepared.	The IGP receives the needed data for calculating the envelope curve.
Weather Data Platform	WDS	A Platform that provides weather data via API.	The IGP needs solar and wind forecasts for the envelope curve.
Communication module	MPO	Distributes grid limits as an envelope curve to FSP	iNGA or SMGW
Measurement Platform	MDP	A Platform where all Station Measurement Data is collected, mapped and prepared.	The IGP receives the needed data for calculating the envelope curve.

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Data collection	The IGP receives the needed data, like weather forecasts and smart meter data.	DSO			

2	Grid forecast	In the IGP, the future grid states are estimated based on the collected data.	DSO			
3	Calculating the envelope curve	If one congestion is predicted, the resulting envelope curve for according asset is calculated.	DSO	cyclic		
4	Sending the envelope curve	The envelope curve is sent to the MPO.	DSO	cyclic		
5	Grid without predicted congestions	The predicted grid congestion has not occurred and there is no more critical grid state predicted	DSO			

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1	Smart Meter Data	Measured active power (and sometimes voltage and current) delivered by the MPO. This is time series, delivered in real-time.	
2	Station Measurements	Measured active power, voltage and current delivered by the MS at the LV/MV station. This is time series, delivered in real-time.	
3	Weather forecasts	Wind and solar forecasts delivered by the WDS. This is time series, delivered in advance.	
4	Envelope curve	The envelope curve will be delivered by the IGP from the DSO to the FSP.	
5	Commands to HEMS	Signals sent to the HEMS	

6 Requirements (optional)

7 Common terms and definitions

Distribution System Operator (DSO)

A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),

Digital Twin

Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelope

Smart Meter Data Platform

A Platform where all Smart Meter Data is collected, mapped and prepared.

Communication module

Distributes grid limits as an envelope curve to FSP

Metering Point Operator (MPO)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Smart Meters.

Measuring Device Provider (MDP)

A natural or legal person who is responsible for operating, ensuring the maintenance and collecting the data of Measurement Devices in the Field like e.g. in LV/MV stations.

Weather Data Supplier (WDS)

A natural or legal person who is selling weather data via API.

Measurement Platform

A Platform where all Station Measurement Data is collected, mapped and prepared.

8 Custom information (optional)

B.4.5 Optimal utilization of the flexibility potential in the network feeder by aggregation of flexible assets within the household via HEMS [GE05]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ge05	Distribution + Flex mgmt.	Optimal utilization of the flexibility potential in the network feeder by aggregation of flexible assets within the household via HEMS

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	19.7.2024	KP Stork, A. Stengl, F. Dorsemagen		
0.3	23.08.2024	KP Stork, A. Stengl, F. Dorsemagen	Chapter 3	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Use load shifting to preventively comply with grid limits in order to reduce grid expansion costs
Objective(s)	Shifting charging power when congestions occurs. Preventive control of charging with consideration of envelope curve
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
The aim of Use Case 5 is to use load shifting to preventively comply with grid limits in order to reduce grid expansion costs in the low-voltage grid. The intended incentive for customers to shift their own consumption is reduced grid tariffs or a share of market revenues. A possible business case could be, for example, price-optimized charging, taking into account the potentials and restrictions in a LV-grid.

Complete description	
The time series (15 min power values) of the network restriction (envelope curve) is provided in Ge04. In Ge05, the envelope curve is picked up one place at an interface by the market operator for the entire household as a framework condition/premise. The interface is defined in coordination between Ge04 and Ge05. The further description focuses on priced optimized household consumption. The first step is to charge an EV. In the second step, an EV, another controllable unit and a HEMS are included in the household. For the first step, the following information are required: - spot price curve, - charging level of the EV at the time of connection between the car and the wallbox, - customer specifications for the desired charging level (how much energy should be in the battery) at the end of the charging time (the "when"). The customer can also choose the "immediate loading" function. The network restriction (envelope curve) must also be taken into account here. Using the framework conditions mentioned, the HEMS' algorithm calculates the charging schedule for the customer with the cheapest hours of the spot market. The charging schedule is implemented by the wallbox every 15 minutes and the EV battery is thus charged. For the second step, a further controllable unit will be selected.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	More than 10 successfully steered charging events	How often a charging event is steered.	Shifting charging power when congestions occurs.
2	Change of charging costs by at least 5%	The charging schedules uses the cheapest hours within the envelope curve in comparison without congestions/envelope curve	Preventive control of charging with consideration of envelope curve

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Customer wants to be part of the flexibility Ge05 for getting reduced grid fees and prices.
Prerequisites	
1	The local LV grid has congestions
2	The envelope curve has been communicated to the HEMS provider for consideration

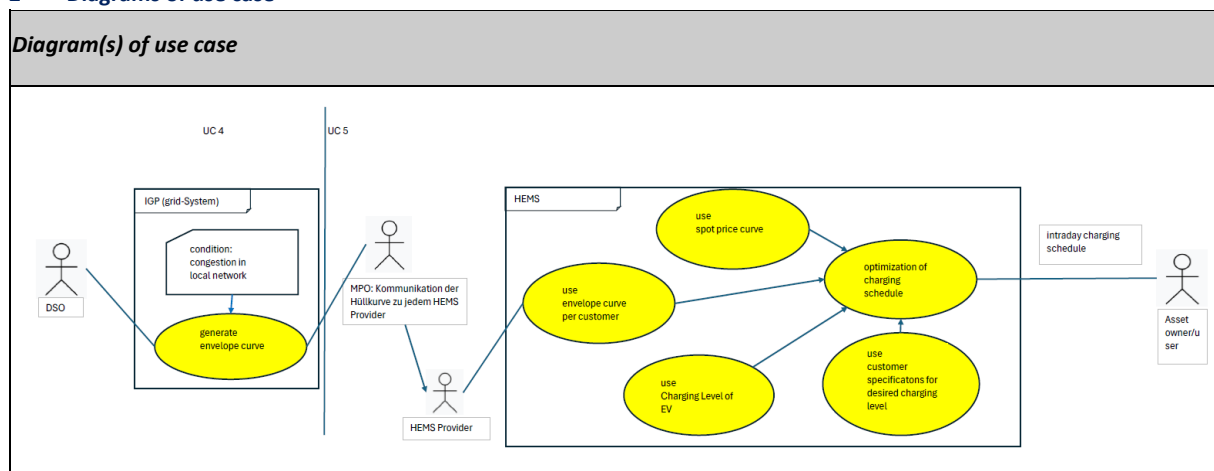
	of network restrictions
3	Customer input/request on flexible asset usage (departure time, state of charge)
4	Spot price curve available

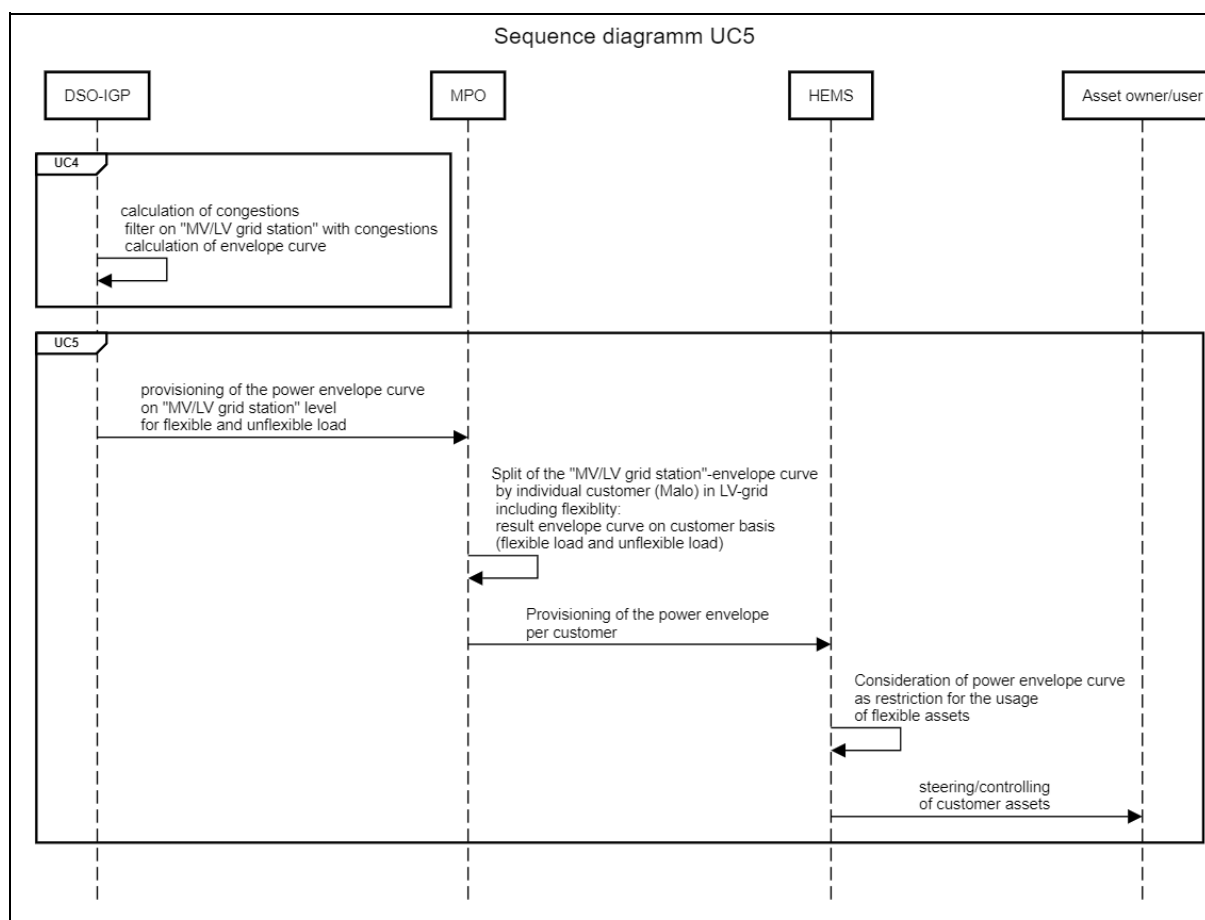
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Ge03, Ge04 and Ge06
Level of depth
Distribution Level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification
Flexibility, Congestion management LV, charging optimisation, EV

1.8 General remarks

2 Diagrams of use case





3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.	
Metering Point Operator (MPO)	Business	Responsible for the installation, operation, reading and maintenance of electricity meters, as well as the measurement process.	
HEMS Provider	Business	Defined as any legal entity that aggregates and controls flexible assets behind the meter.	

Flexibility Service Provider (FSP)	Business	Defined as any legal entity that offers flexibility services in the market, based on acquired (aggregated) capabilities, usually from third parties.	
Asset owner/user	Private	The owner/user of a micro-flexibility.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Intelligent Platform	Grid Distribution System Operator (DSO)	envelio IGP	
Communication module	Metering Operator or DSO	Distributes grid limits as an envelope curve to HEMS Provider	API or SMGW
HEMS technical input channel	HEMS Provider	Takes care of real-time exchanged information for activations of assets etc.	
HEMS business input channel	HEMS Provider	Takes care of business files exchange (departure time, state of charge, price curve etc)	
HEMS optimization	HEMS Provider	System responsible for optimization, asset activation, internal baseline calculations	
Micro-flexibility asset	Asset owner	Micro-flexibility to be controlled	Micro-flexibility are flexible assets at LV-level, mostly in households

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition

1	Provisioning EC	provisioning of the power envelope curve on "MV/LV grid station" level for flexible and unflexible load	DSO-IGP	daily timestamp is reached (i. e. 8:00 o'clock)	DSO has declared and communicated the MV/LV grid station as a congestion area	
2	Selection customer (MaLO)	selection of participating customer in the congestion area	DSO-IGP	DSO has declared the MV/LV grid station as a congestion area	customer must have a contract regarding preventive load management (DSO or supplier)	
3	Split envelope curve	Split of the "MV/LV grid station"-envelope curve by individual customer (Malo) in LV-grid including flexibility: result envelope curve on customer basis (flexible load and unflexible load)	MPO	data (envelope curve) has been received	split algorithm is defined from DSO and transferred; customer data (MaLo) per grid station are provided by DSO	Calculated power envelope per customer (flexible load and unflexible load)
4	Provisioning level customer	Provisioning of the power envelope per customer (flexible load and unflexible load)	MPO	Customer/HEMS asks for power envelope curve	Customer is located in a congestion area and is participating in preventive load management	HEMS received the power envelope curve
5	Consideration of EC	Consideration of power envelope curve as restriction for the usage of flexible assets	HEMS	optimization of home energy management is initiated	demand from flexible asset is needed; forecast of domestic load and production (if PV included) are calculated	schedule of domestic load, flexible asset and PV production
6	Steering	steering/controlling of customer assets (wallbox is switched on and off)	HEMS	steering is needed	schedule of domestic load, flexible asset and PV production	

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
Info 1	envelope curve per customer	Time series with power limitations for a single customer from DSO to HEMS-provider	
Info 2	spot price curve	spot price curve from epex-spot	
Info 3	SOC	State of Charge of Electric Vehicle	
Info 4	customer specifications	customer specifications for desired charging level	

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
Info 5	charging schedule	intraday charging schedule for the asset (EV)	

6 Requirements (optional)

7 Common terms and definitions

Definitions:

HEMS	Home energy management system
LV	Low voltage
EV	Electric vehicle
DSO	Distribution system operator
MPO	Metering point operator
FSP	Flexibility Service Provider
IGP	Intelligent Grid Platform
SMGW	Smart Meter Gateway
API	Application Programming Interface
MV	Medium Voltage
MaLo	Market location (Marktllokation)
EC	Envelope curve

8 Custom information (optional)

B.4.6 Development of advanced tools for preventive congestion management through regional aggregation of flexible assets [GE06]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ge06	Distribution + Flex mgmt.	Development of advanced tools for preventive congestion management through regional aggregation of flexible assets

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	19.7.2024	KP Stork, A. Stengl, F. Dorsemagen		
0.3	23.08.2024	KP Stork, A. Stengl, F. Dorsemagen	Chapter 3	
0.4	03.04.2025	F.Dorsemagen	General Update	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Further application of aggregated flexibility, is considered conceptually in terms of additional use and business cases.
Objective(s)	- Data collection customer - Forecast flexibility - Aggregation of the customers - Calculation of secured power for Redispatch 3.0 - After the TSO accepts the offer, a signal is sent to initiate disaggregation and deliver the service at the individual customer level - Consideration of grid restriction through envelope curve (UC4) - Steering of customers
Related case(s)	business Trading of flexibility

1.4 Narrative of Use Case

Narrative of use case
Short description
In Use Case 6, the further application of aggregated flexibility, which was already determined and used in the previous use case, is considered conceptually. The entire process chain from data collection to control is considered conceptually in order to be able to provide secure power. This secured power can be offered, for Redispatch 3.0.
Complete description
In this Use Case, a concept for use of the aggregated flexibility of multiple customers for grid services for TSOs such as Redispatch 3.0 is developed. The following steps are a first concept and may change during detailed processing. The concept contains the functionalities data collection of the customer, the forecast of the flexibility, the aggregation of the flexibility, the offering to the TSO with secured power, the handling of the TSO request with disaggregation (while considering grid restrictions on LV-level) and steering. The data collection regarding the customer is containing the regional allocation for balancing group TSO, the redispatch-regions, the controllable assets with power values and relevant information about the contract. The next step is the forecast of flexibility for one single customer (power level, duration of flexibility as amount of energy, limit of repositioning) in consideration of the individual LV envelope curve. There must be an aggregation of the customers accounting the aspects like the region - as balancing group or redispatch-region - to handle the TSO request. Regarding to this aggregation there must be a mathematical approach to identify the total secured power that can be offered in the role as flexibility service provider – FSP to the TSO. When congestion in the UHV grid is predicted or occurs, the TSO sends a request for activation to the FSP. The FSP activates the flexibility by disaggregation at individual customer level. He steers the EV charging infrastructure through an interface to a technical aggregator.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	At least 5 % increase in forecasting accuracy		
2	Achieved an aggregation of at least 25 EVs in the algorithm.	EV charging point	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The time frame for shifting the consumption of controllable assets

	satisfies the requirements of the TSOs.
Prerequisites	
1	Envelope curve per customer has been defined and described
2	Customer input/request on flexible asset usage (departure time, state of charge, temperature, ...)

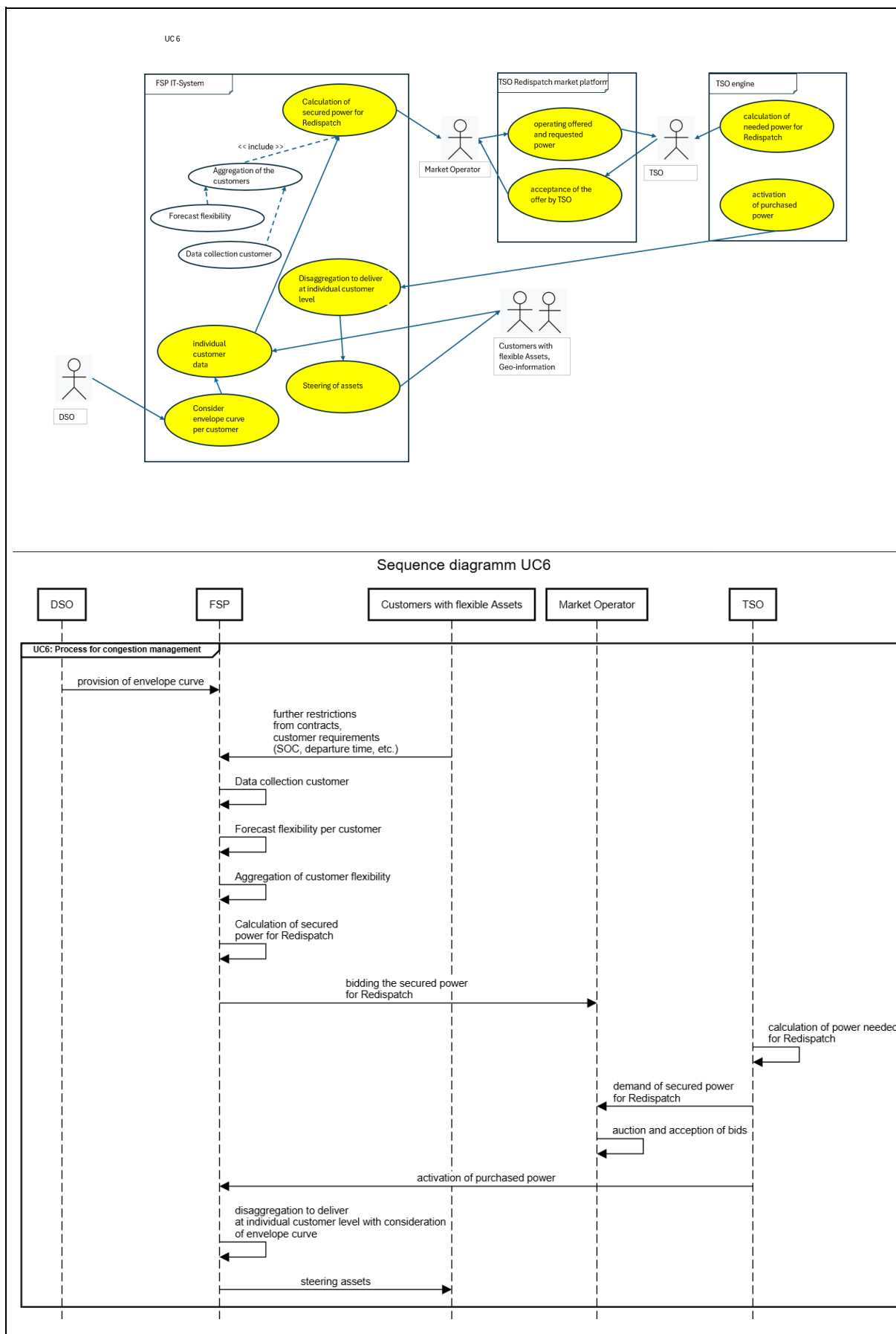
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
GE 5
Level of depth
Distribution Level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification
Congestion management, Flexibility, TSO flexibility usage, Aggregation

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Transmission System Operator (TSO)	Business	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity.	
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.	
Flexibility Service Provider (FSP)	Business	Defined as any legal entity that offers flexibility services in the market, based on acquired (aggregated) capabilities, usually from third parties.	
Market Operator	Harmonised Role	A market operator is a party that provides a service whereby the offers to sell electricity are matched with bids to buy electricity. Additional Information: This usually is an energy/power exchange or platform.	
Customer	Private	The owner/user of a micro-flexibility.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Aggregator	Flexibility Service Provider (FSP)	System responsible for delivering the total portfolio flexibility by aggregation and disaggregation of flexible assets.	
VPP	Flexibility Service Provider (FSP)	System responsible for using an optimization algorithm for choosing optimal market and placing bids on bidding platforms.	
Bidding platform	Market Operator	System collecting TSO offerings and FSP bids, organising them and publishing results	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Consideration customer restrictions	further restrictions from contracts, customer requirements (SOC, departure time, etc.)	FSP	timestamp, aggregation pending		
2	Customer data collection	data collection customer (contracts, asset-restrictions)	FSP	change in inventory	new customer/contract/asset	
3	Flexibility forecast	forecast flexibility per customer	FSP	timestamp	historical data and customer restriction available	
4	Aggregation	aggregation of customer flexibility	FSP	relevant flexibility forecasts available		
5	Calculation of secured power	Calculation of secured power for redispatch	FSP			
6	Bidding the secured power	bidding the secured power for redispatch	FSP			
7	Calculation of needed power	calculation of power needed for redispatch	TSO	timestamp	power for redispatch is needed	
8	Demand of secured power	communication of the demand of secured power for redispatch to Market Operator	TSO	timestamp		
9	Auction	redispatch auction and acceptance of bids	Market Operator	timestamp		
10	Activation of power	activation of purchased power	TSO	grid congestion requires action	FSP has won the bid at the auction	
11	Disaggregation	disaggregation to deliver at individual customer level	FSP	call off the purchased power	selected assets are able to provide the service	selection of steerable assets (MaLO)
12	Instruction for Steering	Instruction for steering at individual customer level	FSP	Selection of the asset in disaggregation		

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
Info 1	customer master data	Master data of the customer like geo-information, assets etc.	
Info 2	customer flex data	Data regarding the customer from to FSP-customer system, especially power and time schedule	
Info 3	secured power for Redispatch	Bidding of secured power from FSP to Market Operator for Redispatch market.	
Info 4	required power for redispatch	Demand of the TSO to Market Operator Platform.	has to be delivered from TSO
Info 5	information on accepted power for Redispatch	information on accepted power for Redispatch	
Info 6	activation of purchased power	The TSO sends the information of needed power to the FSP	
Info 7	control command from FSP-Provider to Asset	control command from FSP to Asset	

6 Requirements (optional)

7 Common terms and definitions

Definitions:

LV	Low voltage
EV	Electric vehicle
DSO	Distribution system operator
MPO	Metering point operator
FSP	Flexibility Service Provider
IGP	Intelligent Grid Platform
SMGW	Smart Meter Gateway
API	Application Programming Interface
MV	Medium Voltage
MaLo	Market location (Marktkloktion)
EC	Envelope curve
SOC	State of charge
mFRR	Manual Frequency Restoration Reserve
TSO	Transmission System operator
UHV	Ultra High Voltage

8 Custom information (optional)

B.4.7 Conceptual description of interoperable solutions that support an efficient TSO-DSO data exchange on the interface level. [GE07]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ge07	TSO / DSO Exchange	Conceptual description of interoperable solutions that support an efficient TSO-DSO data exchange on the interface level.

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	05.06.2024	Julia Köhlke, Florian Kotthoff		
0.3	18.06.2024	Florian Kotthoff		
0.4	17.07.2024	Alexander Schütz		
0.5	17.07.2024	Julia Köhlke	1.7 Further information 3.1 Actors	
0.6	18.7.2024	Alex Schütz, Cemre Akdag, F. Dorsemagen		
0.7	21.08.2024	Julia Köhlke	Example for control power between DSO, TSO and Aggregator in a data space	
0.8	23.8.2024	Alexander Schütz, Cemre Akdag, Felix Dorsemagen	Roles & Systems	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Enhancement of data integration between DSOs and TSOs to improve grid reliability, efficient integration of renewable energy sources and use of flexibilities for the transmission system.
Objective(s)	The European interconnected grid is based on a distribution of tasks according to the voltage levels. Ultimately, this distribution can only function efficiently if the necessary information is available to

	all parties involved. In particular, the redispatch and ancillary power processes, using micro-flexibilities on LV-level for TSO-purposes, are very important objectives for all parties involved. Existing projects such as PKME and systems such as connect+ could be used for the implementation. Specifically, the following goals are to be achieved: - define a target architecture for a future data exchange - define requirements to specify the role of market aggregator with regards to TSO-DSO-Connection - enable the usage of small flexibility sources and test different solutions to initiate and utilize the value chain beginning with the smallest flexibility over to the TSO
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
Use Case 7 aims to enhance data integration between DSOs and TSOs to improve grid reliability and the efficient integration of renewable energy sources. It analyses the possibilities of standardizing data formats and protocols, establishing real-time data sharing for critical parameters, integrating distributed energy resources into grid management strategies, deploying predictive analytics for operational challenges, and ensuring regulatory compliance. Additionally, simulations in a validated software tool can validate historical data, exploring diverse protocols for data transmission, and analyzing the impact of data quality degradation.
Complete description
Efficient data exchange between TSOs and DSOs is essential in today's energy system with its significant share of renewable energy sources. In this energy system, electricity is not produced by a small number of large power plants – instead it is produced by millions of small- and medium sized PV systems and wind turbines. To control the grid, precise and up-to-date information is needed by both the TSO and DSO, and some of this information needs to be exchanged between them. For this Use Case, the following data needs to be considered: - Master data of electricity producers and consumers - Grid topology - Live electricity production data from relevant plants / units - Envelope curves to describe and consider grid restrictions on LV-level - Data transfer of master data between TSO and DSO (grid topology, units) - Data transfer of live data between TSO and DSO (envelope curve, electricity production) - Control power resources One example of the interaction between DSO, TSO and aggregator can be the exchange of control power in the connect+ platform (Redispatch 2.0) or a data space. While the DSO and TSO are primarily responsible for the respective grid stability, the aggregator pools flexible resources and offers them bundled as control power. If the TSO recognizes that additional power is required, this request can be communicated to the aggregator via a data exchange platform and possibly also directly to the DSO. The aggregator checks its available resources and reports how much aggregated power it can provide. The DSO ensures that the provision of this power potential does not cause congestions within the distribution grid. The data exchange platform can be used in this context to create a marketplace in which the aggregator can offer available power resources. The data exchange platform can provide access to real-time and historical data to support decisions and ensure grid stability.

1.5 Key performance indicators (KPI)

Key performance indicators

ID	Name	Description	Reference to mentioned use case objectives
1	Number Master Data points	Number of data points about units and topology exchanged	
2	Number Data Streams	Number of units where a successful data stream was exchanged	
3	Response Time for Power Requests	Tracks the time taken from when a TSO requests additional power to when the aggregator responds with the available power resources.	
4	Increase of RES data integration	measures the increase in the integration of data from renewable energy sources (RES) into the system.	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	There is a political and economical need to use flexibility on LV-level for the TSO. If flexible power on LV-level is only to be used for challenges and business cases in the distribution grid, the described use case is no longer valid.
2	Small flexibilities that are aggregated via a market aggregator have the potential within a redispatch or ancillary power scheme to strengthen and stabilize the grid.
Prerequisites	
1	IT-Infrastructure
2	Assets

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Usage of flexibility through aggregator for TSO (UC 6)
Level of depth
Distribution - Transmission level
Prioritisation
High

<i>Generic, regional or national relation</i>
Generic use case with application in German national context
<i>Nature of the use case</i>
BUC
<i>Further keywords for classification</i>
TSO-DSO coordination, TSO/DSO-data exchange, operational planning, flexibility, congestion management

1.8 General remarks

2 Diagrams of use case

<i>Diagram(s) of use case</i>

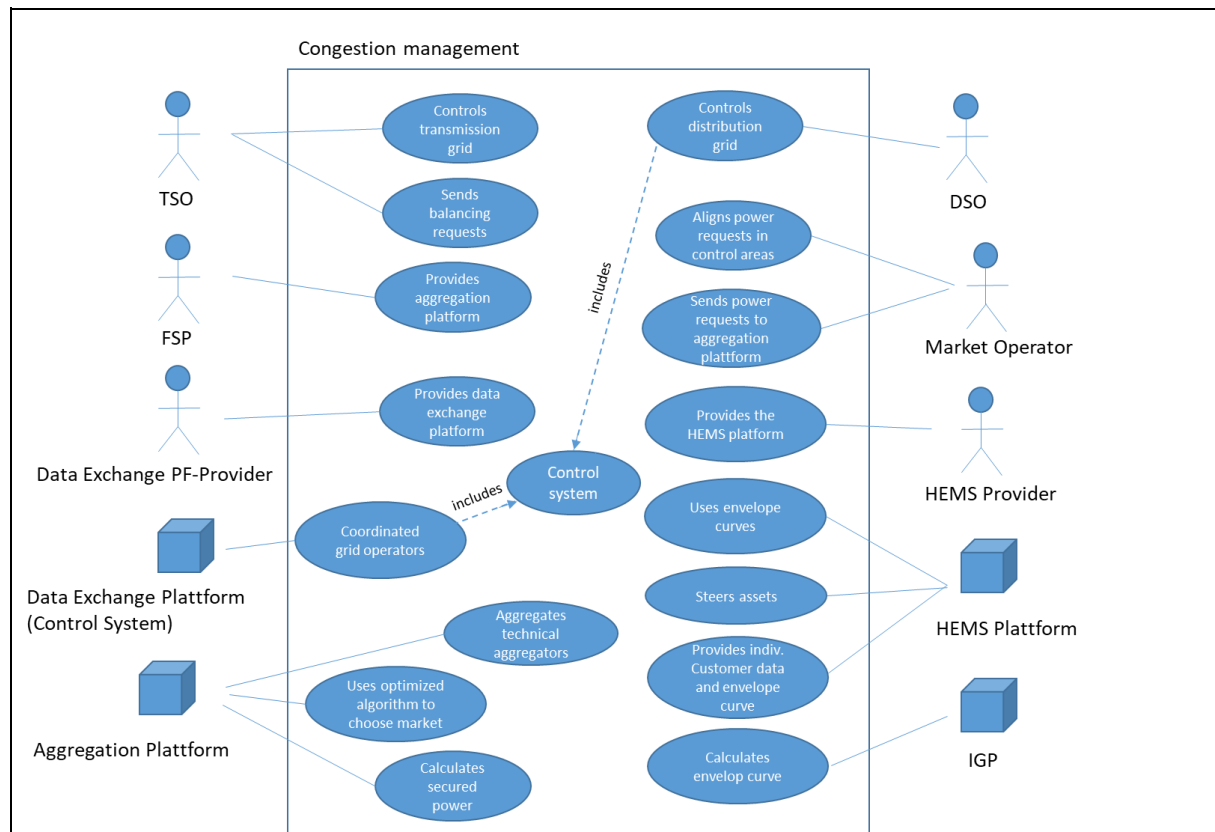


Figure 1: Roles, Systems and Functions

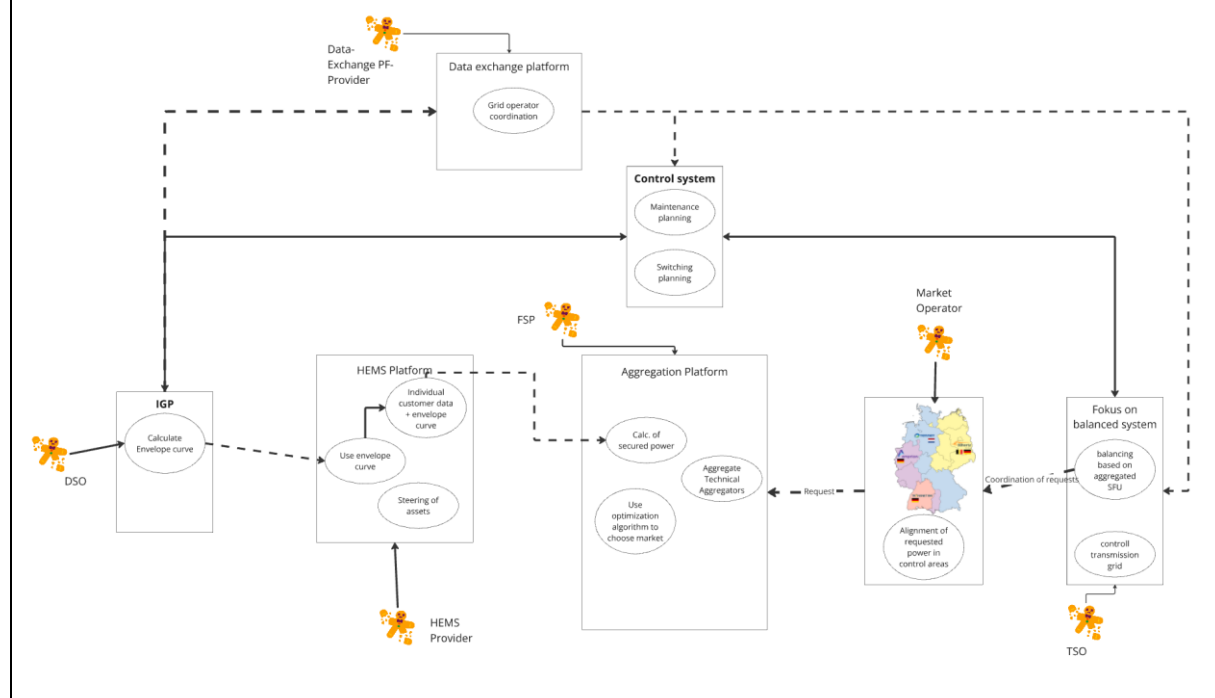


Figure 2: Data exchange

3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Control Area		A coherent part of the interconnected system, operated by a single System Operator and shall include connected physical loads and/or generation units if any.	
Actor name	Actor type	Actor description	Further information specific to this business use case
DSO	System Operator	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.	
TSO	System Operator	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity	
Flexibility Service Provider (FSP)	Business	Defined as any legal entity that offers flexibility services in the market, based on acquired (aggregated) capabilities, usually from third parties.	
Market Operator	Business	Legal entity that provides a system collecting TSO offerings and FSP bids, organising them and publishing results.	
HEMS Service Provider	Business	Defined as any legal entity that aggregates and controls flexible assets behind the meter.	
Data exchange platform operator	Supporting	Provider of a coordinating and data-exchange platform.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case

Aggregation system	Flexibility Service Provider (FSP)	System responsible for delivering the total portfolio flexibility by aggregation and disaggregation of flexible assets.	
HEMS	HEMS Service Provider	System responsible for optimization, asset activation, control and internal baseline calculations as forecast flexibility.	
Data exchange platform	Data exchange platform operator	Platform for fulfilling the market role of data exchange and coordinating the market roles (e.g. Connect+ or OneNet Connector)	
Bidding platform	Market Operator	System collecting TSO offerings and FSP bids, organizing them and publishing results.	
Others		Tbd.	

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
	Master Data information request	The TSO requests an update on newly registered electricity generation units	TSO	weekly		
	Live Data Stream	The TSO requests live data envelope curves from the aggregator of relevant electricity production units	TSO	During congestion management		

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
E1	Produced Electricity 1min	Produced electricity of a unit in MWh in 1min interval	
E15	Produced Electricity 15min	P produced electricity of a unit in MWh in 15min interval	
U1	Registered Unit	Newly registered electricity producing unit, including type, location, and rated power	

6 Requirements (optional)

7 Common terms and definitions

Definitions:

HEMS	Home energy management system
LV	Low voltage
DSO	Distribution system operator
FSP	Flexibility Service Provider
IGP	Intelligent Grid Platform
MV	Medium Voltage
mFRR	Manual Frequency Restoration Reserve
TSO	Transmission System operator
PKME	German Study with the Name "Pilotierung des komplementären, marktbasierten Engpassmanagements"

8 Custom information (optional)

B.4.8 Connection request and online connection check applications for the DSO, TSO as well as for third parties. [GE08]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ge08	Hosting capacities	Visualizing hosting capacities within Connection request and online connection check applications

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	26.04.2024	Felix Dorsemagen (E.ON One)	n.a.	
0.2	28.05.2024	Julia Köhlke (OFFIS)	n.a.	
0.3	17.6.2024	Felix Dorsemagen	n.a.	
0.4	24.6.2024	Ellen Jaenecke (Envelio)	n.a.	
0.5	28.11.2024	Jessica Stephan		

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Development of a grid hosting map.
Objective(s)	Allocate grid hosting capacities Interconnecting different systems of DSOs and TSOs Improve the quality of network planning Optimise DSO and TSP network operation
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description

This task provides an integrated mapping of grid hosting capacities (installed and projected), as well as visibility over the connected assets in the Demonstrator. This includes connection request and online connection check applications for the DSO, TSO as well as for third parties (market operators) for e.g., pre-connection check calculations.

Complete description

Germany has a vast reservoir of unused network capacity for connecting renewable, such as large-scale batteries or on-shore wind energy to the grid. In the future, several renewable energy plants, storage facilities and sector coupling plants should be linked to the same grid connection points. This means that more power from renewables will be connected to the same grid connection point and, thus, the capacity utilization of the individual connection points will be increased over times.

For this purpose, grid hosting capacity reservations and allocations are relevant to the DSOs, TSOs, and other market participants. A grid hosting map can cover all capacities on the distribution and transmission grid, but also margins for a low voltage connected future. However, not all possible capacities have been reserved or allocated yet. Hence, different levels of maturities exist in different areas of Germany - from a very early stage to a full completion of allocation. This also means that more parts of these reserved and allocated network capacities may become available again in the future.

TwinEU uses a demonstration environment that enables to model respective assets for renewable energy generation, grid feed-in and connection points across Germany at a high spatial resolution. Different grid connection capacities and a variety of system technologies should be specified within this demonstration. The demonstrator should equally include connection check applications for DSO, TSOs and third parties. This provides information on interconnected systems, creates transparency between TSOs and DSOs and also makes it easier for other market participants to access the grid connection points. The aim is to develop a grid hosting map that should enhance the grid infrastructure itself. The grid hosting map could facilitate the congestion management, operational planning, the network configuration, the real-time supervision or fault-location of the grid.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
	30 sec. decrease in time needed to establish network capacities.	The effort that is needed to find a suitable location for an asset (i.e. in minutes per asset)	
	10% Increase in visibility of connected assets	Transparency about connected assets in terms of share of in the map included assets to total assets	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	
Prerequisites	
1	The setting relies on grid related, not cross-grid calculations

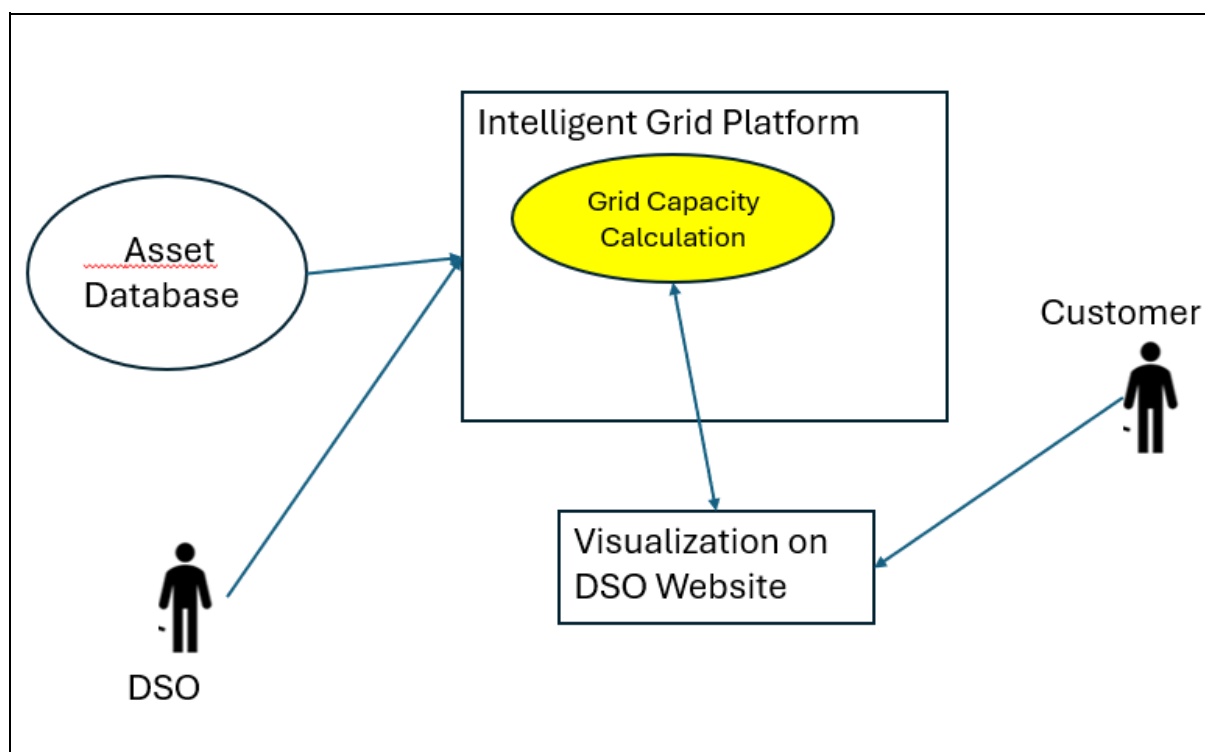
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Use Case 1: Online Monitoring
Level of depth
Distribution - Transmission level
Prioritisation
High
Generic, regional or national relation
National
Nature of the use case
BUC
Further keywords for classification
Hosting capacities, Online Connection Check, Connection Requests

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity. Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast)	
Customer	Private	The owner/user of a micro-flexibility.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Digital Twin	DSO	Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelio.	The IGP calculates on the basis of the received data values for the Hosting capacities on grid sites.

4 References

5 Step by step analysis of use case

5.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
	Data collection	The IGP receives the needed data, like station measurements.	DSO			
	Calculation	With the received data the IGP calculates the left hosting capacities on trafos (different types of sites, etc. - tbd)	IGP			
	Visualization	The IGP + partner (tbd) visualises all measurements within a German/European wide Hosting capacity Map (tbd).	IGP / partner			

6 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1	Station measurements	Measured active power, voltage and current delivered by the MDP at the (LV)/MV station. This is time series, delivered in real-time.	

7 Requirements (optional)

8 Common terms and definitions

Distribution System Operator (DSO)

A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

Defined in the European Union Internal Electricity Market is legally defined in Article 2(29) of the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market in electricity (recast),

Digital Twin

Digital Twin of the grid that enables grid planning and grid operations, e.g. IGP from envelio

Customer

The owner/user of a micro-flexibility.

9 Custom information (optional)

B.5 Hungarian Pilot Site UCs

B.5.1 Digital twin for power line monitoring [HU01]

1 Description of the use case

1.1 Name of use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
HU01	Hungary	Digital twin for power line monitoring

1.2 Version management

<i>Version management</i>				
<i>Version No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
1	05/17 2024	BME team	1-5 Chapters added	
2	06/18 2024	BME & E.ON, APG, MAVIR teams	Modifications in 1-5 Chapters	
3	07/18 2024	BME team	UML diagrams added	
4	11/21 2024	BME & F4STER team	Reflections to UBE comments	

1.3 Scope and objectives of use case

<i>Scope and objectives of the use case</i>	
Scope	Applying dynamic line rating (DLR) is beneficial for revealing the bottlenecks in the aging high-voltage network. DLR systems are based on the conductor's thermal behaviour measured by physical sensors or calculations from weather datasets. The main scope of the Hungarian DT1 is to implement a digital twin for the physical line monitoring system, thus reducing the number of necessary physical devices, improving the performance of conductor temperature calculation, and helping the widespread application of DLR systems.
Objective(s)	The use case's objective is to implement ANN-based digital twins for power line monitoring systems and use the outputs for DLR calculations and the electricity market simulations.
Related business case(s)	-

1.4 Narrative of Use Case

<i>Narrative of use case</i>
Short description

Need: In the last few years, increasing the transfer capacity of power lines has become essential due to bottlenecks in the European high-voltage grid. One possible bottleneck solution is the real-time calculation of the transmission line ampere capacity (ampacity) limit, also known as DLR, which allows for real-time adjusting transfer capacity to weather conditions. However, these systems require real-time measurements. Line monitoring systems that rely only on weather data do not produce sufficiently accurate inputs for the line rating calculation. Systems that include physical sensors monitoring the state of the phase conductor are accurate but, at the same time, require a large number of devices. The high cost of these devices can hinder the DLR system's widespread application in several European regions.

Service: The physical sensor-based line monitoring systems (necessary for DLR calculations) can be substituted by ANN-based digital twins (DTs). These kinds of DTs can provide accurate temperature results (inputs for the ampacity calculations) and decrease the sensor numbers in the grid.

Short description: In the use case, we develop ANN-based DTs acting as virtual sensors in the high-voltage network. We train DTs with different training datasets, transmission lines, and sensor data, and their technical accuracy is tested on a defined time series. During the DT's operation, we investigated whether some physical sensors could be replaced with ANN-based virtual sensors in the Hungarian pilot.

Complete description

The goal of the Hungarian pilot is to create Digital Twins for physical sensor-based line monitoring systems that may be able to provide accurate and reliable data for DLR calculations in the future.

The DT use case of the DLR project runs parallel to each demonstrator's grid. This DT model integrates real-time data from strategically placed sensors on phase conductors, which measure temperature, with an advanced algorithm that defines the optimal locations for these sensors to mitigate sag-clearance issues and enhance system reliability. The algorithm considers various factors, including power line span, conductor specifications, tension at installation, and comprehensive cross-sectional drawings, ensuring sensors are positioned where they are most needed. Surrounding weather stations contribute critical environmental data, capturing wind speed, solar radiation, ambient temperature, and more, while the SCADA system provides invaluable line load parameters. The data collection lays the groundwork for creating an Artificial Neural Network (ANN), which, with weather conditions and SCADA load data inputs, is trained to predict conductor temperature accurately. This predictive capability is pivotal, enabling the DT to calculate phase conductor temperatures without direct sensor input, thereby allowing for strategically relocating sensors to other critical areas, optimizing the monitoring network, and reducing costs. Integrating this ANN into the DT framework empowers operators with dynamic line rating abilities and enhances asset management strategies, paving the way for a more resilient and reliable power grid. By leveraging predictive analytics, the DT model prevents potential sag-clearance problems and supports the power grid's adaptation to varying environmental and operational conditions.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Over 3 physical sensors used	How many physical sensors were used for the data collection of the ANN-based DT training?	
2	Over 3 trained virtual sensors	How many ANN-based DT models have been implemented?	
3	Over 1 of successfully trained models	How many ANN-based DT models have been made where the average achieved accuracy is within plus or minus 2 degrees Celsius?	
4	Virtual sensor accuracy (max & mean)	What is the maximum and average DT accuracy achievable (one-month exam period)?	

5	Virtual sensor accuracy (outliers)	What is the outlier percentage of the DT model (one-month exam period)?	
6	Number of power lines covered with virtual sensor	How many power lines are covered with virtual sensors (DT)?	
7	Number of potential substitution	How many physical sensors can be potentially substituted by ANN-based DT models?	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The more training data results in more accurate virtual sensor performance.
2	The conductor temperature calculation accuracy of the ANN-based DT is better than those calculation methods which rely only on weather data
Prerequisites	
1	The power line is already equipped with an adequate line monitoring system.

1.7 Further information on the use case for classification/mapping

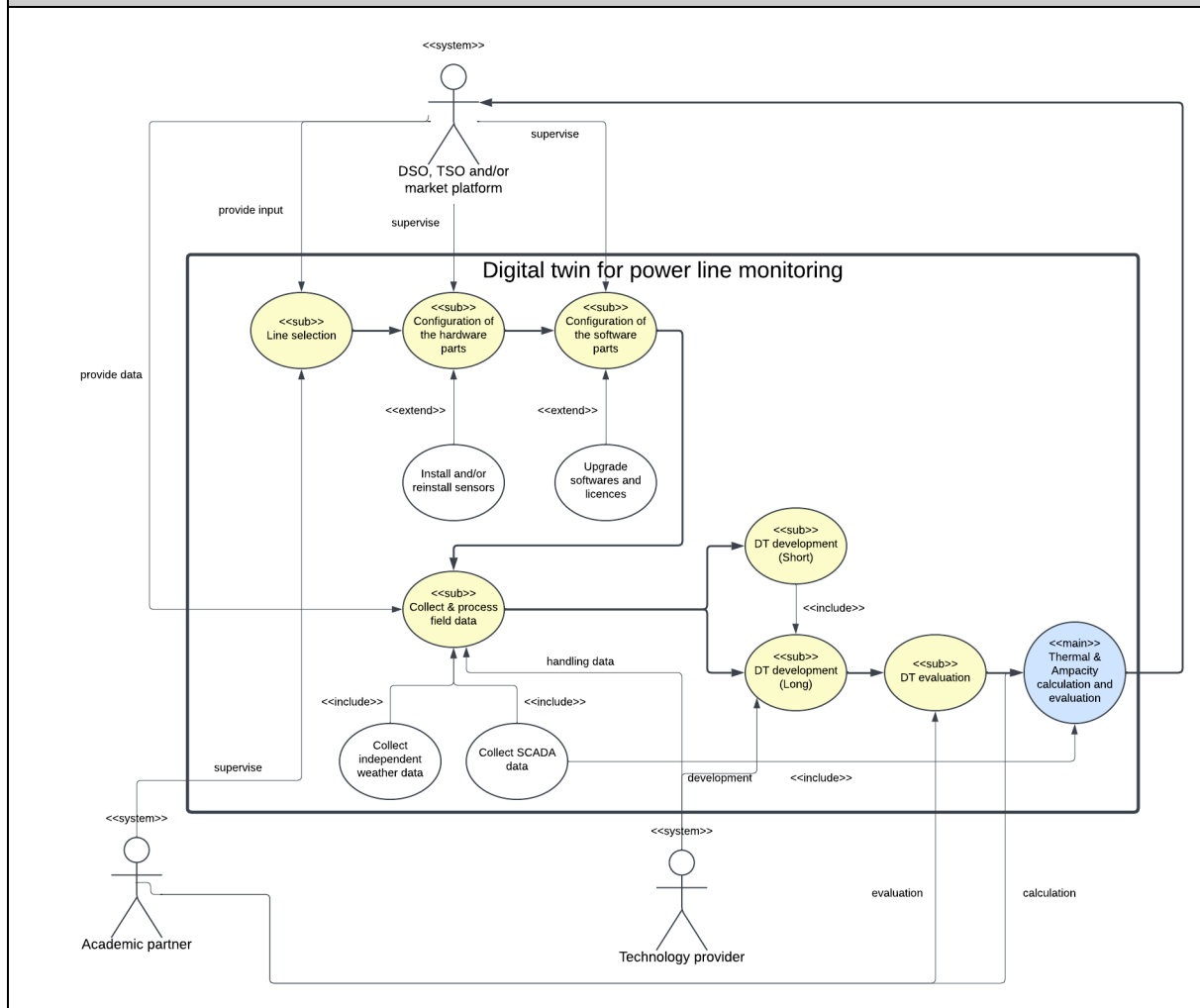
Classification information
Relation to other use cases
BUC results will be used for the market simulation
Level of depth
Generic use case
Prioritisation
High level of priority
Generic, regional or national relation
National use case for Hungary
Nature of the use case
BUC
Further keywords for classification

HV power line, TSO-DSO congestion management, Grid monitoring

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this use case
DSO	- Grid Access Provider - Data Provider - System operator	Active actor Responsible for operating the line monitoring system on its grid. Provides feedback on the operation of the DT.	The DSO operates the distribution network and all related technical matters in the present BUC.

TSO	- Grid Access Provider - Data Provider - System operator	Active actor Responsible for operating the line monitoring system on its grid. Provides feedback on the operation of the DT.	The TSO operates the transmission network and all related technical matters in the present BUC.
Academic partner	- Independent evaluator of the DT - Technical supporter	Active partner in supporting all the technical challenges. Responsible for the independent evaluation of the DT models.	In the present BUC, the academic partner is responsible for the independent technical support between the technology providers and the system operators.
Technology provider	- Project manager - DT developer	Active partner in project management. Responsible for providing the neural network-based conductor temperature calculation and DLR DT.	In the present BUC, the technology provider coordinates the project management and develops the necessary DT models.

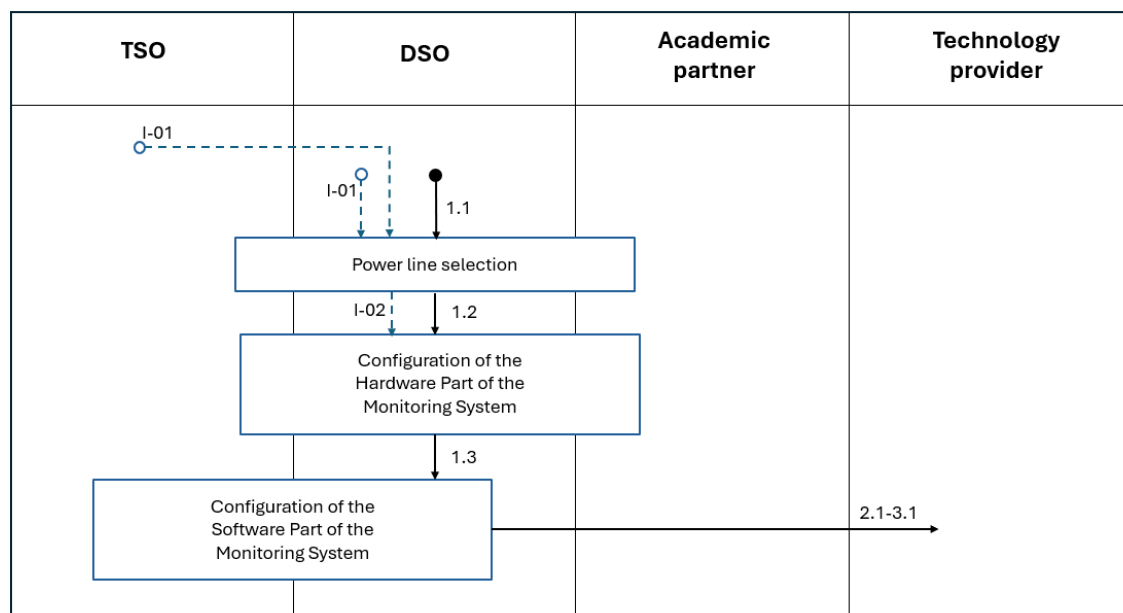
4 Step-by-step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Scenario 1: Preparation steps	Configuration of the line monitoring systems available on the grid (extension if necessary)	TSO/DSO			
2	Scenario 2: Implementing the DT for line monitoring (short training period – ca. 6 months)	Implementation of the software side of the DT	Technology provider	The monitoring system is configured		
3	Scenario 2: Implementing the DT for line monitoring (long training period – ca. 12 months)	Implementation of the software side of the DT	Technology provider	The monitoring system is configured		
4	Scenario 3: Evaluation of the DTs	Independent evaluation of the DT	Academic partner	The DT is in operation		
5	Scenario 4: Usability of the DTs	Application of the results for real operation conditions	All partners	The DT results are validated		

5 Steps - Scenarios

Scenario 1: Preparation steps



Scenario step-by-step analysis

Scenario							
Scenario name		Scenario 1: Preparation steps					
Step No	Event	Name of process/activity	Description of process/activity	Information producer (actor)	Executor (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1		Power line selection	Selecting which power line shall be involved in the project.	DSO/TSO	Academic partner/ DSO/TSO	I-01	
1.2		Configuration of the hardware part of the monitoring system	Configuration of the physical devices, defining the installation locations and installation of new devices (if needed)	DSO/TSO	Academic partner/ DSO/TSO	I-02	
1.3		Configuration of the software part of the monitoring system	Configuration of the communication and IT background.	DSO/TSO	DSO/TSO		

- Step No 1.1 / Power line selection

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Selection of power lines for DT	data analysis	Network analysis

- Step No 1.2 / Configuration of the hardware part of the monitoring system

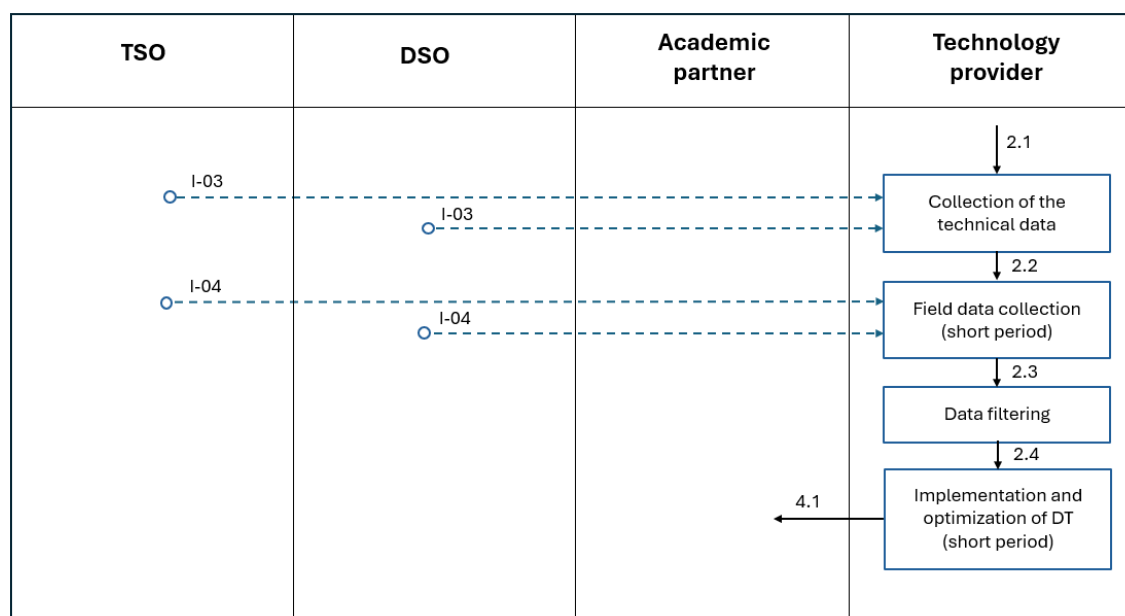
Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Configuration of the physical devices, defining the installation locations and installation of new devices (if needed)	Configuration, field analysis, simulations and installation (if needed)	Power line analysis

- Step No 1.3 / Configuration of the software part of the monitoring system

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Configuration of the communication and IT background.	configuration	Hardware installation

Scenario 2: Implementing the DT for line monitoring (short training period – ca. 6 months)

Scenario step-by-step analysis

Scenario							
Scenario name		Scenario 2: Implementing the DT for line monitoring					
Step No	Event	Name of process/activity	Description of process/activity	Information producer (actor)	Executor (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1		Collection of technical data	Collecting the relevant technical data of the power line	DSO/TSO	Technology provider	I-03	
2.2		Field data collection (short period)	Continuous data collection from the installed field equipment	DSO/TSO	Technology provider	I-04	
2.3		Data filtering	Preprocessing of the collected field data		Technology provider		
2.4		Implementation and optimization of the DT (short training period)	Implementation and training of the power line sensor DT (ANN model)		Technology provider		

- Step No 2.1 / Collection of technical data

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Power line technical dataset	Data transfer	Collection of the relevant technical details of the power line that can determine the DT structure.

- Step No 2.2 / Field data collection

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Grid monitoring devices' dataset	Data transfer	Continuous collection of the data from the field devices.

- Step No 2.3 / Data filtering

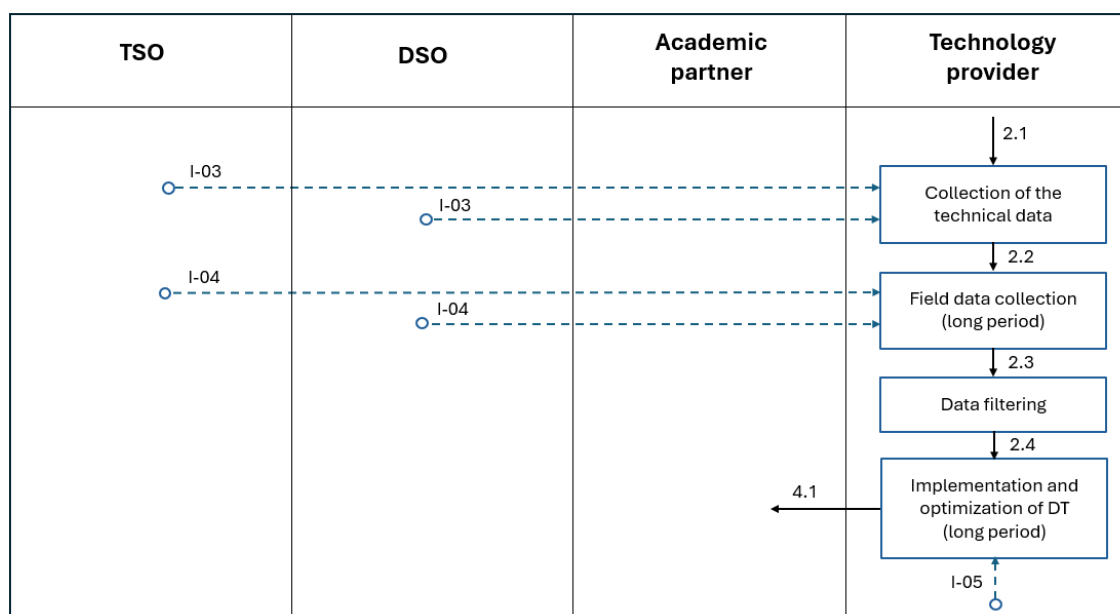
Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Unified and complete dataset	Data preprocessing	Preprocess the collected field data from quality perspectives.

- Step No 2.4 / Implementation of the DT

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Maximizing DT accuracy	Model development	Based on the power line technical details and pre-processed field data, the DT for the power line monitoring system will be implemented.

Scenario 3: Implementing the DT for line monitoring (long training period – ca. 12 months)Scenario step-by-step analysis

Scenario							
Scenario name		Scenario 2: Implementing the DT for line monitoring					
Step No	Event	Name of process/activity	Description of process/activity	Information producer (actor)	Executor (actor)	Information exchanged (IDs)	Requirement, R-IDs
3.1		Collection of technical data	Collecting the relevant technical data of the power line	DSO/TSO	Technology provider	I-03	
3.2		Field data collection (long period)	Continuous data collection from the installed field equipment	DSO/TSO	Technology provider	I-04	
3.3		Data filtering	Preprocessing of the collected field data		Technology provider		
3.4		Implementation and optimization of the DT (long period training)	Implementation and training of the power line sensor DT (ANN model)		Technology provider	I-05	

- Step No 3.1 / Collection of technical data

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Power line technical dataset	Data transfer	Collection of the relevant technical details of the power line that can determine the DT structure.

- Step No 3.2 / Field data collection

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Grid monitoring devices' dataset	Data transfer	Continuous collection of the data from the field devices.

- Step No 3.3 / Data filtering

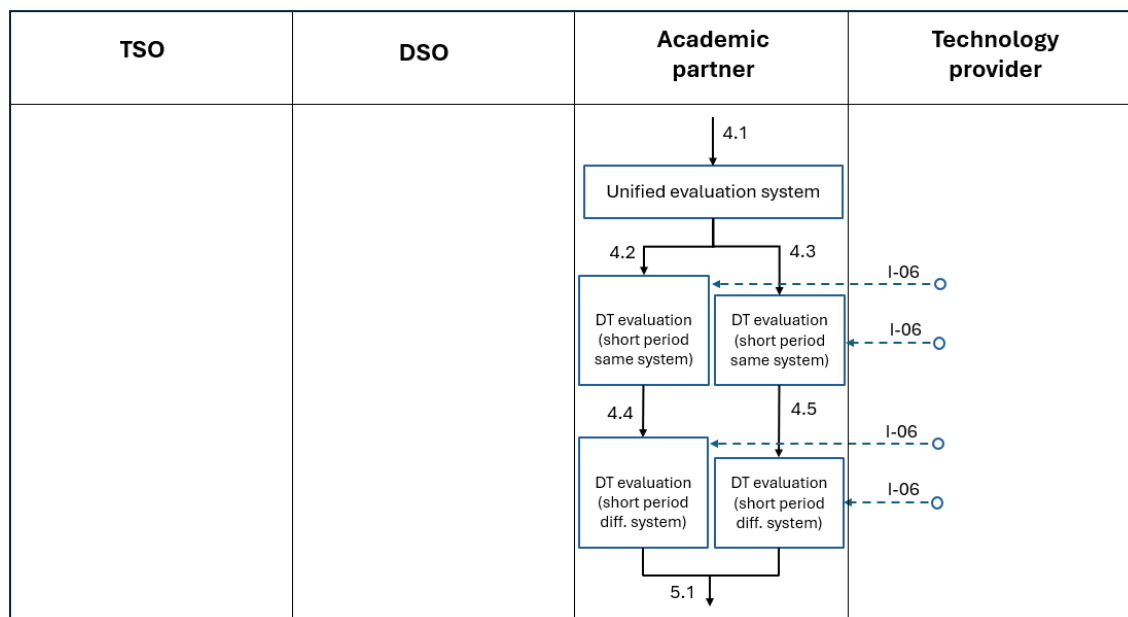
Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Unified and complete dataset	Data preprocessing	Preprocess the collected field data from quality perspectives.

- Step No 3.4 / Implementation of the DT

Business section:Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Maximizing accuracy	DT Model development	Based on the power line technical details and pre-processed field data, the DT for the power line monitoring system will be implemented.

Scenario 4: Evaluation of the DTs

Scenario step-by-step analysis

Scenario							
Scenario name		Scenario 3: Evaluation of the DT					
Step No	Event	Name of process/activity	Description of process/activity	Information producer (actor)	Executor (actor)	Information exchange (IDs)	Requirement, R-IDs
4.1		Unified evaluation system	Development of a unified evaluation system		Academic partner		
4.2		Evaluation of DT performance (short training period; same system)	Compare the DT (short training period) performance to the same physical device measurements	Technology provider	Academic partner	I-06	
4.3		Evaluation of DT performance (long training period; same system)	Compare the DT (long training period) performance to the same physical device measurements	Technology provider	Academic partner	I-06	
4.4		Evaluation of DT performance (long training period; different system)	Compare the DT (short training period) performance to different physical device measurements	Technology provider	Academic partner	I-06	

4.5		Evaluation of DT performance (long training period; different system)	Compare the DT (long training period) performance to different physical device measurements	Technology provider	Academic partner	I-06	

- Step No 4.1 / Unified evaluation system

Business section:

Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Development of a unified evaluation system	Development	Elaboration of the details of a unified evaluation framework.

- Step No 4.2 / Evaluation of DT performance (short training period; same system)

Business section:

Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Determination of achievable accuracy	Data analysis	Compare the DT (short training period) performance to the same physical device measurements – mean and max deviation, outliers

- Step No 4.3 / Evaluation of DT performance (long training period; same system)

Business section:

Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Determination of achievable accuracy	Data analysis	Compare the DT (long training period) performance to the same physical device measurements – mean and max deviation, outliers

- Step No 4.4 / Evaluation of DT performance (short training period; different system)

Business section:

Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>

Determination of achievable accuracy	Data analysis	Compare the DT (short training period) performance to different physical device measurements – mean and max deviation, outliers

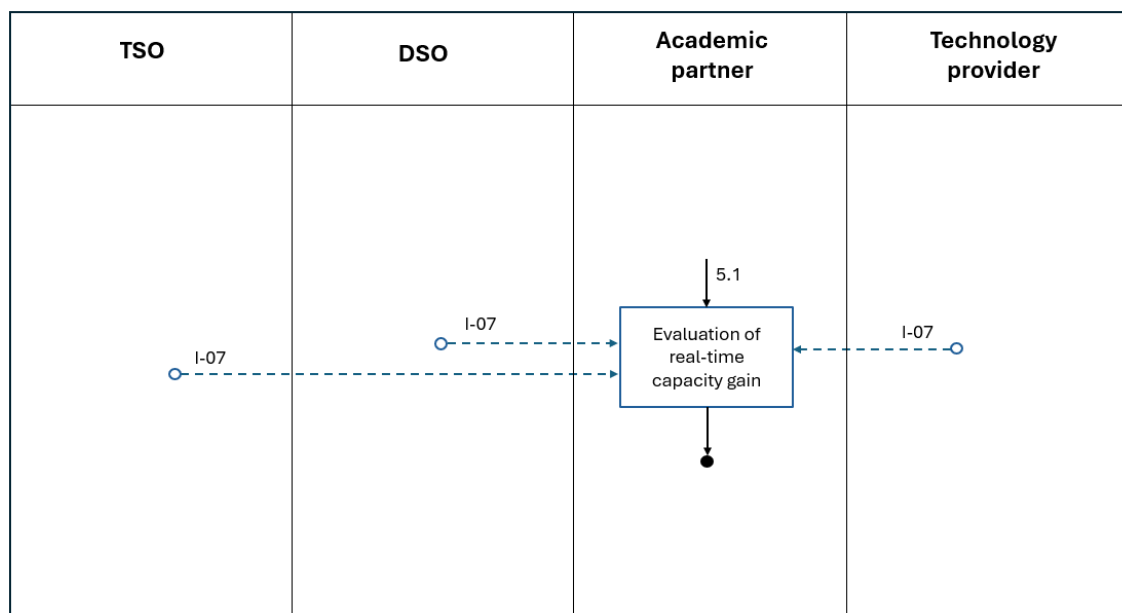
- Step No 4.5 / Evaluation of DT performance (long training period; different system)

Business section:

Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Determination of achievable accuracy	Data analysis	Compare the DT (long training period) performance to different physical device measurements – mean and max deviation, outliers

Scenario 5: Usability of the DTs



Scenario step-by-step analysis

<i>Scenario</i>							
<i>Scenario name</i>		Scenario 3: Evaluation of the DT					
<i>Step No</i>	<i>Event</i>	<i>Name of process/activity</i>	<i>Description of process/activity</i>	<i>Information producer (actor)</i>	<i>Executor (actor)</i>	<i>Information exchanged (IDs)</i>	<i>Requirements, R-IDs</i>

5.1		Evaluation of real-time capacity gain	Determination of the achieved capacity (gain) with the DT	DSO/TSO+ Technology provider	Academic partner	I-07	

- Step No 5.1 / Evaluation of extra capacity gain

Business section:

Information sent:

<i>Business object</i>	<i>Instance name</i>	<i>Instance description</i>
Determination of the grid utilization level	Data analysis	Determination of the achieved capacity (gain) with the DT

6 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
I-01	Name of involved power lines	Grid parameters (Limiting elements in substation, line length, historical load level).	
I-02	Spans for monitoring equipment installation	Cross-section drawings of the power line, technical datasheet of the line elements.	
I-03	Phase conductor data	Technical datasheet of the phase conductor.	
I-04	Field data	Collected weather parameters (ambient temperature, wind speed, and direction, solar radiation), line load (SCADA), and thermal state of the conductor.	
I-05	DT structure	Parameters and hyperparameters of the implemented DT.	
I-06	DT performance	Achieved maximum and mean accuracy of the DT. Percentage of outliers in the DT outputs.	
I-07	DLR (dynamic line rating)	Achieved average ampacity (gain) with the application of DT.	

7 Requirements (optional)

8 Common terms and definitions

<i>Acronym</i>	<i>Term</i>	<i>Definition</i>

Ampacity	Ampere capacity	The maximum amount of electric current a conductor or device can carry continuously under specified conditions without exceeding its temperature limit.
ANN	Artificial neural network	A computational model inspired by the way biological neural networks in the human brain process information, it consists of interconnected layers of artificial neurons that can learn and perform tasks such as pattern recognition, classification, and prediction by adjusting the weights of connections based on data inputs.
DLR	Dynamic line rating	A technology used in power systems to determine the real-time capacity of overhead power lines based on environmental conditions (e.g., temperature, wind speed, and solar radiation). Unlike static ratings, DLR improves efficiency by dynamically adjusting the permissible current-carrying capacity of lines.
SCADA	Supervisory Control and Data Acquisition System	SCADA is an industrial control system used to monitor and control infrastructure and industrial processes. It collects real-time data from remote sensors, provides a central interface for operators to manage systems, and can issue automated or manual control commands. SCADA systems are widely used in utilities, manufacturing, and transportation.

9 Custom information (optional)

B.5.2 Enhanced flow-based capacity calculation for market co-optimization using DLR data [HU02]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
DT2	Hungary	Enhanced flow-based capacity calculation for market co-optimization using DLR data

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
1.0	21/11/2024	Bence Bereczki	First version	
1.1	30/11/2024	All T7.3 partners	Additions based on discussions with HU demo partners	
2.0	04/02/2025	Bence Bereczki, Ágnes Závecz	Finalization	
2.1	Ongoing	All T7.3 partners	Approval, touches	final

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Transmission network constraints are handled with flow-based methodology, and dynamic line rating results of additional flow margins are integrated to enable higher volume of energy and balancing capacity exchange. Resulting DLR enhanced market clearing enables the realization of opportunities and upsides of weather-related uncertainties as additional potential for higher price convergence and social welfare for end-users of the market. Additionally, a new, web-based data platform will be developed to serve dual purposes by combining dynamic data visualization functionalities with data queries to support market participants to make better decisions while stepping into market transactions.
Objective(s)	The objective of the use case is to develop and demonstrate an enhanced, multi-product optimization tool to operate daily, spot energy and balancing capacity market auction.
Related business case(s)	-

1.4 Narrative of Use Case

Narrative of use case
Short description
This use case demonstrates the use of Dynamic Line Rating (DLR) to improve flow-based capacity calculations for cross-border electricity markets. By integrating line monitoring data, the DLR-enhanced approach enables more accurate and adaptive capacity calculations, which optimizes transmission network utilization, reduces congestion, and supports greater integration of renewable energy sources.
Complete description
The goal of this use case is to enhance transmission network capacity calculations by implementing Dynamic Line Rating (DLR) within the flow-based capacity calculation framework. Traditional capacity calculations use static ratings based on conservative assumptions, which often limit the amount of cross-border electricity flow due to grid congestion. By incorporating line monitoring data, DLR provides adaptive, weather-responsive ratings, which more accurately reflect actual line capacities. This enhanced calculation method uses DLR data from sensors and weather stations, processed through algorithms that predict line capacity based on conditions. As a result, the DLR-enhanced flow-based capacity calculation increases available transmission capacity while ensuring system security. This approach supports higher market liquidity and cross-zonal trade by allowing more transmission capacity to be allocated, which benefits the integration of renewable energy sources. The process includes several stages: data collection from line sensors and weather stations, dynamic capacity calculation incorporating DLR, and allocation of additional transmission capacity to market operations. The outputs are shared with market operators and TSOs, allowing for better alignment between available transmission capacity and market needs. This contributes to more efficient grid management and increases the potential for renewable energy integration across regions.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Transmission Capacity Utilization	Measures the increase in transmission capacity available for cross-border flows as a result of using DLR compared to static ratings. This can be tracked as a percentage increase in capacity over time.	
2	Congestion Reduction	Quantifies the reduction in grid congestion on cross-border lines by comparing congestion hours or events with and without DLR implementation.	
3	Capacity Adjustment Frequency	Measures how often DLR adjustments are applied to update capacity ratings based on real-time conditions. This KPI reflects the responsiveness of the system to dynamic changes in grid conditions.	

1.6 Use case conditions

Use case conditions
Assumptions
1 Accurate, real-time data on weather conditions and line temperatures from sensors is available to enable DLR calculations.

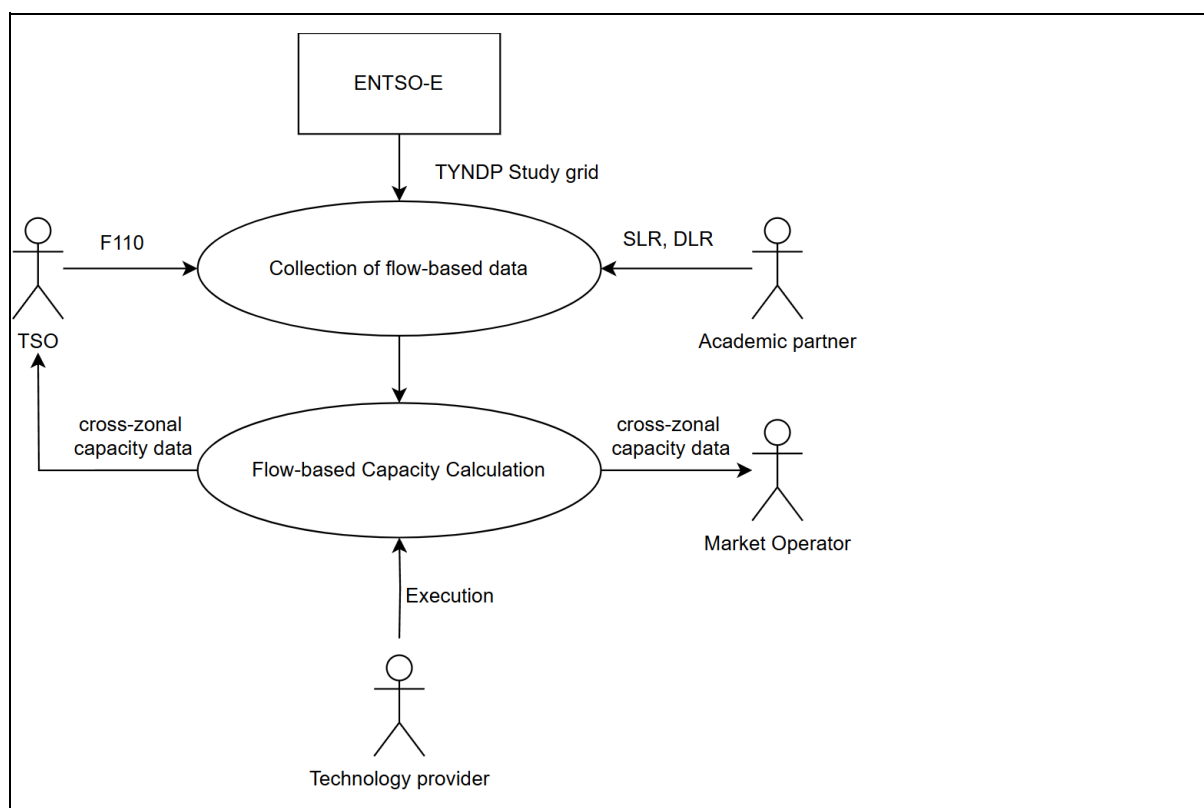
2	The baseline flow-based capacity calculation system is already in place, and DLR can be integrated as an enhancement rather than a replacement.
3	There is a secure and reliable infrastructure for collecting, processing, and transmitting DLR data between sensors, TSOs, and the market operator to support updates.
Prerequisites	
1	Sensors and weather monitoring stations must be installed and operational on relevant transmission lines to collect data for DLR calculations.
2	Market and grid management systems must be able to process and utilize DLR data, ensuring that capacity calculations can adjust dynamically based on real-time conditions.
3	TSOs and market operators must coordinate closely to integrate DLR-adjusted capacities into market clearing processes, ensuring seamless updates to cross-zonal capacities for market operations.

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Results of HU01 - Digital twin for power line monitoring are used.
Level of depth
Generic use case
Prioritisation
High level of priority
Generic, regional or national relation
National use case for Hungary
Nature of the use case
BUC
Further keywords for classification
Flow-based capacity calculation, DLR enhanced market co-optimization

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
MAVIR	Transmission System Operator	MAVIR provides grid-related data, including initial line rating data and other grid parameters for enhanced flow-based capacity calculations	
HUPX	Market Operator	HUPX receives DLR-enhanced flow-based capacity data to incorporate updated cross-zonal capacities into market clearing processes.	
BME	Academic partner	BME collaborates on ensuring the reliability of DLR-enhanced calculations for the flow-based capacity calculations.	
Artelys	Technology provider	Artelys is responsible for performing flow-based (FB) capacity calculations using data from MAVIR and integrating Dynamic Line Rating (DLR) adjustments. Artelys processes and provides the DLR-enhanced capacity data to all stakeholders for improved transmission and market operations.	

3.2 Systems

Actors

Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
HUPX Labs	HUPX	Data platform	
MAVIR FileShare	MAVIR	Data sharing platform	Back-up channel for data provision
Python, PowSyBl	Artelys	Processing of flow-based domains with DLR characteristics	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Collection of flow-based data	Reference flow-based domains without DLR	Artelys/MAVIR	Data publication on JAO PuTo		
2	DLR enhancement	Integration of DLR characteristics into JAO flow-based constraints	Artelys			

Collection of flow-Based data

Scenario step by step analysis

Scenario								
Scenario name		Collection of flow-based data						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1		Flow-based input F110: cross-border trading	Input collection for flow-based capacity: cross-border trading	JAO PuTo	MAVIR	Artelys	1a	
1.2		Flow-based	Input collection		MAVIR	Artelys	1b	

		input F316: PTDF, RAM	for flow-based capacity: PTDF and RAM					
1.3		Flow-based input TYNDP	Input collection for flow based capacity: TYNDP Study grid dataset		ENTSO-E	Artelys	1c	

DLR enhancementScenario step by step analysis

Scenario								
Scenario name		DLR Enhancement						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1		DLR-enhancement of flow-based domains	Use of dynamic inputs from the DLR calculations in the flow based capacity calculation module		Artelys	Hosting agent		2

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1a	F110	F110: cross-border trading	
1b	F316	F316: PTDF, RAM (DLR enhanced)	
1c	TYNDP	TYNDP Study grid dataset	

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
2	DLR parameters	Permanent and temporary intensity profiles for each CNEC where DLR is applicable (Excel file)	

B.5.3 Co-optimizing the energy and balancing capacity market coupling with dynamic flow-based auction [HU03]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
DT2	Hungary	Co-optimizing the day-ahead and intraday energy and balancing capacity market

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
1.0	12/06/2024	Ágnes Závecz	First version	
2.0	21/11/2024	Bence Bereczki	Addition based on discussions with HU demo partners	
2.1	30/11/2024	All T7.3 partners	Further comments	
3.0	04/02/2025	Bence Bereczki, Ágnes Závecz	Finalization	
3.1	Ongoing	All T7.3 partners	Approval, touches final	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Co-optimization of day-ahead and intraday energy and balancing capacity markets within a unified platform, using flow-based capacity calculations to manage transmission constraints.
Objective(s)	The objective of this use case is to maximize cross-border capacity allocation, increase social welfare, and ensure seamless integration of energy and balancing bids in compliance with SDAC and SIDC.
Related business case(s)	HU02

1.4 Narrative of Use Case

Narrative of use case
Short description

The TwinEU project aims to support EU energy policy goals by enabling solutions for a unified Internal Electricity Market. This demonstration focuses on a co-optimized cross-border capacity auction algorithm (OPTIM-CAP) to optimize cross-zonal network capacity usage across both day-ahead and intraday timeframes. This approach facilitates progress toward the European Power Market Model by unifying current, energy exchange-based market couplings with the procurement of balancing capacity, including aFRR, mFRR, and RR, if applicable, including all standard and local product variant (e.g. HU: mFRR 12.5).

Complete description

The integration of balancing capacity auctions into the established SDAC and SIDC solutions involves two main requirements:

- (1) aligning timing and processes on a unified market platform covering both day-ahead and intraday auctions and
- (2) defining a product that enables linked generation capacity offerings. This fosters capacity optimization for market participants in a co-optimized environment.

Existing market couplings for energy transactions address firm, scheduled energy flows. Adding balancing capacity requires handling cross-zonal reserves, particularly for intraday adjustments, and their impact on flows across borders, which the algorithm addresses by calculating worst-case activations to ensure system security.

OPTIM-CAP provides a tool to maximize interconnector and branch utilization, with a co-optimized approach that increases the use of transmission corridors across both day-ahead and intraday markets. This enhances wholesale market efficiency by incorporating capacity updates from DLR calculations. Re-estimated flow-based domains based on the TYNDP study dataset may also be computed in order to address the impact of PSTs, HVDCs, or even line additions.

The co-optimization process involves three stages: pre-processing of bids, optimization with capacity allocation for both energy and balancing, and notification of results. The unified auction platform, covering day-ahead and intraday, collects historical energy and balancing bids, with submissions via the demonstration platform.

The single-shot auction, which consolidates orders for day-ahead and intraday periods, requires optimization for all hours and constraints in a single run. The output provides clearing prices, accepted/rejected bids, capacity flows, and traded volumes for both energy and balancing across both market timeframes. The market coupling algorithm will support the usage of each individual and specific combination of products of DA & ID energy and BC markets.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	Depth of the market	The quantity of orders near the equilibrium price. Hour, rate, zone, quantity, and price parameters => Orders are grouped by type, rate, zone, and hour. For each group, the number and total quantity of orders within $\pm 15\%$ of the equilibrium price need to be determined. The equilibrium prices need to be processed by averaging over hours.	The objective of this use case is to maximize cross-border capacity allocation, increase social welfare, and ensure seamless integration of energy and balancing bids in compliance with SDAC and SIDC.
2	Price sensitivity	Change of upward and downward balancing capacity prices relative to the base case. For each product, zone, and hour, a single value needs to be extracted from price results	The objective of this use case is to maximize cross-border capacity allocation, increase social welfare, and ensure seamless integration of energy and balancing bids in compliance with SDAC and SIDC.
3	Zonal spreads	Upward and downward balancing capacity prices differences along borders. The 4 zones have 4 borders between them: HU-AT, AT-CZ, SK-CZ, HU-SK. Constraints on the power flow across these borders can result in price differences. For each product and hour, the differences in price values across borders need to be calculated.	The objective of this use case is to maximize cross-border capacity allocation, increase social welfare, and ensure seamless integration of energy and balancing bids in compliance with SDAC and SIDC.

4	Reserve costs	Upward and downward balancing cost. One value is needed per zone, product, and hour.	The objective of this use case is to maximize cross-border capacity allocation, increase social welfare, and ensure seamless integration of energy and balancing bids in compliance with SDAC and SIDC.

1.6 Use case conditions

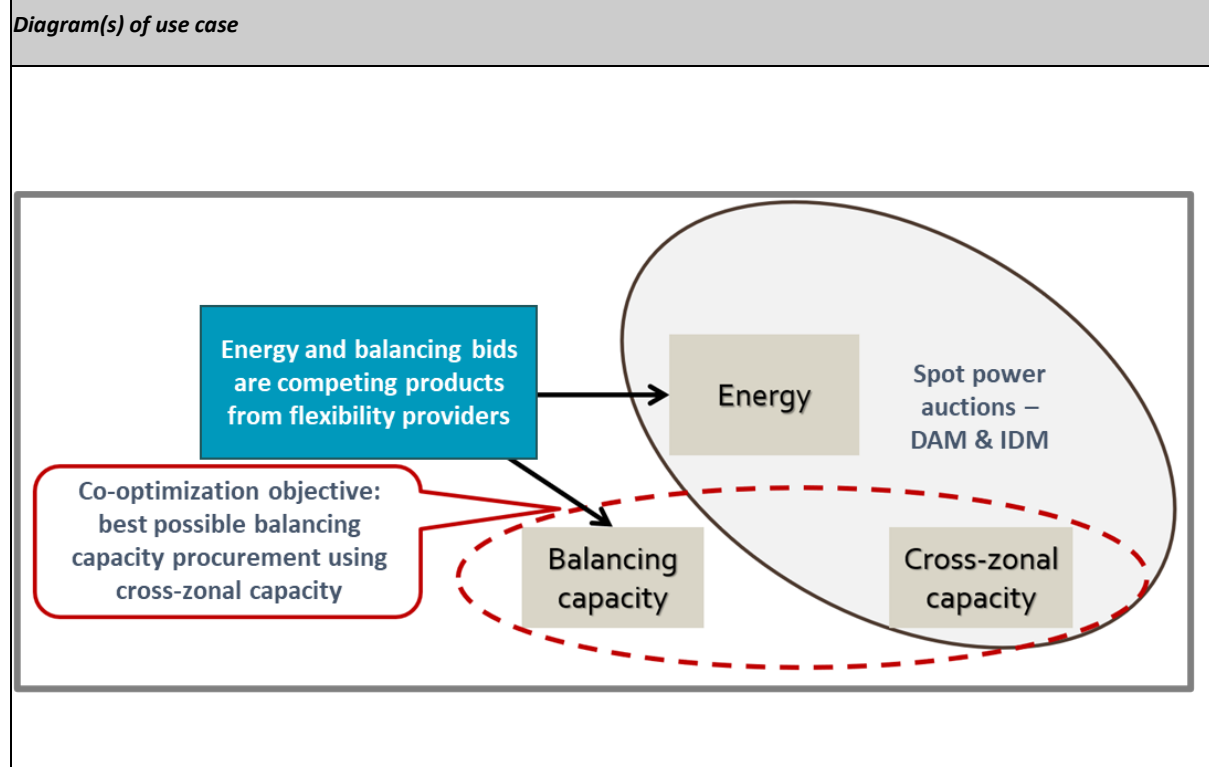
Use case conditions	
Assumptions	
1	Current balancing market bids are known, historical data is available
2	Current energy market bids are known, historical data is available
4	Dynamic Line Rating of the critical transmission lines is known
3	Flow-based cross-zonal capacity allocation is in place
Prerequisites	
1	Balancing Service Providers (BSPs) must be prequalified and accredited based on current requirements, ensuring they can participate in balancing capacity bids within the co-optimization framework.
2	A harmonized set of product definitions and bidding formats for both the day-ahead and intraday markets is required. This includes definitions for balancing products like aFRR, mFRR, and any linked energy products, enabling the platform to handle these products uniformly.
3	The cross-zonal capacity calculation must be compatible with dynamic adjustments using DLR data, allowing updates to capacity constraints in response to grid conditions.
4	Agreements and protocols must be in place among NEMOs, TSOs, and other market operators to enable secure, real-time data sharing. This includes sensitive bid data, real-time grid information, and clearing results necessary for co-optimization.

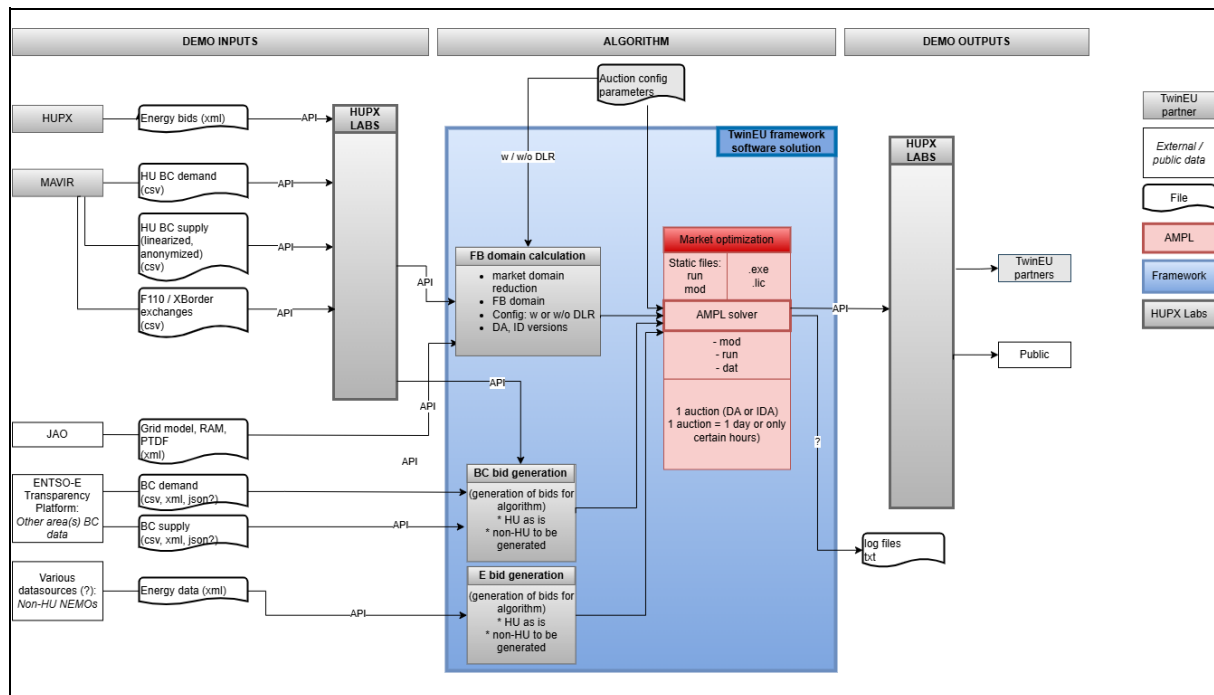
1.7 Further information to the use case for classification/mapping

Classification information	
Relation to other use cases	
Results of HU01 - Digital twin for power line monitoring and HU02 - Enhanced flow-based capacity calculation for market co-optimization using DLR data are used.	
Level of depth	
Generic use case	
Prioritisation	

High level of priority
Generic, regional or national relation
National use case for Hungary
Nature of the use case
BUC
Further keywords for classification
Market co-optimization, balancing capacity and energy bids, flow-based capacity calculation

2 Diagrams of use case





3 Technical details

3.1 Actors

Actors			
Actor name	Actor type	Actor description	Further information specific to this business use case
HUPX	Market Operator	HUPX operates the Hungarian energy market and provides day-ahead & intraday datasets for the co-optimized auctions.	
MAVIR	Transmission System Operator	MAVIR assists the Project with information about the Hungarian balancing capacity market and regional FB capacity calculation process.	
BME	Academic partner	BME is responsible for the creation and scientific foundation of the market co-optimization algorithm, as well as the implementation of foreign bids.	
Artelys	Technology provider	Artelys is responsible for implementing and operating the capacity calculation module and the optimization algorithm which enables the co-optimization of energy and balancing markets.	

3.2 Systems

Actors			
System name	System owner	System description	Further information

			<i>specific to this system use case</i>
HUPX Labs	HUPX	Data platform	
MAVIR FileShare	MAVIR	MAVIR's data provision	Back-up channel for MAVIR's data provision
Python, PowSyBl,	Artelys	Framework application used to preprocess all input data arriving in various formats, preparing the data for the solver, and processing and saving results generated by the solver	
AMPL, Express	Artelys	Solver module used to emulate EUPHAMIA optimization solution	

4 Step by step analysis of use case

4.1 Overview of scenarios

<i>Scenario conditions</i>						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Calculation and transfer of network data	Key grid-relevant flow-based data including PTDF, RAM, DLR and cross-border trading is calculated and provided	MAVIR, Artelys			
2	Gathering energy bids	Gathering of energy supply and demand bids	HUPX, Artelys (public sources)			
3	Gathering BC bids	Gathering of BC supply and demand bids	MAVIR, HUPX, Artelys (public sources)			
4	Calculate and validate market results	In the demonstration, market bid aggregation is done as part of the order book building, as HUPX and international historic orders are submitted into the bidding process. As no CCC is part of the project, no post-coupling validation is being carried out, while check of the feasibility of the results are to be done ex-post, in the demonstration performance analysis. Total post-coupling process is not replicated as some key roles are not part of the realization. However, this omitted part is only about information transmission and	Artelys	1,2,3 complete	1,2,3	

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
		distribution, thus the evaluation of the performance and applicability of the demonstrated approach does not need these parts.				
5	Publication of results	The demonstration's scope includes the necessary calculations and display of information via standard data platform (HUPX Labs). Access to data sets on the platform is aligned to the individual roles of each Actor.	HUPX	4 complete	4	

4.2 Steps – Scenarios

Calculation and transfer of network data

Scenario step by step analysis

Scenario								
Scenario name		Calculation and transfer of network data						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1		Flow-based input F110: cross-border trading	Input collection for flow-based capacity: cross-border trading		TSOs (inc. MAVIR)	Artelys (through HUPX Labs)	1a	
1.2		Flow-based input F316: PTDF, RAM	Input collection for flow-based capacity: PTDF and RAM		TSOs (inc. MAVIR)	Artelys (through JAO PuTo)	1b	
1.3		Flow-based input TYNDP	Input collection for flow-based capacity: TYNDP Study grid dataset		ENTSO-E	Artelys	1c	
1.4		Flow-based input: CORE (marked domain reduction)	Flow-based input F110 modification—CORE area borders represented with price taker orders created from all out-of-the-			Hosting Agent	1a	

Scenario								
Scenario name		Calculation and transfer of network data						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
			simulation cross-border trading					
1.5		Presolve (market domain reduction)	Market domain reduction, F316 modification by keeping only relevant (limiting) conditions			Hosting Agent	1b	

Gathering energy bids

Scenario step by step analysis

Scenario								
Scenario name		Gathering energy bids						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1		Energy collection: participating NEMOs	Input collection for energy market supply and demand bids - marketwise		HUPX		2a	
2.2		Energy collection: not participating NEMOs	Input collection for energy market supply and demand bids - marketwise		Artelys (bid generator based on public data)		2b	

Gathering balancing capacity bids

Scenario step by step analysis

Scenario								
Scenario name		Gathering BC bids						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
3.1		BC collection: participating TSOs	bid Input collection for BC supply bids and demand – marketwise		TSO (MAVIR)	Artelys (through HUPX Labs)	3a	
3.2		BC collection: non-participating TSOs	bid Input collection for BC supply and demand – marketwise		Artelys (bid generator based on ENTSO-E Transparency data)		3b	

Calculate and validate market results

Scenario step by step analysis

Scenario								
Scenario name		Calculate and validate market results						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
4.1		Input preprocessing	data Input preprocessing for AMPL solver	Framework	Artelys	Artelys	4	1-3
4.2		Optimization	Welfare-maximising optimization solution	AMPL, Express	Artelys	Artelys	5a, 5b, 5c	4

Publication of results

Scenario step by step analysis

Scenario								
Scenario name		Publication of results						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
4.1		Log file saving	Auction simulation logs	AMPL, Express	Artelys	Artelys, BME	5a	4
4.2		Results processing	Results processing into public and partner-specific domains	HUPX Labs	Artelys	HUPX	5b, 5c	4
4.3		Result reception and analysis	Party-specific simulation results	HUPX Labs	HUPX	Actors, Public	5b, 5c	4

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1a	Flow-based input 1	F110: cross-border trading	
1b	Flow-based input 2	F316: PTDF, RAM (DLR enhanced)	
1c	Flow-based input 3	TYNDP Study grid dataset	
2a	Energy bids (participating NEMOs)	Energy supply and demand bid sets from HUPX - complete market	
2b	Energy bids (not participating NEMOs)	EPEX SPOT, OKTE, OTE data	
3a	BC bids (participating TSOs)	BC supply bid and BC demand sets from MAVIR - complete market, linearized	
3b	BC bids (not participating TSOs)	APG, SEPS, CEPS data is accessed via ENTSO-E Transparency portal	
4	Pre-processed data	Data transformed for solver	1-3
5a	Log files	Auction / optimization - log files	4

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
5b	Results: Actor	Auction / optimization results available for each partner	4
5c	Results: Public	Auction / optimization results available for public use	4

B.6 Iberian Pilot Site UCs

B.6.1 AI Agent for probabilistic grid status forecast and remedial actions identification for the TSO's Control Centre Operator [Ib01]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib01	Transmission	AI Agent for probabilistic grid status forecast and remedial actions identification for the TSO's Control Centre Operator

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	n.a.	
0.2	10/05/2024	REE	Additional description	
0.3	20/09	REE	Additional description	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Power system operation Digital Twin
Objective(s)	Identify risky grid status for the electrical grid and propose remedial actions
Related business case(s)	Power system operation security

1.4 Narrative of Use Case

Narrative of use case
Short description
Develop a digital twin – an AI agent - that support the transmission control centre during real-time operation decisions.
Complete description
The operation of the power system is more complex due to the high levels of variable renewable generation integration and their associated uncertainty and variability. This digital twin module aims to address this problem for real-time operation (timeframe from 15 min to 24h will be assessed). The digital twin will be able to identify the future probabilistic status of the

grid, analyse potential risk for the system operation and propose actions for its mitigation. In this way the power supply and the security of the system will be preserved.

1.5 Key performance indicators (KPI)

<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
1	Accuracy	Precision of the algorithm to determine the grid action	Precision=number of right recommendations done by the agent/ number of recommendations done by the agent
			<i>*Before starting the results evaluation phase, evaluation of additional KPIs will be done and defined if required</i>

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	Grid status is well known
<i>Prerequisites</i>	
1	The status of the grid as well as its historical states are known (data availability)
2	A model of the grid (IEEE models and real transmission grid will be used for the development)

1.7 Further information to the use case for classification/mapping

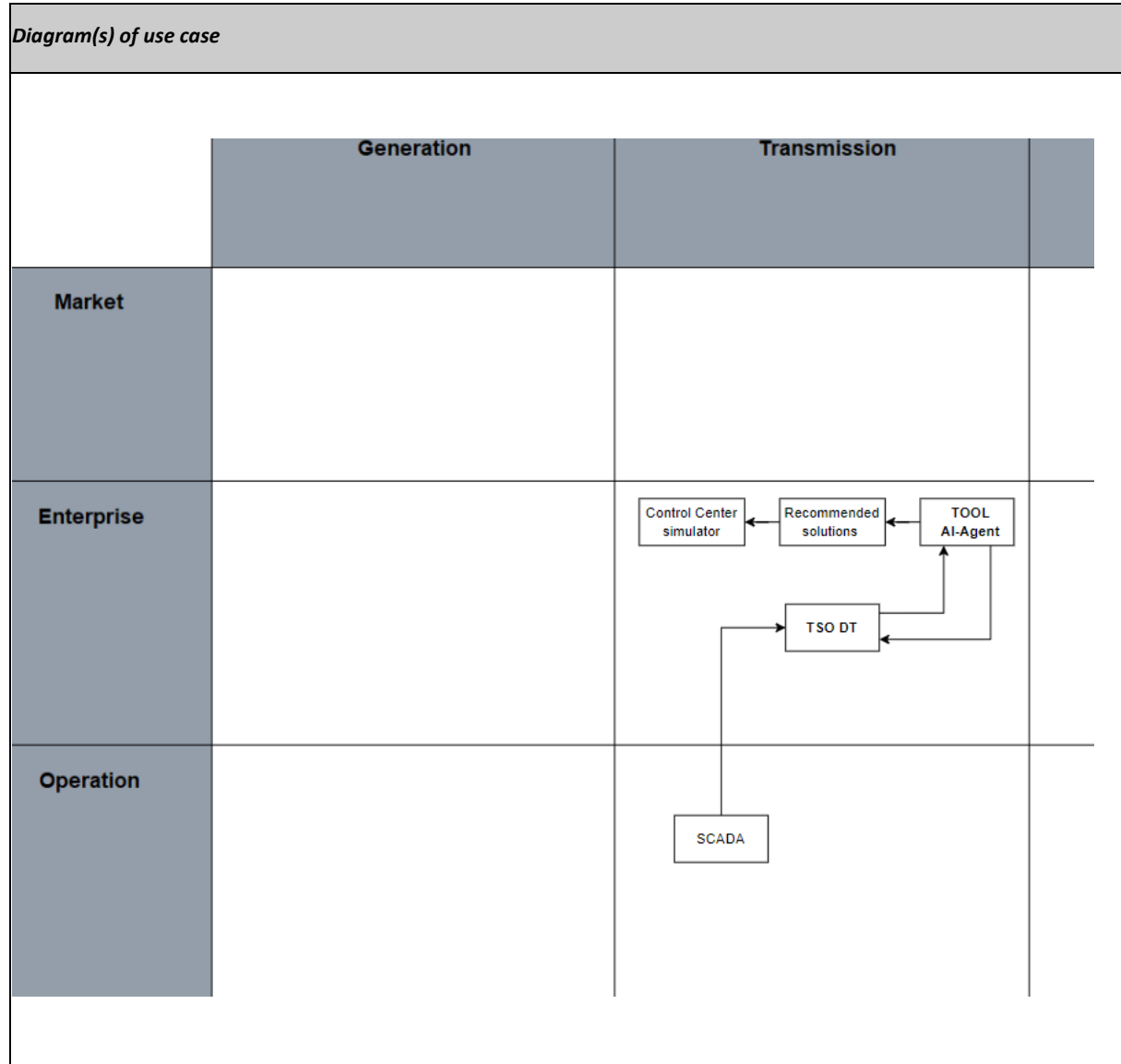
<i>Classification information</i>
<i>Relation to other use cases</i>
UC Ib01 - DT for generation of synthetic series of renewable resources
<i>Level of depth</i>
System
<i>Prioritisation</i>
High
<i>Generic, regional or national relation</i>
Generic
<i>Nature of the use case</i>

System operation security and renewable power integration
Further keywords for classification

1.8 General remarks

n.a.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors	
Grouping (e.g. domains, zones)	Group description

Actor name	Actor type	Actor description	Further information specific to this business use case
REE	TSO	Spanish TSO	Knowledge and data of system operation task done by REE will be used
CIRCE	Research centre	Research	Algorithm developer

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
SCADA-EMS: REE's DT of the control centre	REE	The models in the SCADA/EMS for power system operation	DT of the control centre
SCADA-EMS: Historical data in SCADA/EMS	REE	The data stored in the SCADA/EMS from power system operation	Historical data from system operation
SCADA-EMS training simulator	REE	System to emulate and train power system operation	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Real-Time Grid Analysis	AI analyses grid performance and suggests optimizations.	CIRCE+REE AI Grid Monitoring Agent	Detection of voltage fluctuation or increased load.	AI is connected to grid sensors; data stream available.	AI suggests actions; grid stability is improved.
	Load and Generation Forecasting	AI forecasts grid load and generation trends.	REE	Scheduled forecast or significant data pattern detected.	Historical load and generation data available.	Forecast provided; operators adjust plans as needed.

	Gathering of the Data	AI gathers real-time data from grid sensors.	REE	Data collection interval or manual data request.	Sensors are operational; network connection is stable.	Data collected and sent for analysis.
	AI Calculations	AI performs calculations based on real-time data analysis.	CIRCE AI Computational Agent	New data received or updated forecast required.	Sufficient data is available for analysis.	Calculations complete; results available for reporting.
	AI Reporting	AI generates a report of analysis results and recommendations.	REE+CIRCE AI Reporting Agent	Analysis complete or scheduled report interval reached.	AI calculations completed; report format predefined.	Report generated; operators receive recommendations.

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
Real-time Grid Data	Grid Sensor Data	Data from sensors monitoring voltage, current, and frequency.	Sensors must be operational and connected to the monitoring system.
Load and Generation Forecasts	Forecasted Demand and Supply	Predictions of future power demand and energy generation.	Historical data and AI model accuracy for forecasting.
AI Analysis Results	Grid Optimization Suggestions	Recommendations for grid adjustments based on analysis.	Completed data analysis and predefined decision-making criteria.
Data Collection Status	Data Retrieval Report	Status update on the collection of grid data.	Active sensor network and communication with AI system.
Report of Findings	AI-Generated Report	Summary of AI analysis and recommended actions.	Analysis and calculations must be completed; report format defined.

6 Requirements (optional)

7 Common terms and definitions

- TSO: Transmission System Operator
- SCADA: Supervisory Control And Data Acquisition
- SCADA/EMS: Supervisory Control And Data Acquisition/ Energy Management System
- AI: artificial intelligence

8 Custom information (optional)

B.6.2 DT for generation of synthetic series of renewable resources [Ib02]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib02	Transmission	DT for generation of synthetic series of renewable resources

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	05.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	10/05/2024	REE	Additional description of the UC	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Renewable resource forecast
Objective(s)	Generate synthetic series of renewable resources for power system application
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description
The digital twin will be able to generate series of renewable resources (not generation) like wind, solar and hydro.
Complete description
Correlation of the different series will be modelled for the sequential and interdependency evaluation. The granularity of the series could be customizable so they will be valid for planning purposes (long-term) and operation purposes (short-term).
The output of this digital twin module will be used by other digital twin modules, as renewable resources is a fundamental input in the algorithms for electrical grids planning and operation.

.....

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
1	AP	Series correlation	Synthetic series/historical series are in the range of +-5% 80% of time
			* Before starting the results evaluation phase, evaluation of additional KPIs will be done and defined if required

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Weather phenomena along the Iberian system are known.
Prerequisites	
1	Historical information of weather, renewable resources and DLR.
2	A model of the grid.

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
It is a module useful for electrical grids studies and simulation software (other digital twin modules).
Level of depth
System
Prioritisation
High
Generic, regional or national relation
National, but easily extrapolable to any territory if the input data of different regions are provided to the DT
Nature of the use case

Uncertainty of renewable generation

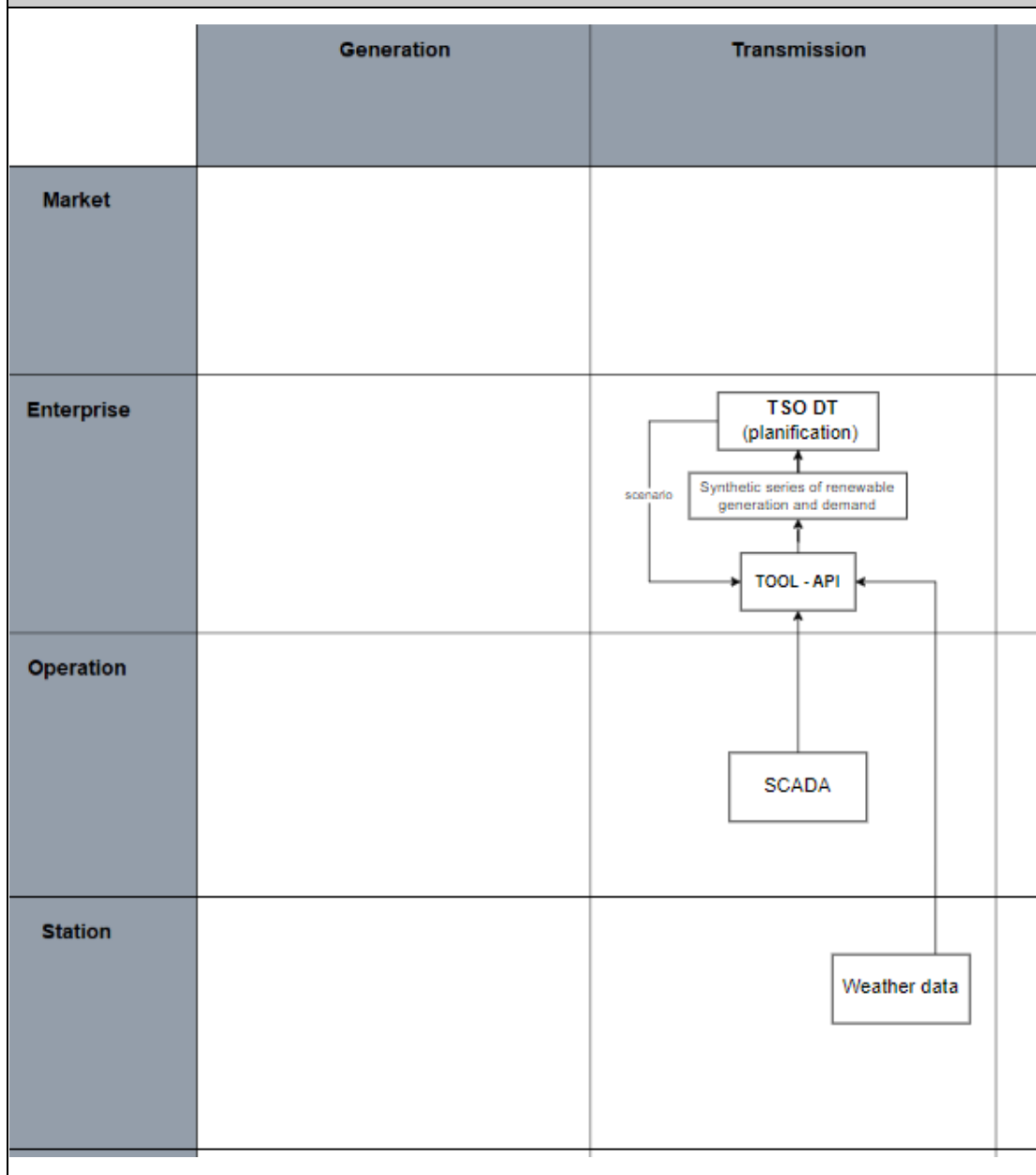
Further keywords for classification

1.8 General remarks

n.a.

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
REE	TSO	Spanish TSO	REE's DT involved
CIRCE	Research Institute	Research	Algorithm developer

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Not named	REE	Database	Historical information of weather data and renewable resources

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
	Data Collection	Gather historical data of weather and correlation analysis	REE	Data gathering	Data sources available	Data can be compiled and used
	AI Training with Power System Data	AI is trained on historical power system data and weather parameters.	CIRCE	Completion of data preparation and aggregation.	Sufficient historical data is available for training.	AI model is trained and ready for scenario generation.
	Scenario Creation	Planning engineer creates power system scenarios based on parameters.	REE, CIRCE	Engineer specifies parameters and trends for scenario.	AI model is trained and operational; input parameters are defined.	Scenario generated with projected loads and generation.
	Load and Generation Time Series Output	AI produces time series for loads and generation based on specified trends.	CIRCE, REE	Completion of scenario creation by the engineer.	Trends and parameters defined by the engineer.	Time series output provided for analysis and planning.

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
Historical Data for Training	Training Data Set	Data series of load, generation, wind speed, and other weather factors.	Comprehensive and high-quality data available for training.
Input Parameters	Scenario Parameters	Parameters defined by the engineer for scenario creation.	Defined trends and specifications must be inputted.
Generated Time Series	Load and Generation Profiles	Projected time series for loads and generation.	AI must be trained; scenario creation completed.
AI Training Status	Model Training Report	Status update on the training of the AI model.	Training process must be completed successfully.
Scenario Analysis Report	AI-Generated Scenario Report	Summary of generated scenarios and insights for planning.	Scenarios must be created; report format predefined.

6 Requirements (optional)

7 Common terms and definitions

- TSO: Transmission System Operator
- AI: artificial intelligence

8 Custom information (optional)

B.6.3 DT-enabled multi-area system dynamic behaviour assessment [Ib03]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib03	Transmission	DT-enabled multi-area system dynamic behaviour assessment

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	26.04.2024	Joao Peças Lopes (INESC TEC)	Complete description	
0.3	30.04.2024	Joao Peças Lopes (INESC TEC)	Complete description	
0.4	31.07.2024	Joao Peças Lopes (INESC TEC)	Technical details	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The progressive integration of electronic converter based Renewable Energy Sources will lead to a reduction of the system synchronous inertia that can endanger the system frequency stability behaviour, especially in poorly interconnected systems, such as the case of Iberian system. A Digital Twin representing the dynamic behaviour of Iberian system interconnected with the central European system is therefore needed to assess the frequency stability of the Iberian grid when facing large disturbances like a sudden loss a large amount of generation. This DT allows to evaluate the robustness of operation and to tailor new ancillary services to cope with the poorer dynamic behaviour.
Objective(s)	(1) Represent the Dynamic behaviour of the Iberian system and evaluate its dynamic robustness'; (2) Identification and provision of frequency ancillary services, including new ones like FFR and virtual inertia.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description

Exploitation of a properly tuned DT capable to represent the dynamic behaviour of the Iberian system and to enable the identification of required frequency ancillary services (including innovative ones like FFR, virtual inertia) to improve dynamic behaviour. This involves contributions from conventional generation, RES generation units and dynamic loads within (or not) under a VPP concept, providing both reserves upward and downward without de-loading of the generation units and the loads.

Complete description

The progressive integration of electronic converter based Renewable Energy Sources will lead to a reduction of the system synchronous inertia that can endanger the system frequency stability behaviour, especially in poorly interconnected systems, such as the case of Iberian system. A Digital Twin representing the dynamic behaviour of Iberian system interconnected with the central European system is therefore needed to assess the frequency stability of the Iberian grid when facing large disturbances like a sudden loss a large amount of generation. This DT enable system dispatch operators to evaluate to robustness of the Iberian system following a possible large disturbance and enable planning engineers to identify the volumes of new frequency ancillary services. Figure 1 in Section 2 describes the dynamic model associated to the DT.

The DT needs to be calibrated using a parameter estimation methodology that tunes the model frequency response to the real system frequency response when facing large disturbances. An initial parameter identification, that involves the identification of the values for system inertia, system damping, generator droops and synchronization coefficients, was performed solving an optimization problem, which corresponds to the minimization of the quadratic error summation between the model frequency response and the real system frequency response using in this case a metaheuristic approach based on a particle swarm algorithm. The real data exploited corresponds to the frequency behaviour during a disturbance related with the sudden loss of 1 GW of Active Power, due to the Almaraz II Nuclear plant unit disconnection in October 2011. The inertia parameters can afterwards be modulated using engineering judgment to evaluate the frequency behaviour for the scenarios of future years. Further calibration is expected during the project using data from frequency behaviours following large disturbances obtained from system operators records for other disturbances. Assessing this data is an important requirement for the quality of the results obtained when using this DT.

The DT will be further expanded to include the AGC operation and corresponding control loops.

This DT allows modelling different generation technologies, including the ones using electronic power converters related to Renewable Energy Sources, as well as hydro pumping units' response. The DT will include blocks representing the dynamic response from demand, like thermal loads, electric mobility and electrolyzers when responding to frequency excursions, for FCR, or response to set points from an AGC platform, in the case of aFRR.

With this DT, and when properly calibrated, it will be possible to evaluate the dynamic behaviour of the Iberian system when facing active power disturbances, identifying the type, volume and characterization of frequency ancillary services (including innovative ones, like FFR, virtual inertia) needed by the system and to be provided by both generation power converters (synchronous and non-synchronous), storage units (hydro pumps or batteries) and responsive demand (EV charging, thermal loads and electrolyzers).

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI_Ib03_1	Frequency Nadir	The Frequency Nadir corresponds to the minimum value of frequency excursion, and it is an indicator of the dynamic robustness of the system. The system is considered in a dynamic safe region if the frequency nadir does not cross the boundary defined for dynamic safe operation (49.2 Hz)	(1), (2)
KPI_Ib03_2	Frequency Zenith	The Frequency Zenith corresponds to the maximum value of frequency excursion, and it is an indicator of the dynamic robustness of the system. The system is considered in a dynamic safe region if the frequency	(1), (2)

		nadir does not cross the boundary defined for dynamic safe operation (50.8 Hz)	
KPI_Ib03_3	RoCoF	The RoCoF corresponds to the maximum value of the time derivative of frequency excursion regarding time (for a time window to be defined), and it is an indicator of the dynamic robustness of the system. The system is considered in a dynamic safe region if the RoCoF does not cross the boundary defined for dynamic safe operation (1 Hz/s)	(1), (2)
KPI_Ib03_4	ACE	Area Control Error should be 0 after 300s	(1), (2)

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Disturbances to be considered are sudden loss of large amounts of generation or large step increase in load level.
2	No virtual inertia is included.
Prerequisites	
1	Update of real data related with frequency time behaviour in the Iberian system and in the Central European system following large disturbances. System Operators related data should be exploited for this purpose. This data will be used to re-tune the parameters of the DT, like equivalent inertias, damping, generator droops in each control area.

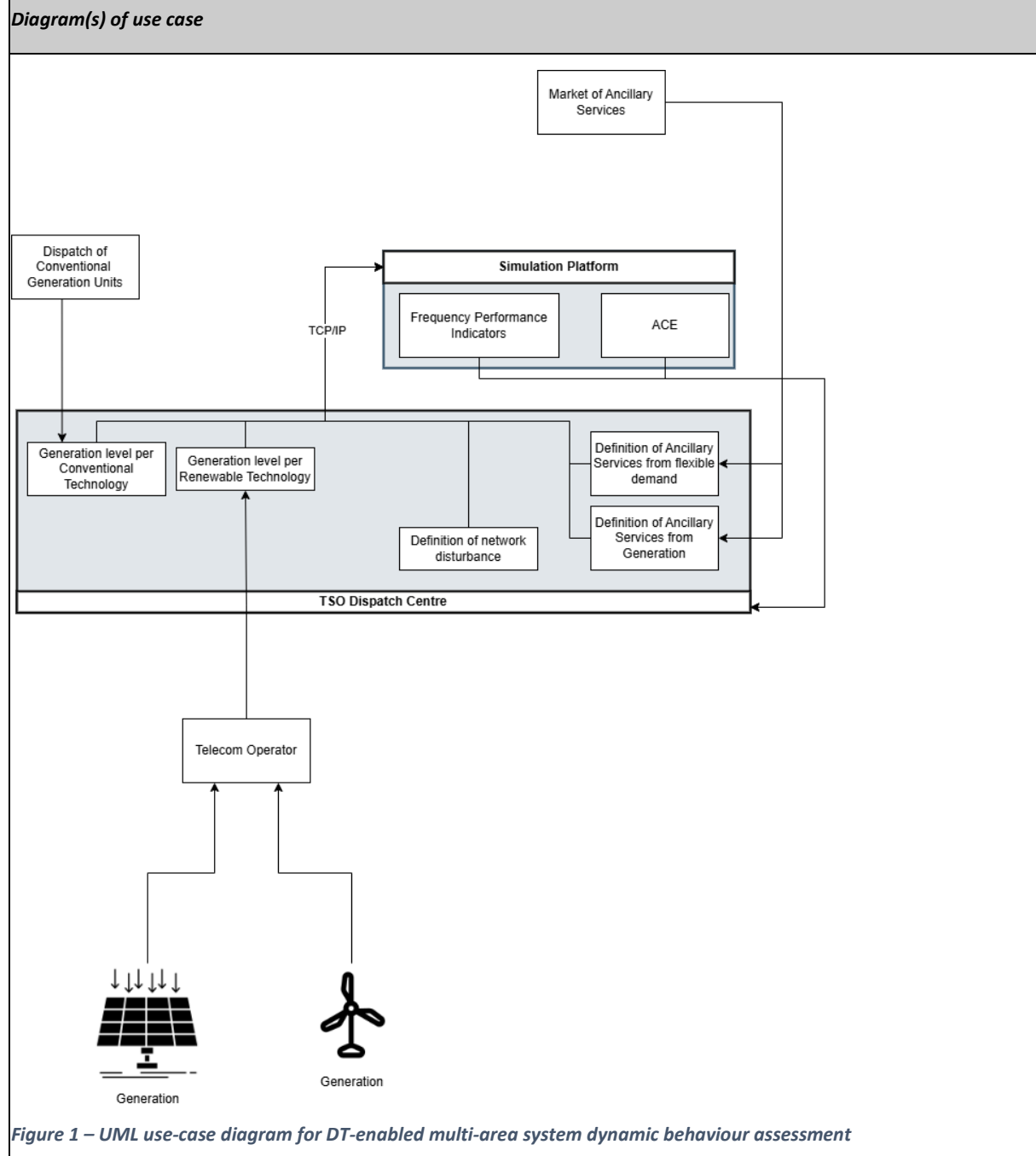
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
No relation with other use cases.
Level of depth
High level
Prioritisation
Generic, regional or national relation
Regional
Nature of the use case

System Use Case
Further keywords for classification

1.8 General remark

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Transmission System Operator (TSO)	Business	According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area. Source: EU Commission Task Force for Smart Grids, EG3	The UC Digital Twin will enable the TSO with a simulation platform to evaluate the dynamic robustness of the system.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
TSO SCADA System	TSO	System responsible for displaying grid measurements, which serve as input for ancillary services etc.	Measurements from the TSO SCADA defines the operational point of the system to serve as input for the DT

3.3 References

F. J. Ribeiro, J. A. P. Lopes, F. S. Fernandes, F. J. Soares and A. G. Madureira, "The role of hydrogen electrolyzers in frequency related ancillary services: A case study in the Iberian Peninsula up to 2040" Sustainable Energy, Grids and Networks 35, 2023.

R. Afonso, J. Peças Lopes, "Assessment of Demand Response Impact on the Frequency Stability of Low-Inertia Power Systems", Proceeding IEEE Power Tech 2023, June 2023

F. Sousa Fernandes, J. Peças Lopes, "Assessment of frequency stability behaviour regarding inertia reduction due to high renewable integration in the Iberian system", Presented in the 11th Bulk Power Systems Dynamics and Control Symposium, IREP 2022, July 25-30, 2022, Banff, Canada, 2022

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
2	Winter Valley Scenario	Scenario characterized by large wind power generation during valley hours	TSO	Assessment of the dynamic robustness of the Iberian system following large disturbance.	Definition of the system operational point.	Identify the volumes of new frequency ancillary services.
3	Peak PV generation scenario	Scenario characterized by large PV power generation	TSO	Assessment of the dynamic robustness of the Iberian system following large disturbance.	Definition of the system operational point.	Identify the volumes of new frequency ancillary services.

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1	Generation level	Generation level of conventional and renewable technology	
ID2	Network Disturbance	Definition of the magnitude of the network disturbance	
ID3	Ancillary Services	Current available ancillary services	
ID4	Frequency Nadir	Minimum value of frequency excursion	
ID5	Frequency Zenith	Maximum value of frequency excursion	
ID6	RoCoF	Maximum value of the time derivative of frequency excursion regarding time (for a time window to be defined)	
ID7	ACE	Area Control Error after 300s	

6 Requirements (optional)

7 Common terms and definitions

Frequency Nadir	Minimum value of frequency excursion
Frequency Zenith	Maximum value of frequency excursion
Rate of Change of Frequency (RoCoF)	Time derivative of the power system frequency
Area Control Error (ACE)	The real-time difference between the measured actual real time power interchange value ('P') and the control program ('PO') of a specific control area or and the frequency control error

($K \cdot \Delta f$), that is the product of the K-factor and the frequency deviation of that specific control area, where the area control error equals $\Delta P + K \cdot \Delta f$

Ancillary Services

Ancillary services are services provided by actors within the electric system that facilitate and support the continuous flow of electricity, so that there is a balance between demand and generation in real time.

8 Custom information (optional)

B.6.4 Abnormal market participation detection and protocol activation for mitigating the risk and consequences [Ib04]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib04	Market / integrated system	Abnormal market participation detection and protocol activation for mitigating the risk and consequences

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	26.04.2024	Javier Rodrigo (OMIE)	Objectives and complete description	
0.3	02.07.2024	Esteban Pastor Calatayud (ETRA)	Scope, use case conditions, further information and general remarks	
0.4	02.09.2024	Esteban Pastor Calatayud (ETRA)	Diagrams of use and technical details	
0.5	27.09.2024	Esteban Pastor Calatayud (ETRA)	Step-by-step analysis of the use case and information exchanged	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Horizontal in the Iberian electricity system. From wholesale markets at transmission level to local flexibility markets at distribution level.
Objective(s)	Selection of abnormal market participation regarding cybersecurity among all stakeholders (specially MO and TSOs or MO and DSOs) for each market service (wholesale markets or/and local flexibility markets).
Related business case(s)	Abnormal market participation detection and protocol activation for mitigating the risk and consequences

1.4 Narrative of Use Case

Narrative of use case
Short description
The DTs already deployed by the market operator (OMIE) and the SOs in the Iberian peninsula will collaborate to identify abnormal market participation, propagating the threat detection to all stakeholders and implementing the necessary countermeasures to secure the normal operation of the market.
Complete description
This UC will undertake the evaluation of possible cyber-attacks in the energy market according to Services & Data & Communications for two kind of market services: wholesale markets and local flexibility markets. Given the threats identification and the definition of eventual abnormal market participation schemes by market players suffering from cyber-attacks, the MO, the TSOs and the DSOs will develop specific mitigation protocols for : <u>Wholesale markets (MO – TSO)</u> • Daily auctions (day ahead market coupled with Europe) • Intraday auctions (MIBEL Area – Spain & Portugal). In 2024, these intraday auctions will be coupled with Europe. • Intraday continuous negotiation (XBID market coupled with Europe) <u>Local flexibility Markets (MO – DSO)</u> • Long term flexibility markets (Developed and managed by OMIE) • Short term flexibility markets (Developed and Managed by OMIE) Which will result into • Protocol activation for mitigating the risk and consequences for local flexibility markets (DSO and MO). • Protocol activation for mitigating the risk and consequences for wholesale markets (TSO and MO).

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
lb04-1	New methodologies/protocols defined for mitigating the risk and consequences	Depending on the defined scenarios and services included in the study during the development of the prepared methodology, there will be a number of protocol of methodologies defined to mitigate the consequences of a cyber threat toward the market participation bot at distribution and transmission levels.	Fully in line with the threat identification and mitigation measures design and implementation.

1.6 Use case conditions

Use case conditions
Assumptions

1	With an exponentially increased number of energy markets participants, the cyberthreats are also exponentially increased and a way to detect an eventual attack can be through their market participation patterns.
Prerequisites	
1	

1.7 Further information to the use case for classification/mapping

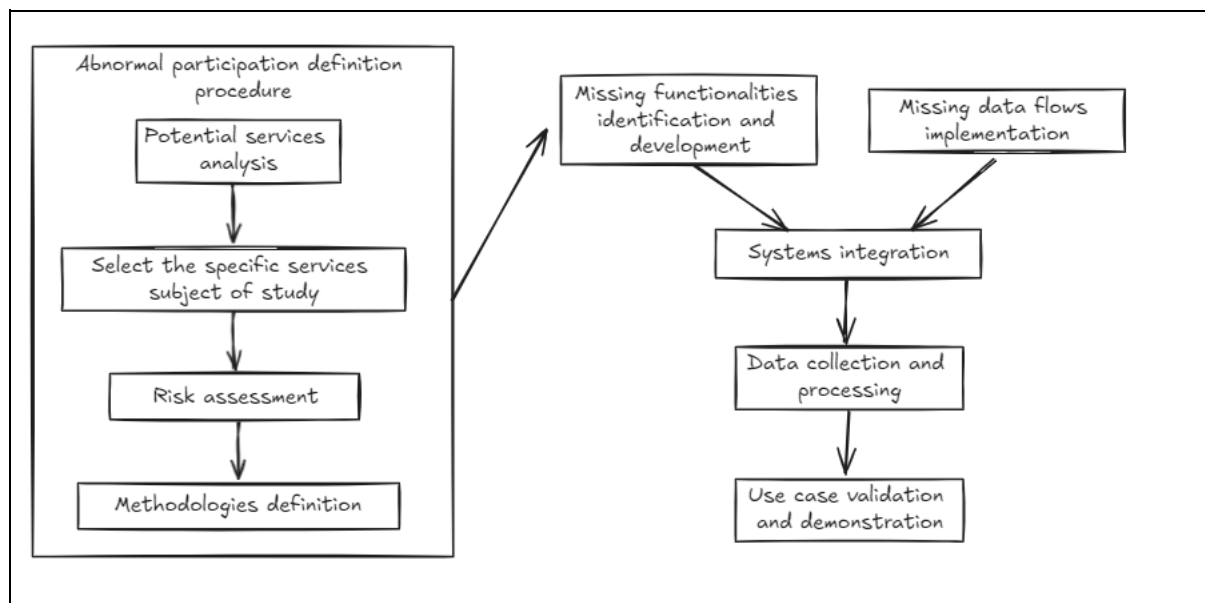
Classification information
Relation to other use cases
<i>n.a.</i>
Level of depth
<i>Business / high-level</i>
Prioritisation
<i>High</i>
.....Generic, regional or national relation
Regional – DSO-level relation
Nature of the use case
Enhancing the resilience and cyber security of the overall Iberian Electricity System
Further keywords for classification
<i>Stakeholders coordination, methodology definition, abnormal market participation definition.</i>

1.8 General remarks

This business use case responds to the methodology initiation for the Iberian Pilot's involvement in WP5 related to the use of digital twinning for cyber-physical grid resilience.

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Levels and roles		The groups of actors have been divided depending on the voltage level, and thus, on the services to be included in the UC, as well as on market operators.	
Actor name	Actor type	Actor description	Further information specific to this business use case
TSO	SO	System operator at HV	Responsible for overseeing and interacting with the market participants undertaking abnormal schemes at HV level.
DSO	SO	System operator at MV and LV	Responsible for overseeing and interacting with the market participants undertaking abnormal schemes at MV and LV levels.
Wholesale MO	MO	MO at HV	
LF MO	MO	MO at MV and LV	

3.2 Systems

Actors	
Grouping (e.g. domains, zones)	Group description
Levels and roles	The groups of systems have been divided depending on the voltage level, and thus, on the services to be included in the UC

<i>System name</i>	<i>System owner</i>	<i>System description</i>	<i>Further information specific to this system use case</i>
Transmission	TSO	Main electricity system	Main system where the wholesale-related services will be linked to and demonstrated
Distribution	DSO	Local electricity systems	Main systems where the LFM-related services will be linked to and demonstrated

3.3 References

n.a.

4 Step by step analysis of use case

4.1 Overview of scenarios

<i>Scenario conditions</i>						
<i>No.</i>	<i>Scenario name</i>	<i>Scenario description</i>	<i>Primary actor</i>	<i>Triggering event</i>	<i>Pre-condition</i>	<i>Post-condition</i>
1	Wholesale markets abnormal participation detection and protocol activation	At transmission and wholesale level, one of the involved actors identifies a potentially abnormal market behaviour by a market player. It can be the market player per se or the System Operator upon a potential cybersecurity breach or the market operator upon other conditions defined. A previously specified protocol for mitigating the risk and consequences is then activated.	MO, TSO, market player	A potentially abnormal market participation is detected		
2	Local flexibility markets abnormal participation detection and protocol activation	At distribution and local level, one of the involved actors identifies a potentially abnormal market behaviour by a market player. It can be the market player per se or the System Operator upon a potential cybersecurity breach or the market operator upon other conditions defined. A previously specified protocol for mitigating the risk and consequences is then activated.	MO, DSO, market player	A potentially abnormal market participation is detected		

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
	Parameters identifying a potential abnormal market participation	Out of the identified scenarios, all the information that leads to potentially	n.a.

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
		identifying an abnormal behaviour in the market participation strategy.	
	Proposed measures to activate the protocol	Once the scenario has been validated by the responsible actor(s) and it has been decided that a protocol must be activated, all the related information to the protocol activation must be shared.	n.a.
	Metrics related to the result of the protocol activation	Grid metrics and values that can verify the success of the protocol activation and its results.	n.a.

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.6.5 DT-based N-1 contingency analysis [Ib05]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib05	Distribution	DT-based N-1 contingency analysis

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	23.04.2024	Pablo Bort Gómez (ETRA)	Modified short/long description and scope.	
0.2.1	26.04.2024	Jordi Granes (ANELL), Carles Rodríguez (ANELL)	Revision of the UC and contribution to scope, short and complete descriptions	
0.3	07.06.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Use case conditions and further information to the use case for classification	
0.4	19.06.2024	Jordi Granes (ANELL), Carles Rodríguez (ANELL)	Revision of the UC and contribution to use case conditions and further information to the use case for classification	
0.5	30.08.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Diagrams of use and technical details	
0.6	27.09.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Step-by-step analysis of the use case and information exchanged	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
Scope	This use case is aimed at resilience assessment by detailed modeling of the distribution network, real-time simulation using sensor data (SCADA) and N-1 contingency analysis by means of power flow optimization.
Objective(s)	The objective of this use case is to analyse the security and stability of the distribution networks under different scenarios and operating conditions, identifying bottlenecks and critical points in the system. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Related business case(s)	Smart coordinated planning of the distribution grid

1.4 Narrative of Use Case

<i>Narrative of use case</i>
Short description
ANELL's DT will perform simulation and optimization of power flow under normal conditions and will conduct N-1 contingency analyses. These analyses assess the network's ability to handle the failure of a list of single risk components without compromising the system, thus ensuring the integrity and resilience of the electrical network.
Complete description
This Use Case focuses on performing a security analysis for distribution networks. The Digital Twin has stored the grid topology and measurements for all the feeders compromised. It is necessary to know whether the grid is capable of supporting the generation and, above all, consumption loads at any time, preventing the grid from collapsing. First, an optimal power flow is performed over the grid under normal conditions to check the network stability. Then, using a list of critical elements of the network such as lines or transformers, among others, a simulation is started by disconnecting each critical element one by one, checking the stability of the network again without that element, by means of a power flow. Therefore, this use case will determine whether the network is N-1 contingent, in case all tests are passed successfully, or not contingent, in case one of the tests fails.

1.5 Key performance indicators (KPI)

<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
lb05-1	Critical elements identified	Number of identified elements that make the grid not to be N-1 contingent.	Relation to O8 and O9 as DT-enabled assessment of the grid

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	An initial contingency assessment of the whole grid wants to be performed by the DSO
2	Upon eventual modifications in the grid, the DSO aims at validating them in advance with the DT-based N-1 contingency assessment.
<i>Prerequisites</i>	
1	The digital Twin of ANELL's distribution network (ÉTER + Digsilent's Model of the grid) is fully deployed and integrated.
2	The DT is able to simulate all boundary conditions agreed for the full set of scenarios in which the contingency assessment of the grid is expected to be tested.

1.7 Further information to the use case for classification/mapping

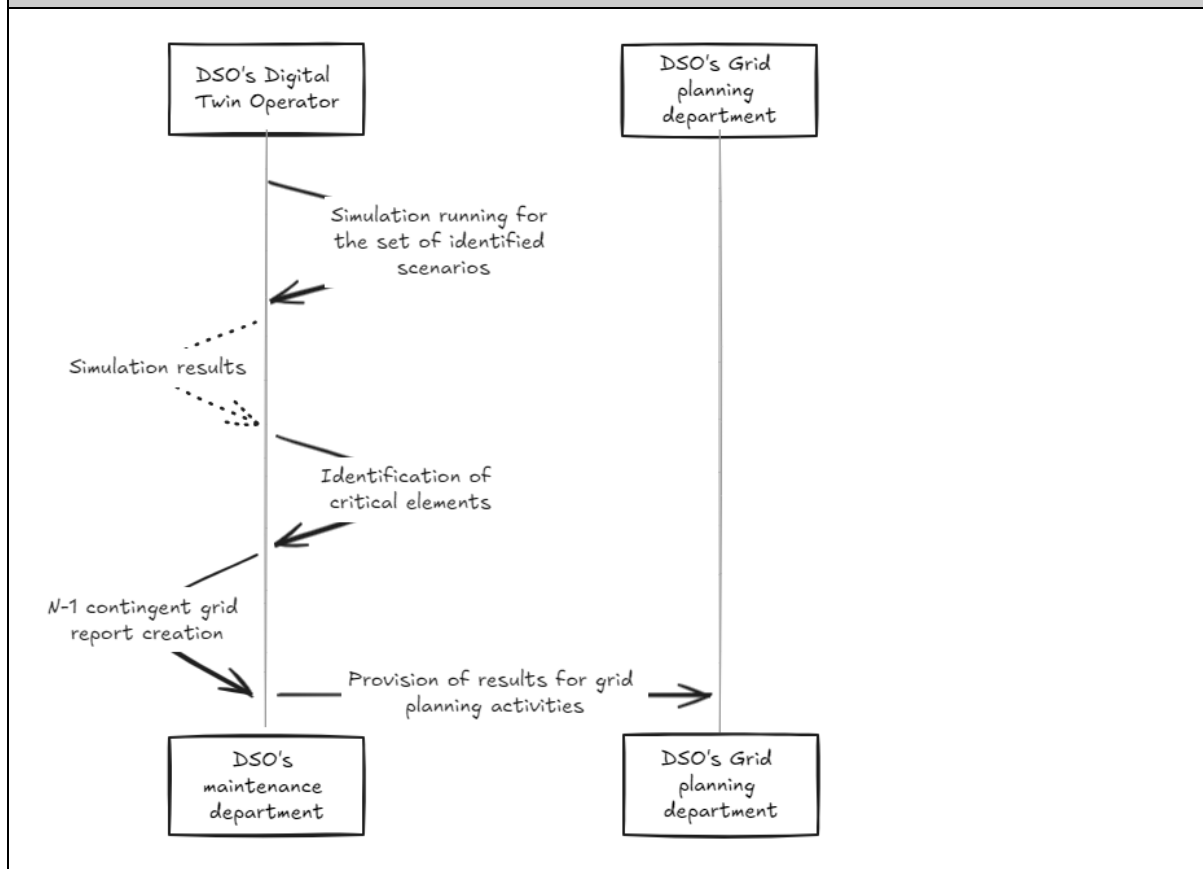
<i>Classification information</i>
<i>Relation to other use cases</i>
This use case is related to UC-Ib07 in terms of the services and algorithms used to run the demonstration case as well as its performance under different boundary conditions and scenarios.
<i>Level of depth</i>
<i>Prioritisation</i>
High
<i>Generic, regional or national relation</i>
Regional – DSO-level relation
<i>Nature of the use case</i>
Grid development and reinforcement planning
<i>Further keywords for classification</i>

1.8 General remarks

n.a.

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Roles within the DSO		The groups have been divided depending on the role that they will take in the demonstration of the UC	
Actor name	Actor type	Actor description	Further information specific to this business use case
DT operator		Could be the engineering department	Aimed at validating the N-1 contingent characteristic of the distribution grid
Grid planning department		Use of the results	Key input for further grid planning activities

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
Distribution		The groups have been created depending on the type of operated systems.	
System name	System owner	System description	Further information specific to this system use case
Electricity Distribution System	DSO	Electricity Distribution network connected to transmission upstream and to final consumers or prosumers downstream	The DSO's system includes the DT of the grid as well as information from the SCADA and all RTU and other HW deployed.
Consumers	Own	Mainly consumption points (read from smart metering data) and RES installations.	The forecasting modules within the DT will feed the twin with such data for simulation purposes.

3.3 References

n.a.

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Scenarios' simulation running	A set of defined scenarios by the DSO are simulated to analyse to what extend the grid is N-1 contingent or not.	DSO	Grid planning purposes	Unknown N-1 contingent characteristic of the grid	Ongoing process to understand N-1 contingent characteristic of the grid
2	Elements identification and report creation	The element that make the grid not N-1 contingent are identified and reported to the grid planning department for any further action	DSO	Grid planning purposes	Unknown N-1 contingent characteristic of the grid	Capacity to make information-based decision on grid planning
3	Improvement suggestion	The DT provides suggestions on grid improvement possibilities that ensure	DT (software developers)	Grid reliability improvement	Initial simulations having been performed	Capacity to test the suggested improvements

		the N-1 contingency is satisfied				
4	New scenario simulation	Simulations are performed on the DT to test if the improvements suggested in step 3 are really satisfying their intended purpose	DT (software developers)	Grid reliability improved	Suggestions having been defined by the DT software	Capacity to perform improvement actions on the grid

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1	Report on critical elements	A report highlighting the critical elements that make the grid not N-1 contingent is shared. The report is generated by the DOS's DT and is sent to the grid planning department with the complete set of results from the twinning simulation activities.	n.a.

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.6.6 DT-enabled new RES integration validated plan in the MV grid [Ib06]**1 Description of the use case****1.1 Name of use case**

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ib06	Distribution	DT-enabled new RES integration validated plan in the MV grid

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	25.04.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Scope, objective and complete	
0.2.1	26.04.2024	Jordi Granes (ANELL), Carles Rodríguez (ANELL)	Revision of the UC and contribution to scope, short and complete descriptions	
0.3	07.06.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Use case conditions and further information to the use case for classification	
0.4	19.06.2024	Jordi Granes (ANELL), Carles Rodríguez (ANELL)	Revision of the UC and contribution to use case conditions and further information to the use case for classification	
0.5	30.08.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Diagrams of use and technical details	
0.6	27.09.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Step-by-step analysis of the use case and information exchanged	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this UC is limited to grid planning purposes in the distribution network and, more specifically, in the medium voltage (MV) level, in the context of a large deployment of commercial and utility-scale renewable energy plants.
Objective(s)	The objective of this use case is leveraging the potential of the DT at distribution level to provide a pre-validation stage for connection points for renewable energy plants being requested in different nodes of the grid. This use case is contributing to: - O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains - O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Related business case(s)	Smart coordinated planning of the distribution grid

1.4 Narrative of Use Case

Narrative of use case
Short description
Collaboration between the DT of the distribution system and the DTs of the RES power plants for the integration assessment in different nodes of the grid. The result of the Use Case will be a viability assessment for further deployment of RES systems in critical areas of the grid, which will contribute to the grid planning activities.
Complete description
The deployment of new renewable energy power plants is achieving record values year after year. The high profitability of the investment and the facilitation by public authorities aiming at reaching the 2030 and 2050 climate targets are driving these records. In this context, new renewable power plant ranges from self-consumption installations, up to large plants with hundreds of megawatts of peak power. The electricity systems must be ready for such a wide range of power installations at all levels of the system. The distribution system is still behind the transmission systems in terms of grid planning for this new scenario. That has mainly to do with the fact that the distribution business is with a much more scattered in terms of ownership of the networks being operated by small, medium and large companies, from electric cooperatives to large multinational companies. TwinEU leverages the implementation of Digital Twins for the uptake, in terms of grid capacity planning, of distribution companies by analysing the impact that newly deployed commercial and utility-scale renewable power plants will have in their networks. The software tool that embeds ANELL's DT, ETRA's ÉTER, includes the generation of time series of data able to replicate the behaviour of a renewable power plant (focused on PV but different types could be considered if it is of interest) and simulates, supported on the grid models hosted by ANELL, the dynamic behaviour of the grid during a relevant period of time (period to be defined). During this simulation, the DT will analyse the evolution of the grid based on multiple input parameters and forecasts, identifying critical points and situations that may derive from such RES connections. Additionally, ÉTER enables the simulation of multiple combinations of scenarios of different power plants connected simultaneously, identifying the unfeasible combinations and their bottlenecks. The results of these analyses will be used by ANELL for grid planning purposes for the short, medium and long terms.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
lb17-1	Available RES power hosting capacity	This KPI measures the increased RES available power capacity that could be deployed along the grid thanks to the simulations implemented by the DSO's DT.	In relation to O8, this KPI measures the increased power enabled by leveraging data and DT-based simulations.

1.6 Use case conditions

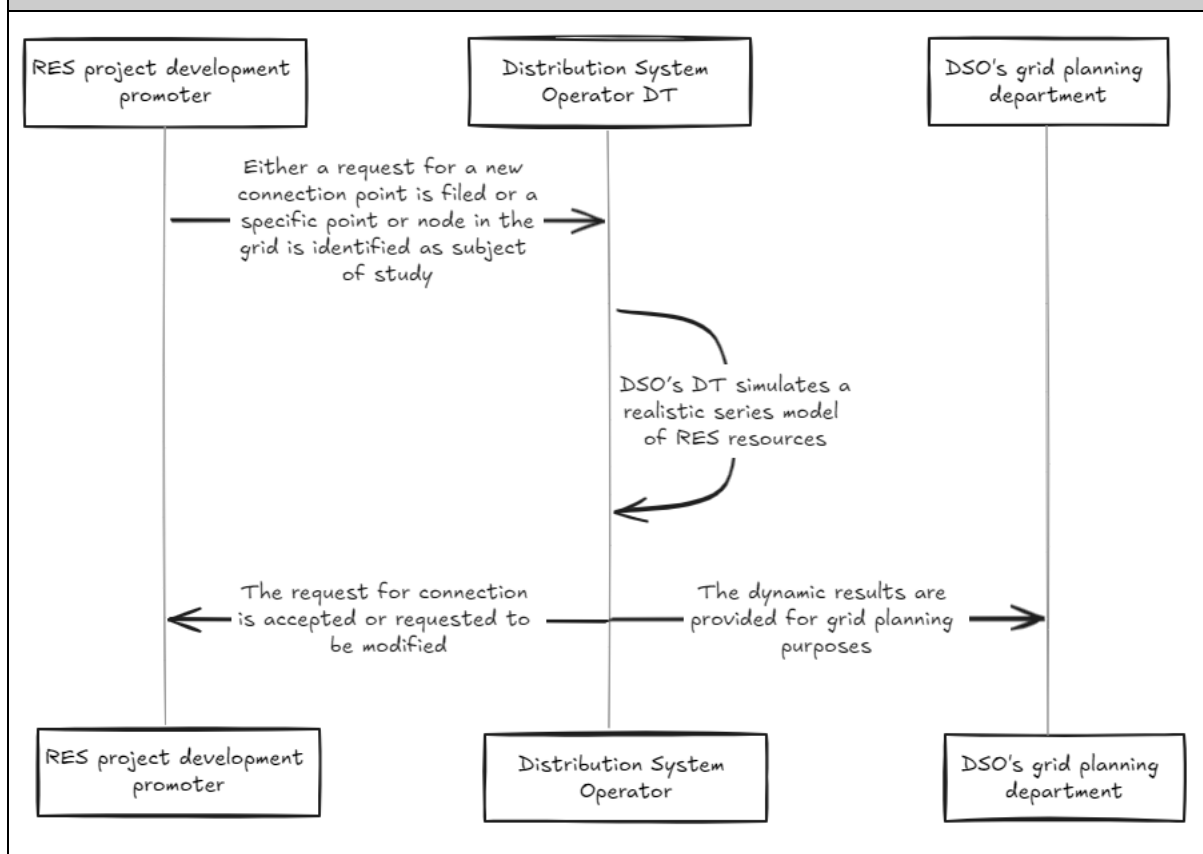
Use case conditions	
Assumptions	
1	A new connection point request is identified, or potential nodes want to be explored
2	Calculations consider hourly based data
Prerequisites	
1	The digital Twin of ANELL's distribution network (ÉTER + ANELL's Model of the grid) is fully deployed and integrated.

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
UC-lb17: DT-endorsed permanent connection grant through the settlement of a Local Flexibility Market to internally balance the production surplus in congestion-creation hours/scenarios.
Level of depth
Prioritisation
High
Generic, regional or national relation
Regional – DSO-level relation
Nature of the use case
Grid planning towards a wide deployment of RES power plants in the distribution level.

Further keywords for classification**1.8 General remarks**

n.a.

2 Diagrams of use case**Diagram(s) of use case****3 Technical details****3.1 Actors**

Actors			
Grouping (e.g. domains, zones)		Group description	
Zones of the Distribution System to be defined.		This use case is focused on the distribution level. The specific zones to be coordinated within the grid will later on be defined.	
Actor name	Actor type	Actor description	Further information specific to this business use case

Distribution System Operator (DSO)		Actor responsible for operating, maintaining and further developing the electricity distribution grid.	DSO operator will be responsible for the proper operation of the distribution grid and its DT.
Market Operator (MO)		Actor owning, operating maintaining and updating local flexibility markets	The MO operates and manages the services included in the LFMs

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
Role		The group have been created depending on the role they undertake during the UC demonstration	
System name	System owner	System description	Further information specific to this system use case
Electricity Distribution System	DSO	Electricity Distribution network connected to transmission upstream and to final consumers or prosumers downstream	The DSO's system includes the DT of the grid as well as information from the SCADA and all RTU and other HW deployed.
RES electricity generation systems	Market players	Mainly PV plants at commercial scale.	Renewable electricity generation plants.

3.3 References

n.a.

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1.1	Connection point request	Either a request for a new connection point is filed or a specific point or node in the DSO grid is identified as subject of study	DSO	Connection point request	Unknown capacity	Capacity in process to be known
1.2	Need to study a specific node by the DSO			Need to study a specific node by the DSO		
2	DT-based simulations	DSO's DT simulates a realistic series model of RES resources	DSO	Need to study a specific node by the DSO	Unknown capacity	Capacity in process to be known

3.1	Acceptance/rejection of the connection point request	The request for connection is accepted or requested to be modified	DSO	Connection point request	Unknown capacity	Known capacity
3.2	Information for grid planning purposes	The dynamic results are provided for grid planning purposes	DSO	Need to study a specific node by the DSO		

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
1	Gris status and topology	Actual grid data	n.a.
2	Generation and consumption forecasts	Simulation-based forecasting data	n.a.
3	New plants characteristics	Power characteristics and curves	n.a.

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.6.7 DT-based grid maintenance planning activities [Ib07]**1 Description of the use case****1.1 Name of use case**

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ib07	Distribution	DT-based grid maintenance planning activities

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	25.04.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Scope, objective and complete	
0.2.1	26.04.2024	Jordi Granes (ANELL), Carles Rodríguez (ANELL)	Revision of the UC and contribution to scope, short and complete descriptions	
0.3	07.06.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Use case conditions and further information to the use case for classification	
0.4	19.06.2024	Jordi Granes (ANELL), Carles Rodríguez (ANELL)	Revision of the UC and contribution to use case conditions and further information to the use case for classification	
0.5	02.09.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Diagrams of use and technical details	
0.6	27.09.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Step-by-step analysis of the use case and information exchanged	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this UC is limited to grid planning purposes in the distribution network in the context of planned maintenance works in different critical nodes or lines of the grid.
Objective(s)	The objective of this use case is to improve the maintenance works through the use of the DT for simulation purposes in a dynamic manner throughout the expected duration of the maintenance works. Additionally, the RT monitor system of the DT will ensure that the expected grid behaviour is actually happening during the works. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Related business case(s)	Smart coordinated planning of the distribution grid

1.4 Narrative of Use Case

Narrative of use case
Short description
The DT will run simulations for the planned maintenance activities by the DSO, having as an outcome the grid behaviour during these activities. Additionally, the real-time branch of the DT will constantly monitor in the grid and the performance of the execution during the service. The final aim is the validation of the service and/or the reinforced learning of the DT.
Complete description
The distribution business is gaining responsibilities from the classic power delivery from bulk generation to end-users towards managing highly complex systems with non-dispatchable generation units, flexible assets, conventional consumers and a rapidly changing environment with more and more RES power deployed each year and new business models currently being sand-tested such as local flexibility markets. This increase in complexity generates the need of higher visibility over the network and smoother planning when it comes to maintenance works that may jeopardise the normal power supply. Answering this need TwinEU leverages the implementation of Digital Twins in order to, first, plan the maintenance works in a way that optimises the security of supply to the maximum extent and then, validate in real-time that the forecasted grid evolution is indeed going as expected. For the planification of the maintenance works, the systems run the power flow and estate estimation algorithms to identify eventual issues that may arise in the network during the period of time in which the activity will be ongoing. This will allow the DSO to plan a schedule with minimum affection on the power supply. For the real-time operation, the algorithms are constantly receiving RT data to recalculate the values and verify the correct functioning of the system.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives

lb07-1	Accuracy in recalculated power flows	Diversion between the expected behaviour of the grid forecasted by the DT for the period of time in which the maintenance activities will take place.	This KPI related the UC with the real implementation (O8) in daily activities beyond planning.

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Maintenance activities (one or few) of the physical distribution network have to be performed or explored and the DSO wants to validate during the specific action that the grid responds as expected.
Prerequisites	
1	The digital Twin of ANELL's distribution network (ÉTER + Digsilent's Model of the grid) is fully deployed and integrated.
2	The DT received measurements from the grid in RT and is able to recalculate the power flows on the run, for a near-future scenario, modifying or adverting the DSO of any potential change .

1.7 Further information to the use case for classification/mapping

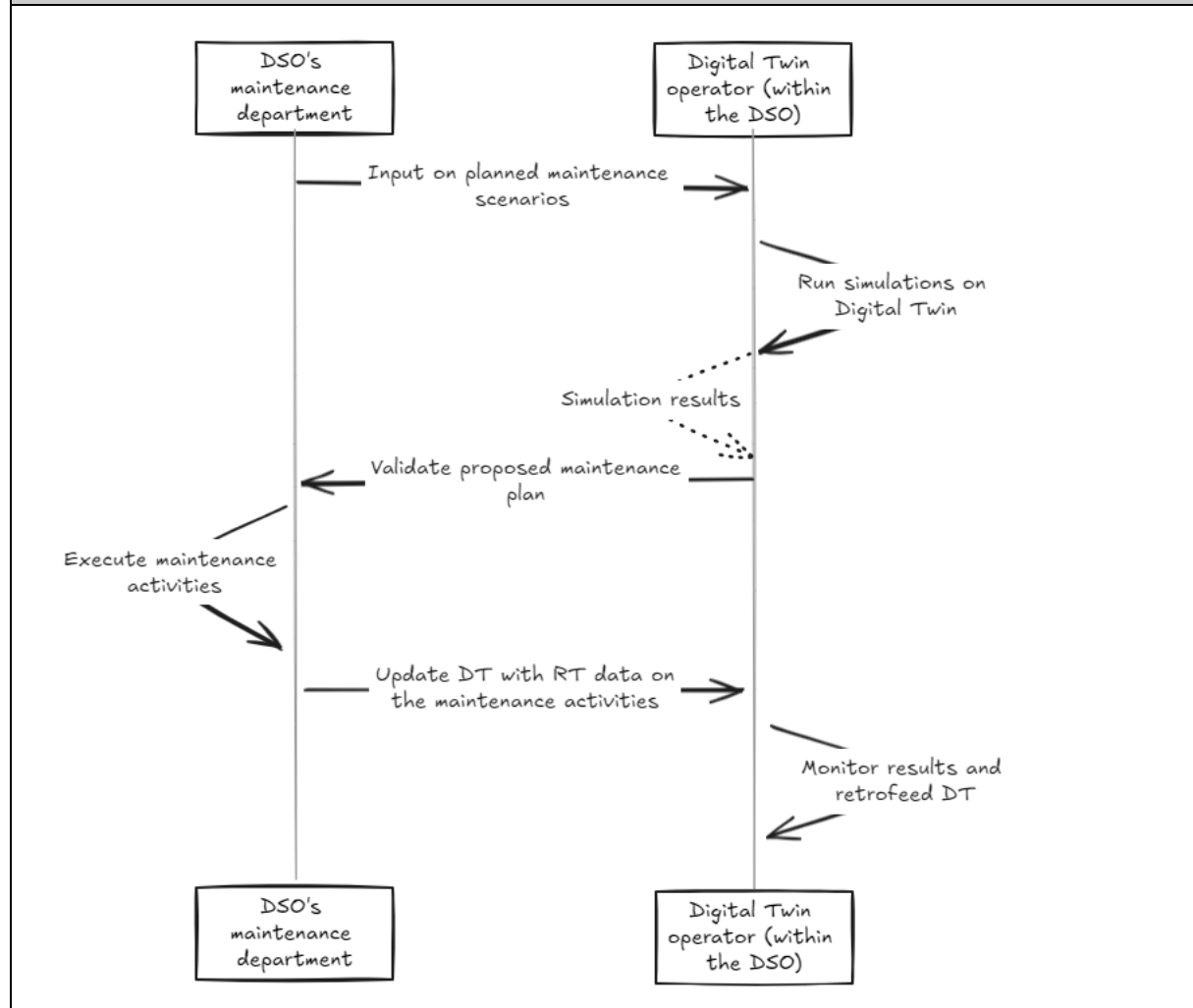
Classification information
Relation to other use cases
This use case is related to UC-lb05, with the specificity that the faulting element is designated by the works planned and the boundary and environmental conditions are determined by the moment in which this works are to be performed.
Level of depth
Prioritisation
High
Generic, regional or national relation
Regional – DSO-level relation
Nature of the use case
Maintenance activities planning
Further keywords for classification

1.8 General remarks

n.a.

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors	
Grouping (e.g. domains, zones)	Group description
Roles within the DSO	The groups have been divided depending on the role that they will take in the demonstration of the UC

Actor name	Actor type	Actor description	Further information specific to this business use case
Maintenance department		Propose maintenance activity	Inform the grid of eventual maintenance activities to be validated by the DT-based simulation
DT operator		Typically the control room	Aimed at RT verification of the maintenance activities impact in the grid and its deviation from what was projected by the DT.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
Distribution		The groups have been created depending on the type of operated systems.	
System name	System owner	System description	Further information specific to this system use case
Electricity Distribution System	DSO	Electricity Distribution network connected to transmission upstream and to final consumers or prosumers downstream	The DSO's system includes the DT of the grid as well as information from the SCADA and all RTU and other HW deployed.
Consumers	Own	Mainly consumption points (read from smart metering data) and RES installations.	The forecasting modules within the DT will feed the twin with such data for simulation purposes.

3.3 References

n.a.

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Maintenance planning	The DSO's department in charge of the maintenance activities aims at performing a series of maintenances activities, the viability of which must be validated by the suitability of the grid to hold the security of supply during such periods of time. Thus, the DSO's DT studies the grid	DSO	Maintenance activities planning	The grid needs a specific maintenance activity	The works are validated by the DT maintaining security of supply.

		capacity and reaction based on the expected boundary conditions.				
2	Maintenance action	During the maintenance, which might take some days or weeks in large cases, N-1 contingency analysis should be performed	DSO	Maintenance planning		

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
1	Information on the specific work to be undertaken	The DSO's department in charge of the maintenance activities send the requested unavailabilities in the grid to the DT for validation.	n.a.
2	Results of the simulation	The DSO's DT validates or requests a modification based on the result obtained on the scenarios simulation running.	n.a.

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.6.8 Long term flexibility in MV [Ib08]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib08	Distribution	Long term flexibility in MV

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.1	25.04.2024	Pablo Blázquez Martín (Cuerva)	Initial development of the UC	
0.1	25.04.2024	Manuel Reyes (ADAION)	Initial development of the UC	
0.2	04.06.2024	Pablo Blázquez (Cuerva)	Development of the UC	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Implement long term flexibility
Objective(s)	1. Identify the long-term flexibility needs (for planning and operation) to prevent congestion versus the conventional approach, investing in new assets (such as lines).
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description This use case aims to identify long-term flexibility requirements for both planning and operational phases to prevent grid congestions, traditionally addressed by investing in new assets such as lines. The actions focus on increasing consumption or decreasing generation as strategic measures to manage and balance the grid effectively.

Complete description	
This use case focuses on developing a comprehensive strategy to identify and implement long-term flexibility requirements essential for the efficient management of the electrical grid. The ultimate objective is to prevent congestion, a common challenge that can significantly impact the reliability and stability of power distribution networks. Traditionally, the approach to mitigating congestion has involved capital-intensive investments in new infrastructure, such as constructing additional transmission lines. However, this case explores alternative solutions that emphasize operational flexibility, specifically through mechanisms to increase consumption during periods of low demand or decrease generation when there is an excess supply. The cornerstone of this approach is a detailed analysis to understand the grid's existing capabilities and limitations, along with future demands that could strain the system. This analysis considers several factors, including the integration of renewable energy sources, which introduces variability in power generation, and the evolution of consumption patterns, possibly influenced by the widespread adoption of electric vehicles and smart appliances. Implementing strategies such as: DR, DER management, Forecasting, etc... requires a multi-faceted approach, combining technological innovation with regulatory support and stakeholder engagement. It involves not just technical solutions but also a shift towards more dynamic and responsive grid management practices. The anticipated outcomes of this use case include a more resilient grid capable of handling the challenges posed by modern energy demands and the transition to renewable energy. By prioritizing flexibility and efficiency, it is possible to mitigate congestion without the significant costs and environmental impacts associated with constructing new transmission lines. This approach not only ensures the reliability and sustainability of the power supply but also supports the broader goals of energy transition and decarbonization.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
	Overload reduction	Measure the number of times overloads are prevented in the outgoing lines of the substation or secondary-substation.	1
	Utilization of Flexible Resources	Evaluate the amount of flexible resources used compared to those available.	1
	Implementation Cost vs Savings	Compare the implementation cost of the flexibility solution with the savings in CAPEX and OPEX compared to the traditional solution.	1
	Availability and Reliability of Flexibility Service	Measure the number of hours flexibility services were available and reliable.	1

1.6 Use case conditions

Use case conditions	
Assumptions	
1	identified flexible resources are available and willing to participate in the flexibility scheme.

2	The existing infrastructure and technology are capable of supporting the monitoring and control required for flexibility activation.
Prerequisites	
1	Detailed planning of flexibility activation, including scheduling, monitoring, and response protocols.
2	Developing a financial model to ensure the long-term economic viability of the solution.

1.7 Further information to the use case for classification/mapping

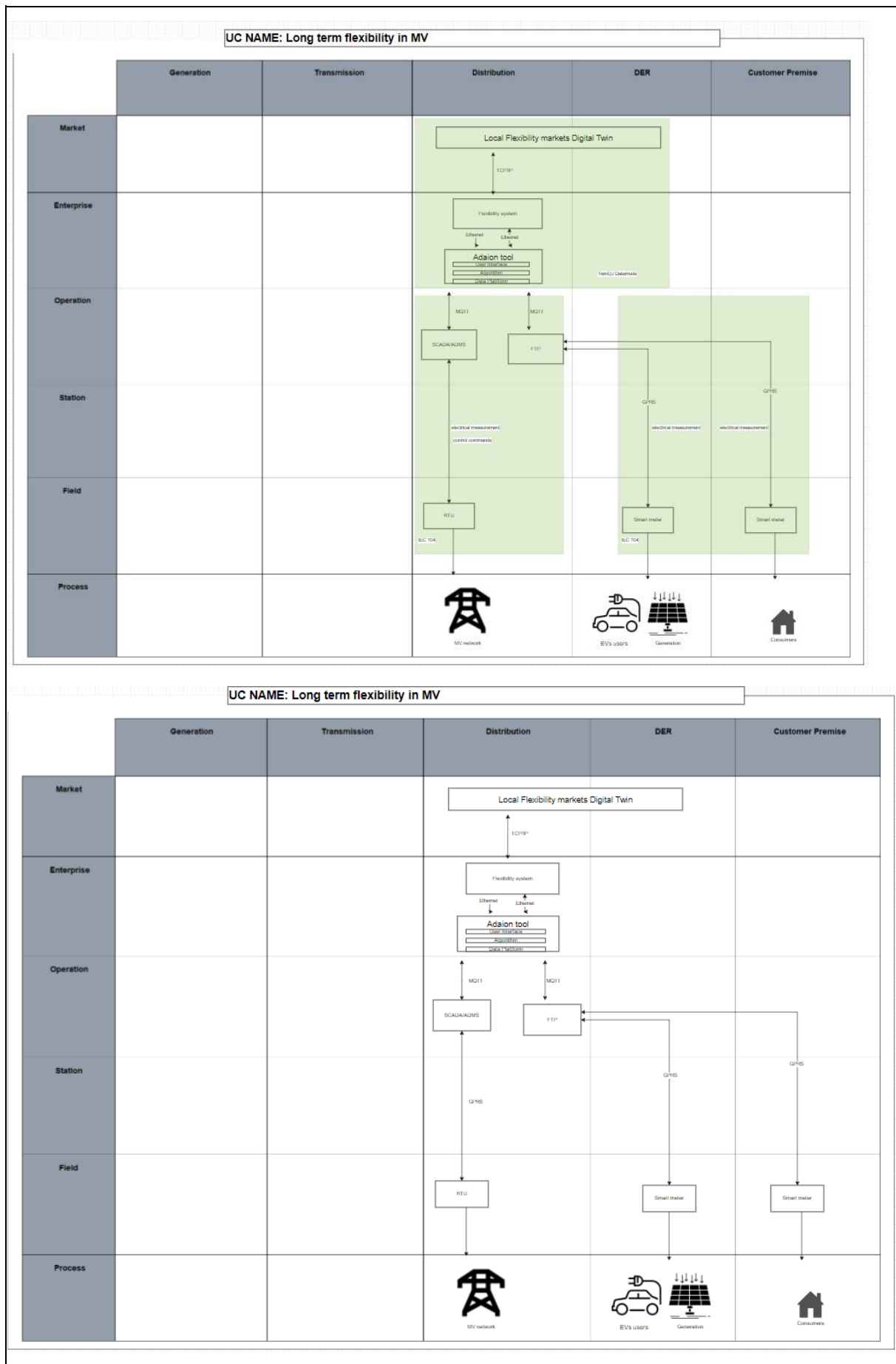
Classification information
Relation to other use cases
For this use case, it is necessary that the quality of the data and the model be as high as possible (use case 8)
Level of depth
MV and LV level
Prioritisation
Generic, regional or national relation
Regional relation
Nature of the use case
Technical & Economical
Further keywords for classification
#market #Flexibility

1.8 General remarks

Collaboration among stakeholders and advanced technology integration are essential for enhancing long-term flexibility and grid resilience in the MV system. Continuous monitoring will support future improvements and scalability.

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution	Cuerva	DSO	Local Distribution System Operator managing the network.
Technology Development	Adaion	Software Provider	Develops software solutions for predictive analytics.
Research	CIRCE	Research Provider	Focuses on energy resources and consumption research.
Market Operations	OMIE	Market Operator	Manages the Spanish electricity market dynamics.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Cuerva Distribution System	Cuerva	The network infrastructure managed by Cuerva for energy distribution.	Supports long-term flexibility and congestion management.
Adaion Tool	Adaion	Software system providing predictive analytics for energy management.	Enhances decision-making through data-driven insights.
Iberian Market System	OMIE	System managing the Spanish electricity market dynamics.	Critical for integrating flexibility solutions in the market.

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition

1	Flexibility Assessment	Assess flexibility needs for the distribution network to prevent congestion.	Cuerva	High demand forecast	Identified flexible resources available	Flexibility needs documented
2	Demand Response Trigger	Implement demand response strategies during peak load periods.	Cuerva	Peak load identified	Agreement from consumers to participate	Peak demand mitigated
3	Predictive Analysis	Use predictive analytics to forecast grid behaviour and optimize operations.	Adaion	Data input received	Availability of historical grid data	Adjusted operational strategies

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1	Load Forecast Data	Information on expected load demands over specified timeframes.	
ID2	Renewable Generation Profiles	Data regarding the predicted output of renewable energy sources.	
ID3	Flexibility Resource Status	Status updates on available flexibility resources ready for deployment.	
ID4	Market Price Signals	Information on current and forecasted market prices for electricity.	

6 Requirements (optional)

7 Common terms and definitions

- Digital Twin (DT): A digital replica of physical assets, systems, or processes that enables real-time monitoring and management.
- Flexibility Resource: Energy resources capable of adjusting their output or demand in response to market signals or grid conditions.
- Demand Response (DR): A strategy to manage customer consumption of electricity in response to supply conditions.
- Renewable Energy Sources: Sources of energy that are replenished naturally, such as solar, wind, and hydroelectric power.
- Market Operator: An organization responsible for managing and overseeing the electricity market transactions and operations.
- Grid Resilience: The ability of the electrical grid to withstand and recover from disturbances while maintaining reliable power supply.
- Scenario Analysis: A methodology used to assess potential future scenarios and their impacts on the grid and operations.

8 Custom information (optional)

B.6.9 Flex Connections [Ib09]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib09	Distribution	Flex Connections

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.1	25.04.2024	Pablo Blázquez Martín (Cuerva)	Initial development of the UC	
0.1	25.04.2024	Manuel Reyes (ADAION)	Initial development of the UC	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	
Objective(s)	1. Determine flexibility requirements (planning and operation) for EV Chargers for ensuring grid voltage quality. Traditional solution: Grid reinforcement and closed-ring operation Actions: increase consumption/decrease generation of the EV Chargers
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description This use case focuses on determining the flexibility requirements for Electric Vehicle (EV) Chargers in both the planning and operational phases to ensure grid voltage quality. Traditionally, maintaining voltage quality amidst the increasing load from EV chargers has been addressed through grid reinforcement and adopting closed-ring operation systems. However, this approach seeks to manage the load more dynamically by either increasing consumption or decreasing generation from EV chargers, as a more cost-effective and efficient alternative to traditional grid upgrades.

Complete description	
In the context of the rapidly growing adoption of electric vehicles (EVs), this use case addresses a critical aspect of energy management: ensuring grid voltage quality in the face of increasing demand from EV chargers. The traditional method of coping with this demand involves significant physical upgrades to the grid infrastructure, such as grid reinforcement and the implementation of closed-ring operation systems, to maintain stability and voltage quality. These methods, while effective, are capital-intensive and time-consuming, prompting the exploration of more dynamic, innovative solutions. The core of this use case is the strategic determination of flexibility requirements for EV chargers during both the planning and operational stages of grid management. Flexibility in this context refers to the ability to adapt the charging patterns of EVs—either by increasing consumption during periods of low demand and high renewable generation or by decreasing generation (or consumption) during peak demand times. This approach aims to balance the load more effectively, ensuring that voltage levels within the grid remain within optimal ranges without necessitating extensive physical upgrades. This dynamic approach to managing EV charging seeks to introduce a level of operational flexibility that traditional grid reinforcement measures cannot provide. By leveraging the inherent controllability of EV charging processes and integrating these with advanced grid management technologies, it is possible to ensure voltage quality and grid stability in a more cost-effective, efficient, and sustainable manner.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
	Voltage Quality Improvement	Measure the improvement in grid voltage quality due to the implementation of flexibility measures.	1
	Flexibility Utilization Rate	Assess the extent to which the flexibility of EV chargers is utilized to manage grid load.	1
	Load Balancing Efficiency	Measure the efficiency of load balancing achieved through the flexibility of EV chargers.	1
	Grid Stability	Assess the overall stability of the grid as a result of implementing flexibility measures.	1

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Sufficient EV chargers are available and capable of participating in the flexibility scheme.
2	Existing grid management technologies can integrate seamlessly with the control systems of EV chargers.
Prerequisites	
1	Detailed planning for flexibility activation, including scheduling, monitoring, and response protocols.

1.7 Further information to the use case for classification/mapping

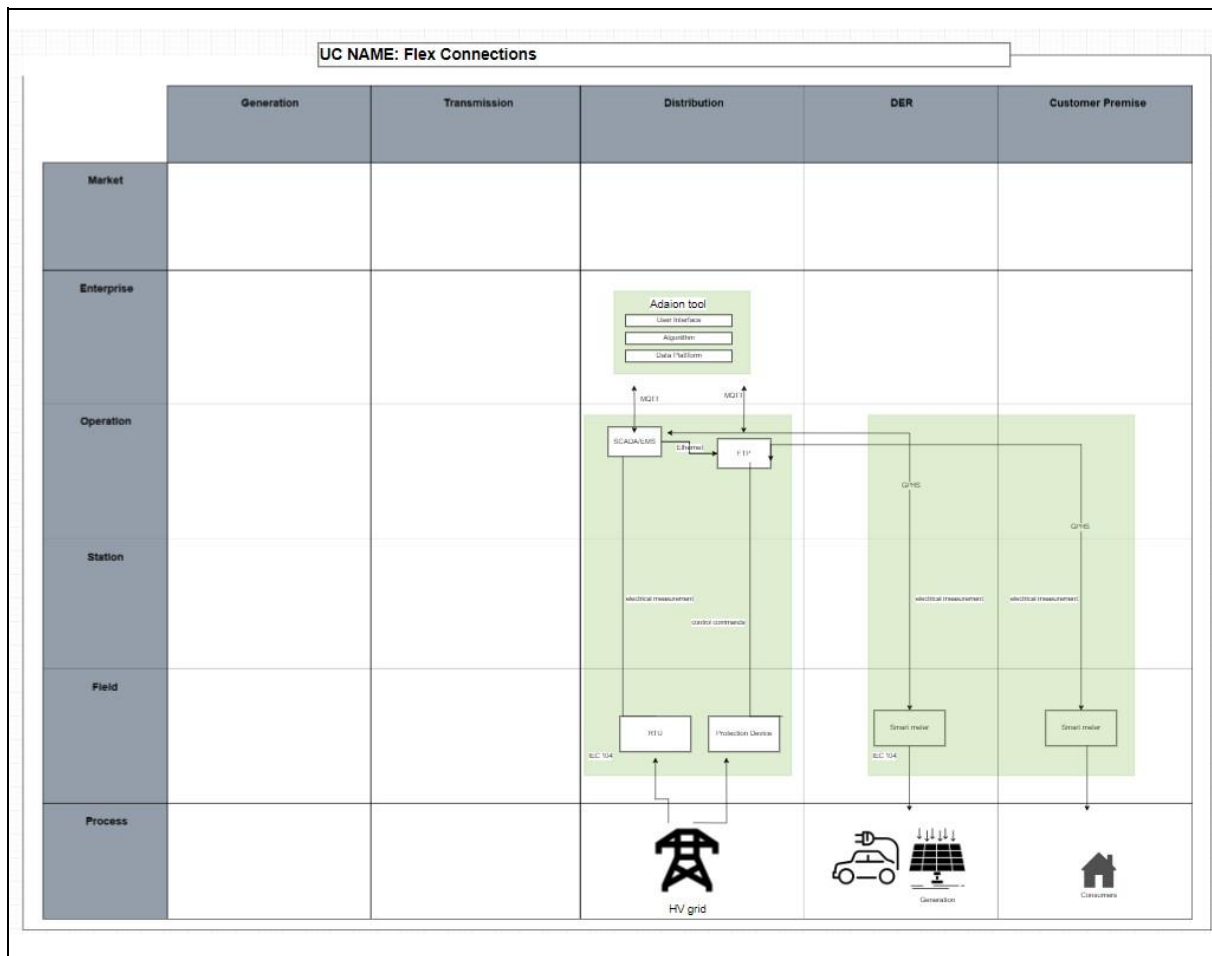
Classification information
Relation to other use cases
For this use case, it is necessary that the quality of the data and the model be as high as possible (use case Ib8 and Ib9)
Level of depth
MV and LV level
Prioritisation
Generic, regional or national relation
Regional relation
Nature of the use case
Technical & Economical
Further keywords for classification
#EV #Flexibility

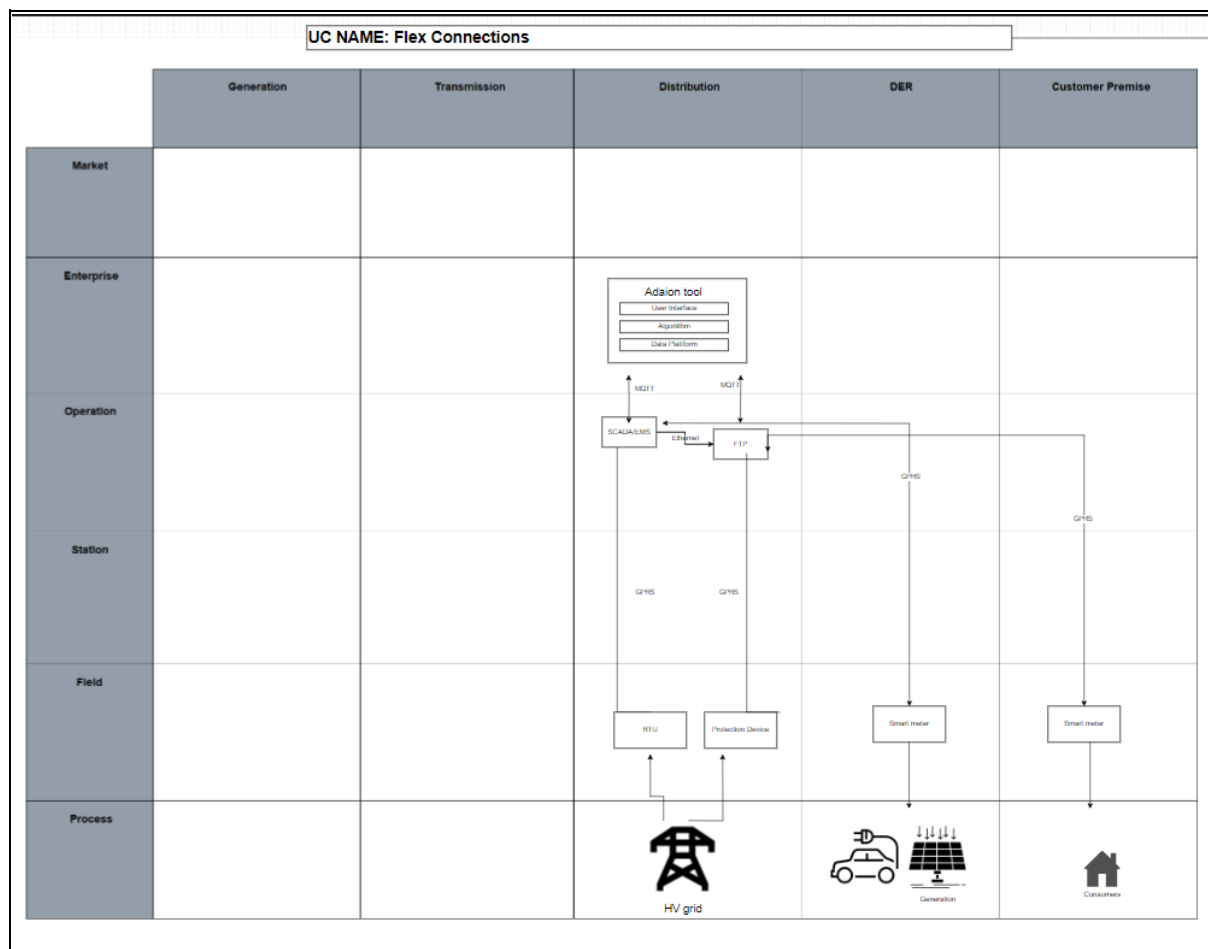
1.8 General remarks

Collaboration among stakeholders and effective integration of technologies are crucial for ensuring grid voltage quality through EV flexibility

2 Diagrams of use case

Diagram(s) of use case





3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Cuerva	DSO	Local Distribution System Operator managing the grid.	Engaged in implementing flexibility measures for EVs.
Adaion	Software Provider	Develops predictive analytics and management software for EVs.	Provides tools for optimizing EV charging strategies.
CIRCE	Research Provider	Focuses on energy resource management and research initiatives.	Supports research for flexible connections and grid stability.
OMIE	Market Operator	Manages market dynamics for electricity in Spain.	Essential for integrating EV flexibility into market operations.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Cuerva Distribution System	Cuerva	The network managed by Cuerva for flexible EV integration.	Supports long-term flexibility and voltage quality.
Adaion Predictive Analytics	Adaion	Software system providing predictive analytics for EV management.	Enhances decision-making through data-driven insights.

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Flexibility Assessment	Assess flexibility requirements for EV Chargers to ensure voltage quality.	Cuerva	High demand forecast	Identified EV chargers available	Flexibility needs documented
2	Demand Response Trigger	Implement demand response strategies to manage peak load.	Cuerva	Peak load identified	Agreement from consumers to participate	Peak demand mitigated

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1	Load Forecast Data	Expected load demands from EV chargers over specified timeframes.	
ID2	Charging Status	Current operational status of EV chargers participating in the flexibility scheme.	

6 Requirements (optional)

7 Common terms and definitions

- Flexibility Resource: Energy resources that can adjust their output or demand in response to grid conditions.
- Demand Response (DR): Strategies to manage consumer energy usage during peak load times.
- Voltage Quality: Measure of the effectiveness of the electricity supply in maintaining voltage levels within acceptable ranges.

8 Custom information (optional)

B.6.10 Probabilistic cross-border capacity allocation [Ib10]**1 Description of the use case****1.1 Name of use case**

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ib10	Transmission / cross-border	Probabilistic cross-border capacity allocation

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	05.05.2024	Gonçalo Glória (R&D NESTER)	Subsection 1.3 to 1.4	
0.3	18.06.2024	Kamalanathan Ganesan (R&D NESTER)	Subsection 1.5, 1.6 and 1.7	
0.4	11.10.2024	Kamalanathan Ganesan (R&D NESTER)	Sections 2, 3 4 and 5	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
Scope	Probabilistic cross-border capacity computation based on Available Transfer Capacity (ATC) methodology, allowing the assessment and definition ex ante of the expected maximum capacity between adjacent bidding zones (in the case of this pilot, between Portugal and Spain)
Objective(s)	• Provide an approach to calculating the amount of electricity that can be safely traded across borders that naturally incorporates uncertainty • Congestion Management to prevent overload on the transmission system. It acts as a safeguard to ensure security of supply. • To contribute to the coordinated transmission capacity allocation with tools better adapted to weather-dependent generation uncertainty to manage risks associated with cross-border trading.
Related business case(s)	

1.4 Narrative of Use Case

<i>Narrative of use case</i>

Short description	
Leveraging the integrated Iberian DT continuum, a data-driven robust optimisation approach will be applied in order to compute the ATC for the day-ahead and intraday market, drawing probabilistic scenarios of Variable Renewable Energy (VRE) generation and grid contingencies to optimize strategies using the DT and compare with business as usual.	
Complete description	
In relation to the day-ahead and intraday markets, the congestion management mechanism plays a crucial role in preventing congestion in the interconnections. This mechanism is primarily supported by the capacity allocation methodologies, which ensure efficient utilization of the available transmission capacity. A Capacity Calculation Methodology is a systematic approach used to determine the available capacity between different bidding zones. The calculation methodologies specified by the regulation provide guidelines for this process. It's important to highlight that while regulation outlines requirements for flow-based and coordinated net transmission capacity (ATC – available transfer capacity) approaches, they do not prescribe the exact process or algorithm to be used. Instead, it's the responsibility of the Transmission System Operators (TSOs) within each common calculation region to propose a unified capacity calculation methodology based on these regulations. The ATC, or sometimes also referred to NTC, methodology is used in South West Europe System Operation Region (SWE SOR). In the ATC methodology, TSOs determine a net transfer capacity (NTC) for each direction at the border of their control area. This determination is based on historical data from a reference day and considers factors such as potential loop flows, seasonal variations, and a justified security margin. The NTC values represent the maximum allowed commercial exchanges that can be accommodated without exceeding the maximum physical flow of critical network elements. These values are established through agreement among the relevant TSOs. By subtracting the already allocated capacity (AAC) from the NTC, the ATC values are derived. The goal of this UC is to add probabilistic scenarios on top of the typical ATC and propose an optimisation method that maximizes the ATC considering the uncertainty arising from forecasting errors. In probabilistic ATC calculation, historical data, such as load profiles, generation patterns, and weather conditions, are analyzed to develop probabilistic scenarios of system behaviour. These capture the inherent uncertainty associated with factors like demand fluctuations, renewable energy generation variability, and equipment outages. This way, TSOs can simulate a wide range of possible scenarios to assess the probability distribution of transfer capability under different conditions. By considering multiple scenarios and their associated probabilities, it is deemed that probabilistic ATC calculation provides a more comprehensive and realistic assessment of cross-border transfer capacity, aligned with the probabilistic risk assessment of the system security. This approach allows TSOs to better understand the reliability and robustness of the grid under varying conditions, helping to identify the probability of potential constraints and vulnerabilities. Additionally, probabilistic ATC calculation enables TSOs to trade-off the risk of overload critical network elements with the ATC, making more informed decisions in the system operational planning, ultimately allowing the use of the grid according to risk.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
lb10-1	% of total Cross-border capacity utilization	This KPI measures the percentage of total available transmission capacity that is actually used. Helps to evaluate whether the allocated capacity is being effectively utilized by market participants. This will inform about the margins between the ATC ¹ estimated by the probabilistic method and the real historic flows in the interconnection.	

lb10-2	% of cross-border Capacity Adequacy Probability	This KPI measures the reliability of the calculated cross-border capacity under various probabilistic scenarios. It indicates that the available capacity will meet or exceed the required capacity when dealing with uncertainties in demand, generation and network conditions.	3
lb10-3	Grid Security Improvement Index (%)	This KPI evaluates the overall security of the grid by integrating multiple critical parameters such as voltage levels, phase angles and loading of critical network elements (CNEs). It provides a view of the ability to keep the grid's operational security with the probabilistic ATC calculation.	2

1.6 Use case conditions

Use case conditions	
Assumptions	
1	All input data regarding generation, demand, network status is accurate and timestamped (synchronized between the PT and ES control areas).
2	A clear regulatory framework governing cross-border capacity allocation, including rules for market operation.
Prerequisites	
1	System operators have access to historical data.
2	Up-to-date Common Grid Model (CGM) available to all parties.
3	Individual Grid Digital Twin (IGDT) system supporting the coordinated transmission capacity calculation in each control area

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Level of depth
System Use Case
Prioritisation
High
Generic, regional or national relation

Generic
Nature of the use case
Further keywords for classification
Probabilistic load flow, Available transfer capability, Capacity allocation methodology

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case

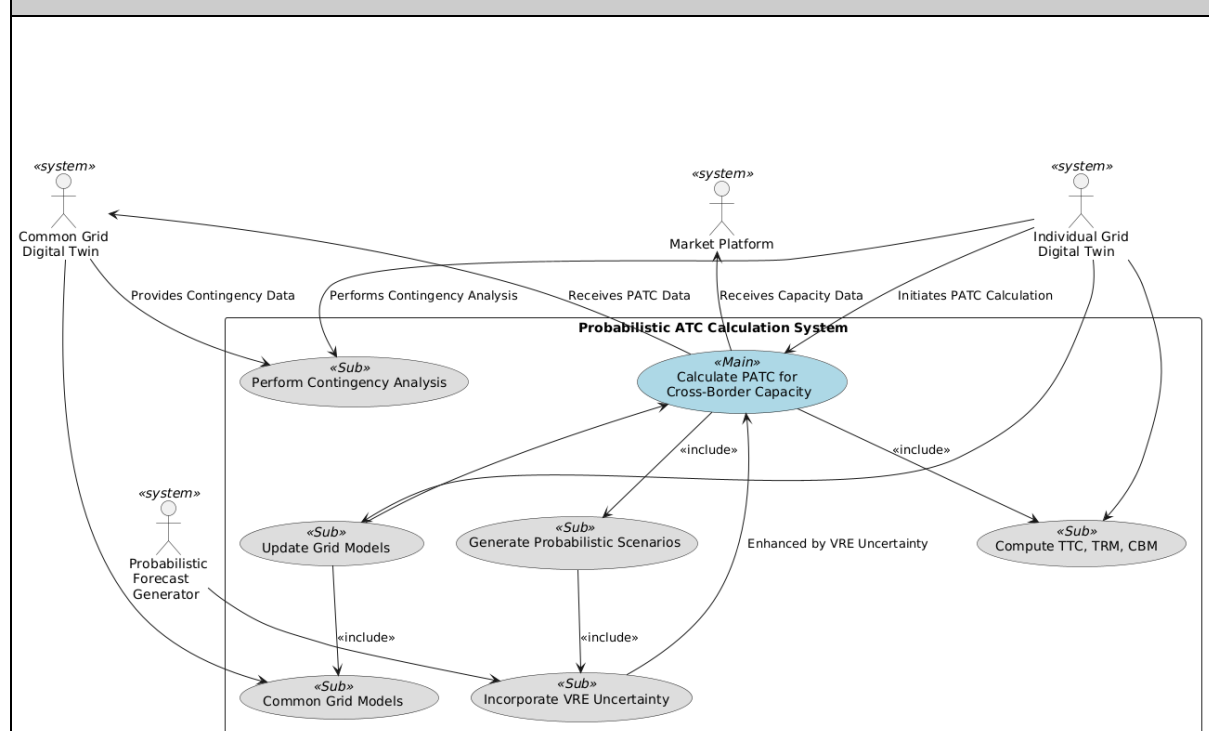
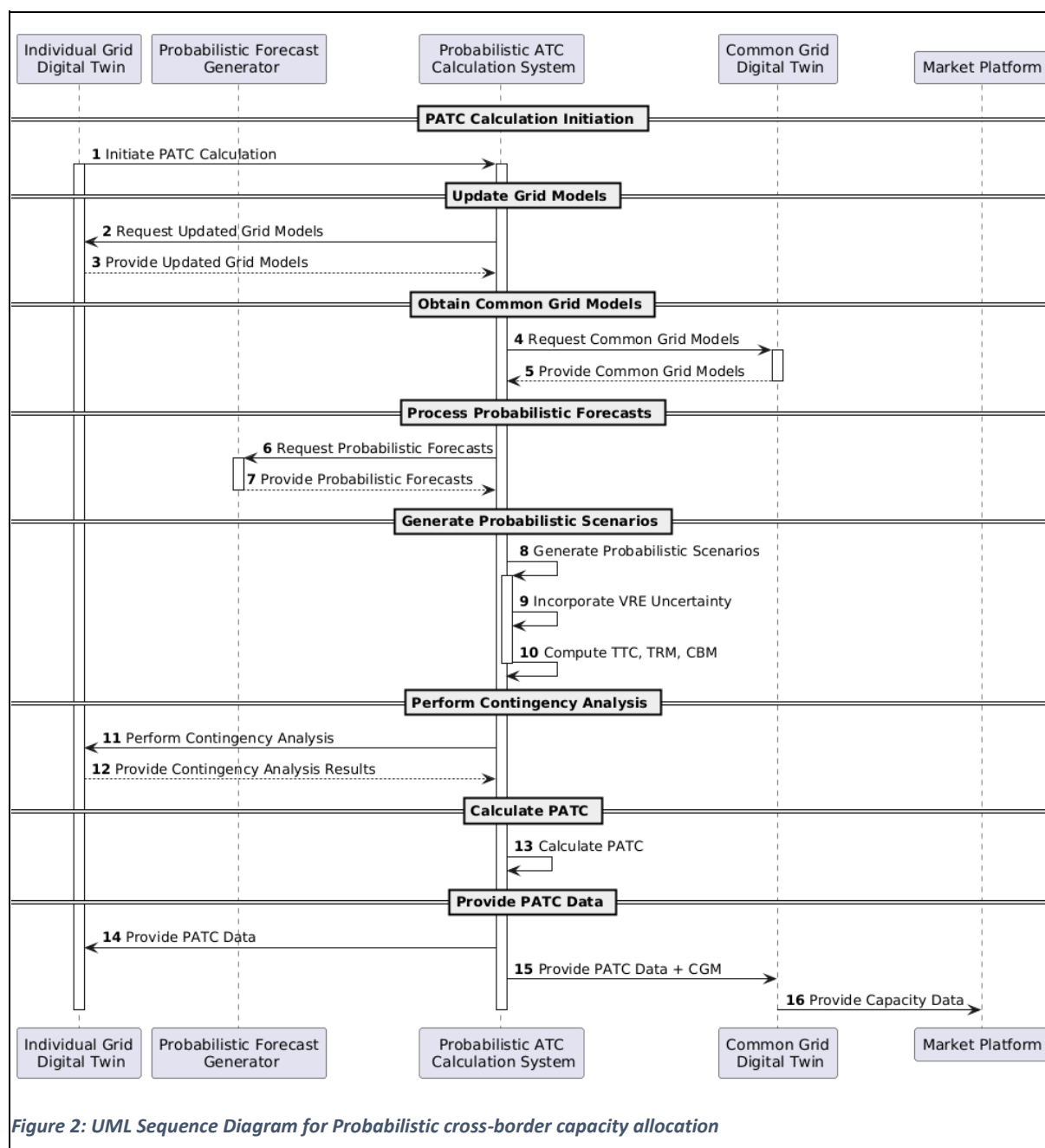


Figure 1: UML use-case diagram for Probabilistic cross-border capacity allocation



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Individual Grid Digital Twin	Digital Twin	System supporting the coordinated transmission capacity calculation in each control area	- Initiate the ATC calculation process. - Perform contingency analysis.

			- Select remedial actions. - Coordinate with other actors. - Provides probabilistic scenarios to CGDT
Probabilistic forecast generator of VRE generation and demand (PFG)	Data Provider	Entity that provides probabilistic forecast data necessary for modelling Variable Renewable Energy (VRE) generation and demand uncertainties.	Supplies probabilistic forecasting data to the PCCS to incorporate VRE and demand uncertainty into probabilistic scenarios.
Market Platform	Digital Twin	Responsible for managing electricity market operations, including capacity allocation and market clearing processes.	Receives capacity data (ATC) for market operations in the day-ahead and intraday markets.
Common Grid Digital Twin (CGDT)	Digital Twin	A Regional Security Coordinator that facilitates coordination between TSOs by providing coordinated grid models and contingency data.	- Implements regional DT and performs contingency analysis, providing regional contingency data to the PCCS. - Assists in ensuring grid security and reliability.
Probabilistic ATC Calculation (PCCS)	ATC Calculation module	A system that calculates the Available Transfer Capacity (ATC) using a probabilistic approach, incorporating VRE uncertainty and grid contingencies to optimize cross-border capacity.	- Computes the Probabilistic TTC (and the other ones we've talked about) - Communicates ATC results to other actors.

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	PATC Calculation in	Calculation of Probabilistic Available Transfer Capacity (PATC) during the operational	Individual Grid Digital Twin (IGDT)	IGDT initiates PATC calculation	- Grid models and probabilistic	- PATC is calculated and

	Operational Planning	planning phase , involving grid model updates, probabilistic forecasts, and contingency analysis		request to PCCS	to forecasts available	are provided to CGDT and MP.
					- All systems are operational - Communication channels are functioning	- Updated grid models are shared. - Systems return to standby mode ready for the next planning cycle

4.2 Steps - Scenarios

Scenario								
Scenario name:		ATC Calculation						
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information Exchanged (IDs)	Requirement, R-IDs
1	IGDT initiates PATC calculation	Initiate PATC Calculation	IGDT requests PCCS to start the PATC calculation process.	PATC Calculation Initiation	Individual Grid Digital Twin (IGDT)	Probabilistic ATC Calculation System (PCCS)	IE1 - PATC Calculation Request	
2	PCCS requests updated grid models	Update Grid Models	PCCS requests updated grid models from IGDT.	Grid Model Update	PCCS	IGDT	IE2 - Updated Grid Models	
3	IGDT provides updated grid models	Provide Updated Grid Models	IGDT provides updated grid models to PCCS.	Grid Model Provision	IGDT	PCCS	IE2 - Updated Grid Models	
4	PCCS requests common grid models	Obtain Common Grid Models	PCCS requests common grid models from CGDT.	Common Grid Model Request	PCCS	Common Grid Digital Twin (CGDT)	IE3 - Common Grid Model	
5	CGDT provides common grid models	Provide Common Grid Models	CGDT provides common grid models to PCCS.	Common Grid Model Provision	CGDT	PCCS	IE3 - Common Grid Model	
6	PCCS	Process	PCCS requests	Probabilistic	PCCS	Probabilistic	IE4 -	

	requests probabilistic forecasts	Probabilistic Forecasts	probabilistic forecasts from PFG.	c Forecast Processing		stic Forecast Generator (PFG)	Probabilistic Forecast	
7	PFG provides probabilistic forecasts	Provide Probabilistic Forecasts	PFG provides probabilistic forecasts to PCCS.	Probabilistic Forecast Provision	PFG	PCCS	IE4 - Probabilistic Forecast	
8	PCCS generates probabilistic scenarios	Generate Probabilistic Scenarios	PCCS generates probabilistic scenarios incorporating VRE uncertainty	Scenario Generation and Capacity Margin Calculation	PCCS	PCCS (Internal Process)	IE5 - Probabilistic Scenarios and Capacity Margins	
9	PCCS incorporate VRE generation and demand uncertainties	Generate Probabilistic Scenarios including VRE and demand uncertainty	PCCS generates probabilistic scenarios incorporating VRE uncertainty	Scenario Generation and Capacity Margin Calculation	PCCS	PCCS (Internal Process)	IE5 - Probabilistic Scenarios and Capacity Margins	
10	Computes TTC, TRM and CBM	Computes TTC, TRM and CBM	Using the scenarios and uncertainties, PCCS Computes TTC, TRM and CBM	Capacity Margin Calculation	PCCS	PCCS	IE5 - Probabilistic Scenarios and Capacity Margins	
11	PCCS requests contingency analysis	Perform Contingency Analysis	PCCS requests IGDT to perform contingency analysis.	Contingency Analysis Request	PCCS	IGDT	IE6 - Contingency Analysis	
12	IGDT provides contingency analysis results	Provide Contingency Analysis Results	IGDT provides contingency analysis results to PCCS.	Contingency Analysis Provision	IGDT	PCCS	IE7 - Contingency Notification	
13	PCCS calculates PATC	Calculate PATC	PCCS calculates the PATC using models, forecasts, scenarios, and contingency analysis results.	PATC Calculation	PCCS	PCCS (Internal Process)	IE8 - Calculated PATC	
14	PCCS provides	Provide PATC Data	PCCS sends calculated PATC	PATC Data Provision	PCCS	IGDT	IE10 - PATC Data	

	PATC data		data to IGDT					
15	PCCS provides PATC data	Provide PATC Data	PCCS sends calculated PATC data + CGM to CGDT	PATC Data Provision	PCCS	CGDT	IE9 - Grid Model and Probabilistic ATC Data	
16	CGDT provides capacity data	Capacity data	CGDT sends capacity data to Market Platform	Capacity Data	CGDT	Market Platform	IE11 - Capacity Data to Market Platform	

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
IE1	PATC Calculation Request	IGDT request the Probabilistic ATC Calculation System (PCCS) to initiate the calculation of Available Transfer Capacity (ATC) using a probabilistic approach.	
IE2	Grid Model Update	PCCS requests updated grid models from IGDT to ensure that the latest network configurations and planned outages are included in the calculation. Including network topology, equipment statuses, and planned maintenance schedules relevant to the planning horizon.	
IE3	Common Grid Models (CGMs)	CGDT provides the CGMs, which are aggregated grid models combining Individual Grid Models (IGMs) from different IGDTs to ensure a consistent regional network model.	
IE4	Probabilistic Forecast	PCCS requests probabilistic forecasts from the Probabilistic Forecast Generator (PFG) to account for uncertainties in Variable Renewable Energy (VRE) generation and associated uncertainties based on weather predictions and historical data, during the planning period.	
IE5	Probabilistic Scenarios and Capacity Margins	PCCS internally generates probabilistic scenarios and computes capacity margins (TTC, TRM, CBM) by incorporating VRE uncertainties and grid models. (Note: This is an internal process within PCCS.)	
IE6	Contingency Analysis	PCCS requests IGDT to perform contingency analysis to assess the grid's ability to handle potential component failures or outages during the planning period.	
IE7	Contingency Notification	IGDT provides contingency analysis results to PCCS, highlighting potential vulnerabilities and network limitations under various failure scenarios (e.g., N-1 conditions).	
IE8	PATC Calculation	PCCS estimates the Probabilistic ATC (PATC) calculation based on the collected data, probabilistic scenarios, and contingency analysis results. (Note: This is an internal output of PCCS.)	

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
IE9	Grid Model and Probabilistic ATC Data	PCCS provides the calculated PATC data to the Common Grid Digital Twin (CGDT) and the Market Platform (MP) for further coordination and dissemination to market participants.	
IE10	PATC Communication to IGDT	PCCS communicates the calculated PATC to IGDT, ensuring they are informed of the accepted available transfer capacities for operational planning and coordination.	
IE11	Capacity Data to Market Platform	CGDT sends capacity data, including ATC values, to the Market Operator (OMIE) to facilitate capacity allocation in the electricity market.	

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.6.11 Cross-border assessment of flexibility and pre-qualification [Ib11]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib11	Transmission / cross-border	Cross-border assessment of flexibility and pre-qualification

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	05.05.2024	Gonalo Gl3ria (R&D NESTER)	Subsection 1.3 to 1.4	
0.3	04.06.2024	Gonalo Gl3ria (R&D NESTER)	Subsection 1.5 to 1.8	
0.5	30.10.2024	Gonalo Gl3ria (R&D NESTER)	Redefinition of the UC scope and completion of the UC template	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Enabling coordination among System Operators (SOs) and Flexibility Service Providers (FSPs) regarding the capability of cross-border flexibility products, namely fast frequency reserves in the Iberian region.
Objective(s)	- Design and test the prequalification process phase between neighbour SOs; - Exchange (cross-border) information for the Grid and Product prequalification through the DTs. - Facilitate the entry of FSPs into the various flexibility markets cross-border, namely for a new Fast Frequency Reserve (FFR) market.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of use case
Short description

Create a demo that test the scenario in which one FSP can be prequalified to provide flexibility to another SO, in which the FSP has no direct connection to, namely for a new FFR product. An FSP connected to one SO can be prequalified to a neighbouring SO. With the digital twin this UC could be tested between PT-ES.

Complete description

The prequalification phase plays a critical role in ensuring the smooth functioning of flexibility markets. It guarantees that FSPs can deliver their services without negatively impacting the involved grids. Regarding the forecast phase for the SOs it facilitates the assessment of the potential flexibility available from the neighbour SO grids.

The Active System Management (ASM) report emphasizes two crucial prequalification processes:

- **Product Prequalification:** This assesses the FSP's ability to meet the general requirements set by the SOs for the specific flexibility product they offer. This ensures the product functions as intended and delivers the desired service.
- **Grid Prequalification:** This verifies whether the grid can manage the delivery of the flexibility product without causing instability or congestion. This assessment helps maintain grid security and reliability.

Both prequalification processes are subject to regular reviews and updates, especially when the FSP's technical characteristics or the connected grid undergo significant changes.

The FFR is a key mechanism for stabilizing power systems, particularly in low-inertia scenarios, which are increasingly common due to the integration of renewable energy sources. Inertia in an electricity system is essentially the system's ability, due to the kinetic energy stored in rotating masses, to counterbalance sudden frequency changes. In systems with declining inertia, like those with high penetration of renewable energy, the risk of rapid frequency drops increases when a major disturbance, such as the loss of a large electricity production unit or an HVDC interconnection, occurs. For this reason, maintaining a frequency above 49.0 Hz in all scenarios is critical.

The Iberian Pilot aims to demonstrate how FFR can be effectively utilized in such low-inertia situations, providing rapid frequency response to help stabilize the system. The response from FFR depends on three main factors: the magnitude of the disturbance, the system's inertia at the time, and the speed of reserve activation. Hence, the volume of FFR needed at any given moment depends on the system's prevailing inertia and the size of the largest expected incident.

Inspired by Nordic best practices, the Iberian Pilot is structured to explore an Iberian market for FFR procurement. In this model, FSPs or Balancing Service Providers (BSPs) would undergo a prequalification process to confirm that Reserve Units meet technical requirements. An autonomous response from the units is crucial for quick, localized adjustments in the event of frequency disturbances.

Technical compliance involves prequalification tests, validating the reserve units' capability to respond promptly and effectively when the system frequency dips below a predefined threshold. The full activation of reserve power is required within a specific timeframe, typically a few seconds, depending on the severity of the disturbance.

In this UC the idea is to have an Iberian market in which a periodic forecast for FFR procurement needs will be made available, allowing FSPs and BSPs to align their operations and plan for potential market opportunities. Procurement of FFR will occur on a national hourly market, where BSPs submit bids for reserve capacity the evening before the operational day.

By implementing this Iberian Pilot for FFR, the initiative provides valuable insights into market design and technical requirements tailored to systems with variable inertia levels upon major disturbances in Europe electrical system. This pilot is poised to offer recommendations for enhancing grid stability recurring to FFR focusing on the forecast needs and prequalification. Additionally, it fosters a cross-border market environment that incentivizes FSPs and BSPs to develop reserve units capable of rapid, automated responses to frequency changes, ultimately contributing to a more secure, resilient, and renewable-integrated electricity system. This approach not only builds upon the Nordic model but also tailors it to the unique characteristics and inertia variations of the Iberian Peninsula. By testing and refining this model, the pilot aims to establish a robust framework for FFR procurement that could be expanded throughout other low-inertia regions, supporting a sustainable energy future across the Iberian grid.

By implementing the UC the idea is to have:

- Streamlined procedures minimize complexity and effort for both FSPs and SOs, regarding FFR.
- Increased participation by lowering entry barriers that encourages broader participation, leading to a more robust and competitive flexibility market (FFR mainly).
- Standardized processes facilitate smoother cross-border participation, allowing FSPs to operate seamlessly in FFR market.
- Tuned Digital Twins regarding grid models and communication framework, in order to facilitate the coordination between the involved parties (SOs and FSP, if applicable)
- Increased the SOs FSP portfolios.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
lb11-1	Available flexibility	This indicator measures the flexible power that can be used for FFR at a specific grid segment, i.e., the available power flexibility in a defined period (e.g., per day) that can be allocated by the SO at a specific grid area. It relates to the total amount of power in the specific grid area in the same period.	
lb11-2	Percentage of successfully prequalified FSPs	This indicator calculates the percentage of FSPs in the demo that are successfully prequalified, against the number of FSPs available in the grid area under analysis.	
lb11-3	Volume of flexibility by prequalified units	This indicator measures the volume of prequalified flexibility.	
lb11-4	Number of implemented cross border products	This indicator measures the number of implemented products that can be traded in more than one country (cross border products). This KPI is valid for UCs that aim to harmonize the definition and process of flexibility products among SOs in different countries.	
lb11-5	Curtailement avoidance	This indicator measures the amount of power that is not curtailed by the usage of cross-border flexibility.	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Prequalification to be taken at unit level, aggregated or portfolio level if technically feasible
2	There are aggregators/FSPs/BSPs, with resources located in different countries, which want to participate in cross-border flexibility markets.

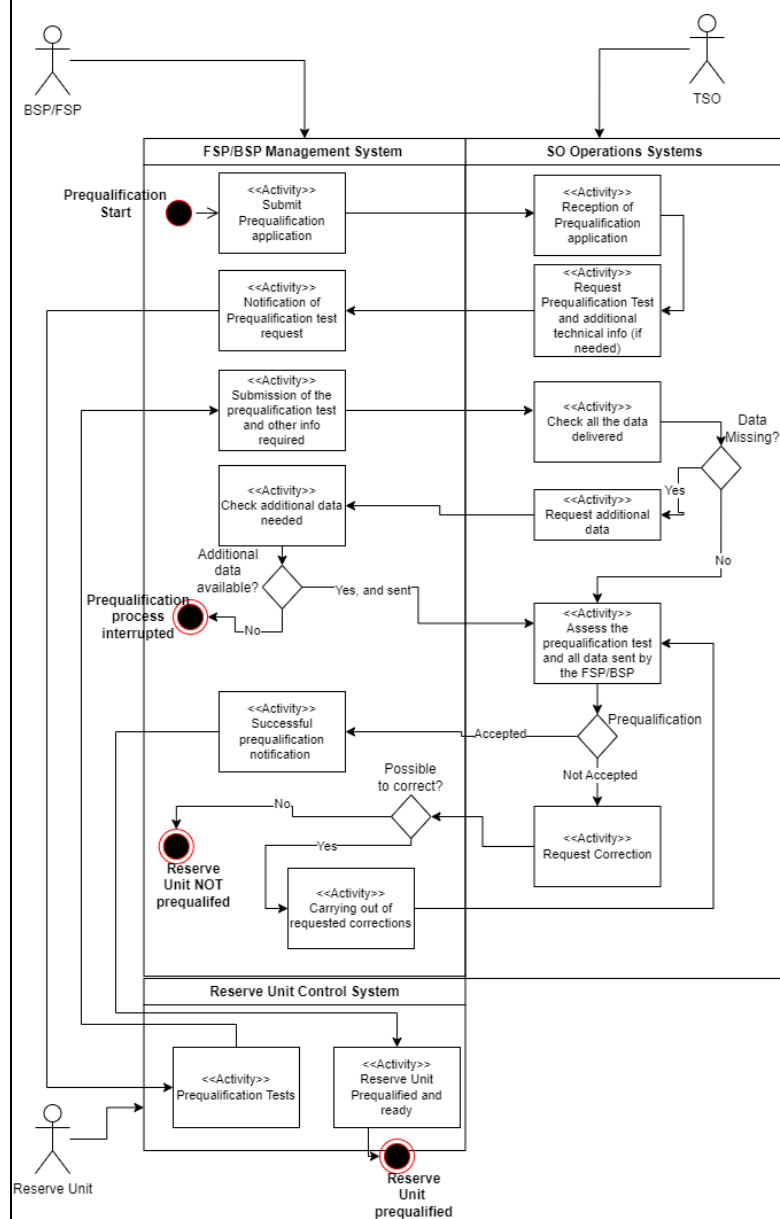
3	There are resources/disturbances affecting networks in different countries.
4	Agreements to share confidential information between different FSPs and SOs are done.
5	For demonstration purposes, the grids of the two pre-qualifying SOs may be directly connected, meaning adjacent control areas. This assumption allows for the testing the harmonization of the pre-qualification processes and the exchange of information for a cross-SO prequalification through the DT/connector
Prerequisites	
1	System Operators have access to all required information about FSPs
2	The grid qualification occurs only if 'product prequalification' of the concerned resource has been successful.
3	FSPs exchange information with their resources.

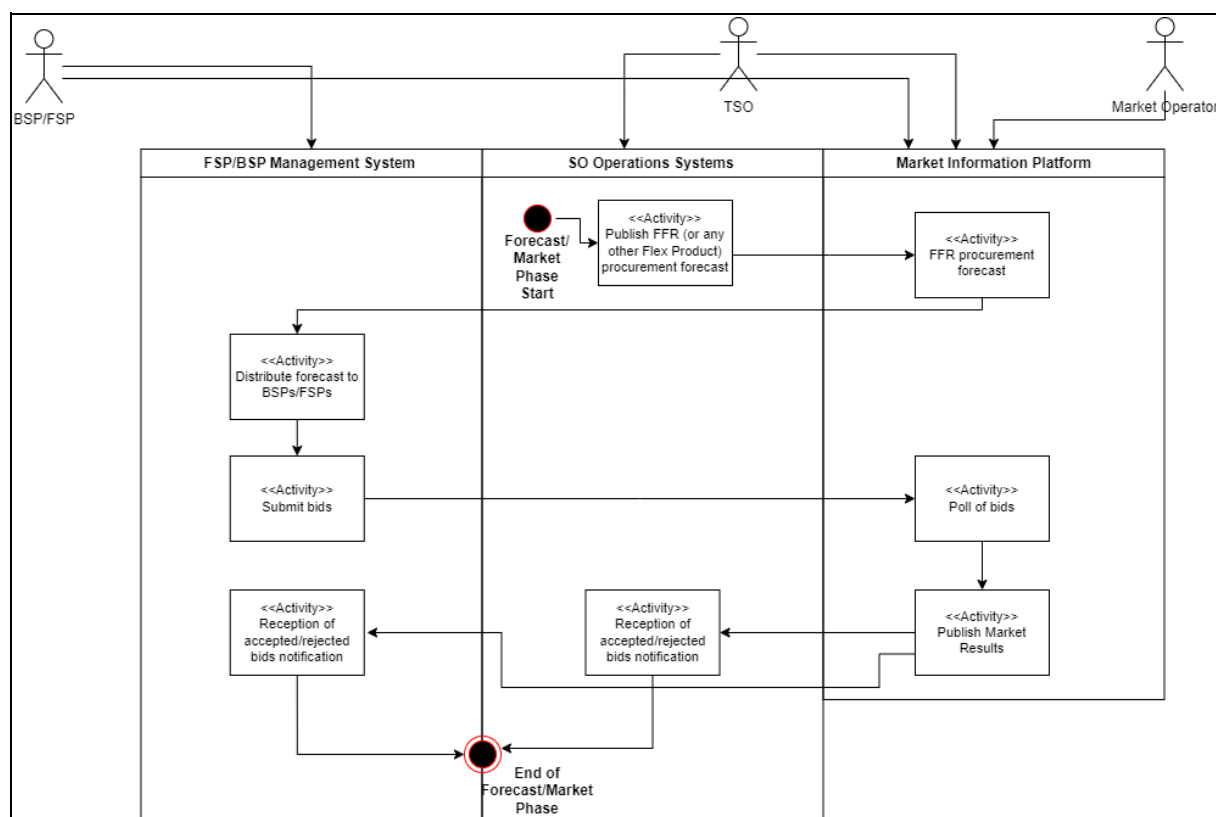
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Level of depth
System Use Case
Prioritisation
High
Generic, regional or national relation
Generic
Nature of the use case
Further keywords for classification
Prequalification; Flexibility; Cross-Border; FFR

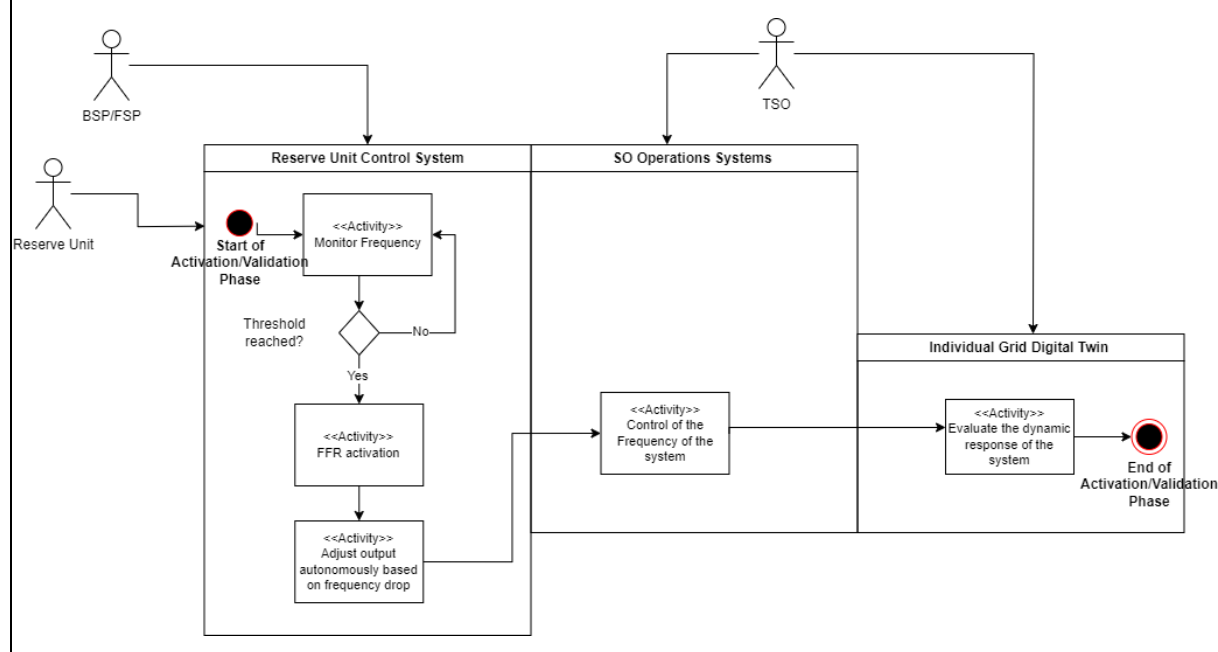
1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case**Scenario 1- Prequalification phase****Scenario 2 – Forecasting/Market Phase**



Scenario 3 – Activation/Validation Phase/



3 Technical details

3.1 Actors

Actors	
Grouping (e.g. domains, zones)	Group description

Actor name	Actor type	Actor description	Further information specific to this business use case
TSO - Transmission System Operator	Role	According to the European Commission, the TSO is “an organisation committed to transporting energy in the form of natural gas or electrical power on a national or regional level, using fixed infrastructure”. The certification procedure for TSOs is listed in Article 10 of the 2009 Electricity and Gas Directives.	
BSP/FSP	Role	Is a market participant that offers balancing or flexibility services to System Operators by adjusting power production or consumption in response to grid needs. In accordance with standards, BSPs/FSPs are responsible for ensuring that their reserve units meet technical requirements, complete prequalification, and respond to activation signals or frequency thresholds to support grid stability.	
Reserve Unit	Asset	A physical asset, such as a generator or controllable load, that a BSP/FSP controls to deliver balancing and/or flexibility services.	
Market Operator	Role	According to Article 2(7) of the Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (recast), market operator designates “an entity that provides a service whereby the offers to sell electricity are matched with bids to buy electricity”.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case
Individual Grid Digital Twin	TSO	Virtual replica of the grid (or a specific section of the grid), designed to simulate and analyze grid conditions dynamically. This system models grid performance by integrating real data, enabling accurate forecasting, fault detection, and impact assessment of flexibility services like FFR. By providing a detailed visualization of grid behaviour, it supports System Operators in optimizing resource allocation, improving grid stability, and enhancing coordination with BSPs/FSPs.	
SO operations systems	TSO	System designed to oversee and regulate the FFR market, manage prequalification verifications, and monitor activation events. This system’s prequalification verification ensures Reserve Units meet the technical standards required for market participation, often involving requests for tests or further data. Its connected to the forecasting and procurement systems giving capabilities to allow the System Operator to publish demand forecasts and process	

		capacity bids for reserve services. For real-time operations, the Activation Monitoring System continuously observes the frequency and confirms Reserve Unit activations, while the Performance Assessment and Compliance component reviews performance data post-activation to ensure compliance with FFR requirements.	
Market information Platform	Market Operator	The Market Information Platform is a shared hub for information dissemination and bidding, accessible to all FFR market participants. This platform publishes forecasts and key procurement information, helping BSPs prepare bids aligned with the System Operator's needs. In addition to storing historical and real-time market data, the platform offers a bid submission interface, allowing BSPs to place their bids based on forecasted demand and market conditions. This shared resource centralizes market information, enhancing transparency and accessibility.	
FSP/BSP Management System	BSP/FSP	System that serves as the central platform for BSPs/FSPs, handling the prequalification, bidding, and notification processes necessary for market participation. Within this system, the prequalification process enables BSPs to submit applications and relevant technical documents to ensure their Reserve Units meet market requirements. For bid management, the BSP Management System should allow the submission of FFR capacity bids and the handling of contracts. Additionally, this system can provide real-time updates, prequalification statuses, and compliance feedback, streamlining the communication between BSPs/FSPs and System Operators.	
Reserve Unit Control System	Reserve Unit	Is an autonomous control and monitoring system at each Reserve Unit, responsible for ensuring compliance with local frequency thresholds and performing frequency-responsive adjustments. The system continuously measures local frequency, autonomously activating and adjusting reserve power output when a frequency threshold is crossed. Following an activation, it logs performance data and communicates the response back to the System Operator for post-event assessment, thereby ensuring a reliable, real-time response to frequency disturbances in the grid.	

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Prequalification Phase	The prequalification phase ensures that Reserve Units meet technical and operational standards to	TSOs and FSPs	BSP/FSP Management System initiates the		

		participate in flexibility services. During this phase, the FSP/BSP submits detailed information and may perform tests to validate compliance with SO and product requirements. Once approved, the Reserve Unit is eligible to enter the flexibility market and provide frequency support services, namely FFR		prequalification process		
2	Forecast/Market Phase	In the forecast/market phase, the SO publishes reserve needs, and Balancing Service Providers (BSPs) submit bids accordingly. The SO reviews and awards bids to ensure grid stability resources are secured for low-inertia or frequency events	TSOs and FSPs	Publishment of FFR forecast needs		
3	Activation/Validation Phase	In the activation/validation phase, Reserve Units autonomously respond to frequency drops, activating reserves as needed. The SO monitors these activations to validate performance and compliance. This phase ensures reserves effectively support grid stability during disturbances and the DT supports in the assessment of the grid stability	TSOs and FSPs	Frequency or low-inertia event (for FFR product)		

Scenario								
Scenario name		Prequalification Phase						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1		Submit Prequalification application	BSP/FSP submits the intention of prequalification to		BSP/FSP	TSO	Info1 – Prequalificat	

			participate in a certain flexibility market				ion application	
1.2		Reception of Prequalification application						
1.3		Request Prequalification Test and additional technical info (if needed)	Request additional technical data/tests		TSO	BSP/FSP	Info2 – Infos/Tests Request form	
1.4		Notification of Prequalification test request						
1.5		Prequalification Tests	Perform tests required for the product under analysis		BSP/FSP	Reserve Unit	Info3- Technical tests	
1.6		Submission of the prequalification test and other info required	Provide technical data / perform tests records		BSP/FSP	TSO	Info4 – Report and Records	
1.7		Check all the data delivered	Confirmation if the required information was received					
1.8		Request additional data	If necessary, the TSO requests additional data/tests		TSO	BSP/FSP	Info2- Infos/Tests Request form	
1.9		Check additional data needed						
1.10		Assess the prequalification test and all data sent by the FSP/BSP	Involves the TSO reviewing technical data and test results provided by the BSP to confirm compliance with operational standards. This assessment ensures that the Reserve Unit meets all requirements for reliable activation in the flexibility market.					

1.11		Request Correction	When gaps or issues are identified in the submitted data or test results, the TSO asks the BSP to make necessary adjustments. This step ensures the Reserve Unit fully meets prequalification standards before approval.		TSO	BSP/FSP	Info2-Infos/Tests Request form	
1.12		Carrying out of requested corrections						
1.13		Successful prequalification notification	Upon approval, the TSO notifies the BSP System that the Reserve Unit has passed prequalification and can now participate in the FFR market (for example)		TSO	BSP/FSP	Info5-Prequalification Result	
1.14		Reserve Unit Prequalified and ready	Reserve Unit set and allowed to participate in the market under analysis					

Scenario								
Scenario name		Forecast/Market Phase						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
2.1		Publish FFR (or any other Flex Product) procurement forecast	The TSO System publishes an FFR procurement forecast to the Market Information Platform, accessible by all BSPs.		TSO	Market Information Platform	Info6 – Product procurement needs forecast	
2.2		FFR procurement forecast	Involves the TSO projecting the amount of FFR required based on anticipated grid conditions. This forecast					

			is then published to guide BSPs in preparing bids for the upcoming market period.					
2.3		Distribute forecast to BSPs/FSPs	BSPs access this forecast through the Market Information Platform		Market Information Platform	BSP/FSP	Info6 – Product procurement needs forecast	
2.4		Submit bids	When BSPs/FSPs enter their capacity offers for FFR (or other product) based on the published forecast. These bids specify the amount of reserve the BSP can provide and the associated price for the upcoming market period.		BSP/FSP	Market Information Platform	Info 7 - Bids	
2.5		Poll of bids	Collecting and organizing all submitted bids. This pooled data (by merit order and technical assess) is then used to determine which bids will be accepted to meet the required FFR capacity.					
2.6		Publish Market Results	Announces the accepted bids and clearing prices					
2.7		Reception of accepted/rejected bids notification			Market Information Platform	TSO and BSP/FSPs	Info8 – Awarded bid contracts/notification	

Scenario								
Scenario name		Activation/Validation Phase						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs

3.1		Monitor Frequency	The Reserve Unit Control System continuously monitors frequency locally.					
3.2		FFR activation	Upon detecting a significant frequency drop, local frequency measurement triggers an automatic activation event					
3.3		Adjust output autonomously based on frequency drop	Adjusts power output based on the frequency drop, reporting it to the TSO		Reserve Unit	TSO	Info9 – Electrical measurements	
3.4		Control of the Frequency of the system	Continuously monitoring the grid's frequency to ensure it remains within operational limits. By managing generation and demand, the TSO can take corrective actions, such as activating reserves, to maintain system stability and prevent frequency deviations.		TSO	Individual Grid DT	Info9 – Electrical measurements	
3.5		Evaluate the dynamic response of the system	Utilizes a digital twin to simulate and analyze the grid's behaviour					

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
Info1	Prequalification application	A formal submission from the BSP/FSP containing technical details, documentation, and certifications required for Reserve Unit prequalification.	
Info2	Infos/Tests Request form	A request issued by the SO, detailing any additional information or specific tests needed from the BSP/FSP to complete the prequalification assessment.	
Info3	Technical tests	A set of performance tests conducted on the Reserve Unit to demonstrate compliance with activation and response standards required for market participation.	

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
Info4	Report and Records	Documentation of test results, performance data, and compliance status, submitted by the BSP/FSP to verify technical standards and track prequalification history.	
Info5	Prequalification Result	An outcome notification from the SO to the BSP/FSP, indicating whether the Reserve Unit has passed, failed, or requires further adjustments.	
Info6	Product procurement needs forecast	A forecast published by the SO showing expected Fast Frequency Reserve (FFR) demand (or any other product, guiding BSPs/FSPs in preparing bids for the upcoming period.	
Info7	Bids	Capacity and price offers submitted by BSPs/FSPs in response to the SO's forecast, detailing the volume of FFR (or any other product) they can provide and their proposed rates.	
Info8	Awarded bid contracts/notification	A notification sent by the SO to the BSPs/FSPs confirming accepted bids, including contract details and activation terms.	
Info9	Electrical measurements	Frequency, power output and other data collected from Reserve Units and grid sensors, sent to the SO for monitoring and validation.	

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.6.12 Integration of TSO-DSO-MO-Prosumer market coordination [Ib12]**1 Description of the use case****1.1 Name of use case**

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ib12	Market / integrated system	Integration of TSO-DSO-MO-Prosumer market coordination

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	04.04.2024	Esteban Pastor Calatayud (ETRA)	Name of the UC and short description.	
0.2	10.05.2024	Gonçalo Glória (R&D NESTER)	Subsection 1.3 to 1.4	
0.3	10.07.2024	Yang Cao (R&D NESTER)	Chapter 1 focus on the market coordination.	
0.4	11.09.2024	Yang Cao (R&D NESTER)	Chapter 3	
0.5	20.12.2024	Yang Cao (R&D NESTER)	Chapter 2 & 4	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	Address the challenges and need for collaboration between the different roles of the energy value chain, enhancing coordination and market integration on the Portuguese power system.
<i>Objective(s)</i>	- Improved communication and data exchange between TSOs, DSOs, MOs, and prosumers to enable better grid management and operational planning. - Definition and testing, through the DT, a new market framework integrating local and wholesale markets - Promote prosumers to actively participate in the markets, potentially earning revenues by providing flexibility services to the grid in the Portuguese system - Improving the cost effectiveness of the resolution of the real-time technical constraints, by forwarding the non-used local flexibility market reserves in the resolution of the eventual transmission grid technical constraints.
<i>Related business case(s)</i>	UC Ib13

1.4 Narrative of Use Case

<i>Narrative of use case</i>

Short description	
Based on an integration framework for wholesale and local markets (energy/balancing/flexibility), use the federated digital twin to simulate the integration Transmission System Operator -Distribution System Operator – (Local) Market Operator and Prosumer (TSO-DSO-MO-Prosumer) framework, assess it and improve it (and/or draw recommendations for deployment) according to the results, exploiting coordinated grid qualification in operational planning, or near real-time contingency analysis.	
Complete description	
To improve grid balancing in face of the increase installation of distributed energy resources it is necessary to facilitate coordination among TSOs, DSOs, Local Market Operators (LMOs) and Flexibility Service Providers (FSPs). The main objective of this UC is to propose and validate an innovative market framework based on collaboration among these entities, fostering synergy and efficiency in the provision of services. The envisioned market framework adheres to existing TSO-FSP and TSO-DSO coordination practices, as well as the DSO-LMO and DSO-FSP market-based coordination paradigm. It will study new approach focusing on the TSO-DSO market coordination. It emphasizes the development of mechanisms for acquiring system services from FSPs to meet local requirements. This approach involves leveraging market-based practices that empower DSOs to procure system services effectively from FSPs. Moreover, interactions with TSOs are considered during the design of technical or market-based coordination strategies to ensure alignment with broader grid operations and optimize system performance, including coordination with the local market operator. Existing markets, such as wholesale energy day-ahead and intraday markets, and balancing markets, provide a foundation for integrating new flexibility markets. This market framework will be tested through DT and simulation to assess the feasibility and potential of market-driven coordination in effectively matching local flexibility requirements with DSO and TSO needs for grid stability and efficiency, particularly in the resolution of real-time technical constraints. Furthermore, the economic performance of the proposed integrated market framework will be assessed in a twofold perspective: i) based on the revenues for prosumers (i.e. local FSPs), as an indicator of the incentive for prosumers to actively participate in the markets; and ii) based on costs of the real-time resolution of technical constraints, as an indicator of the eventual cost reduction and, therefore, contribution to maximize social welfare of the proposed approach.	

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
lb12-1	Number of qualified Local FSPs	This KPI measures the number of pre-qualified FSPs that provide reserves to the DSO and are also qualified to provide grid support in real-time to the transmission grid. The target is greater than zero.	
lb12-2	FSP Revenues	This KPI measures the revenues of FSPs, particularly local FSPs, obtained by providing grid support to solve technical constraints in real-time. The target is greater than zero.	
lb12-3	Service cost difference	This KPI assesses the cost reductions in real-time technical constraint management. The target is greater than zero.	

1.6 Use case conditions

Use case conditions

Assumptions	
1	Participation of prosumers in long- and short-term Local energy markets.
2	Market time unit: 15 minute.
3	Product procured: Active power Availability and/or activation (upwards and downwards)
Prerequisites	
1	Available flexibility from prosumer to respond to eventual failures in the grid.

1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
UC Ib13
Level of depth
TSO-DSO Level
Prioritisation
High
Generic, regional or national relation
Generic
Nature of the use case
System Use Case
Further keywords for classification
Market coordination, Electricity Market, Flexibility

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



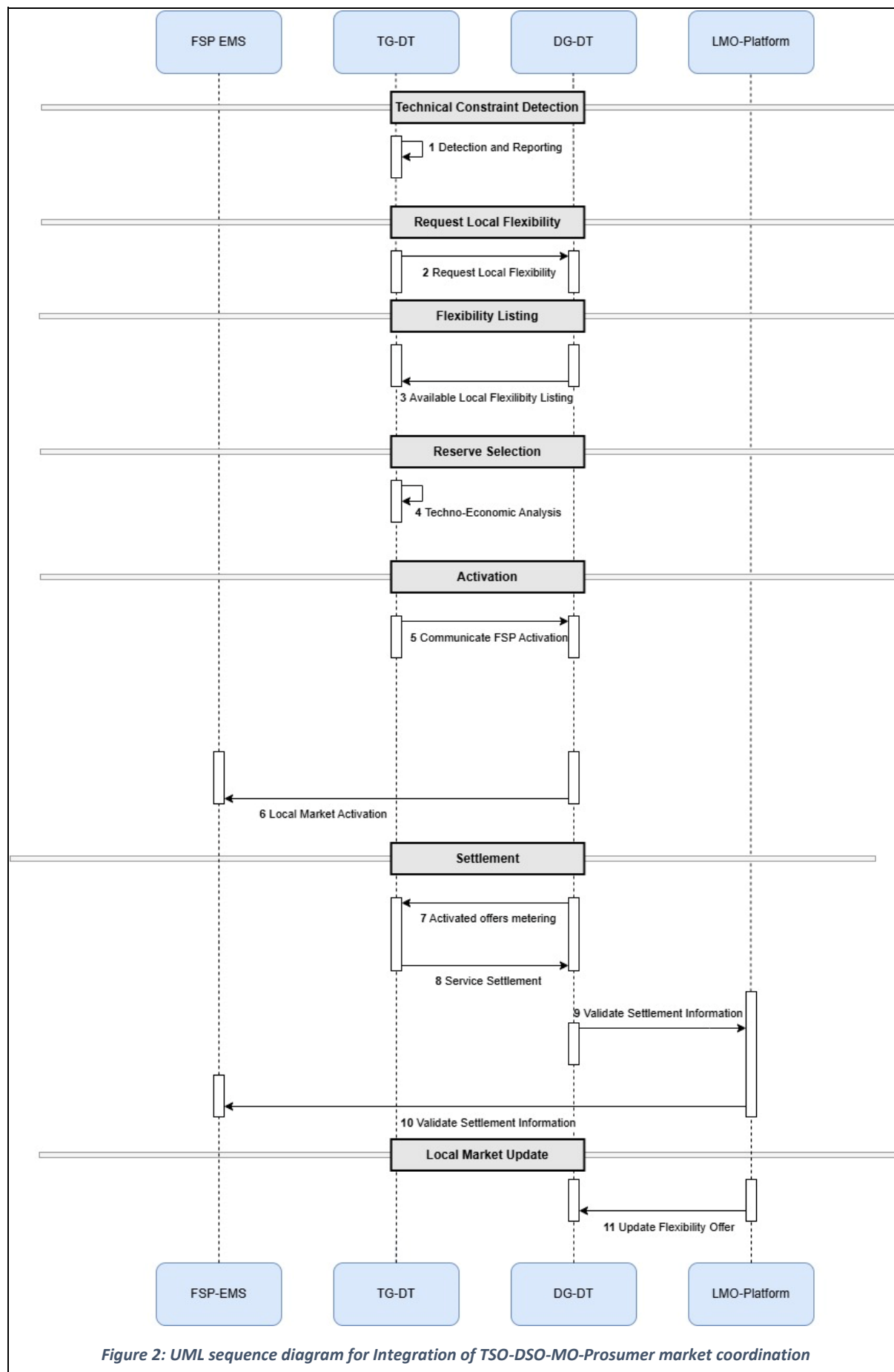


Figure 2: UML sequence diagram for Integration of TSO-DSO-MO-Prosumer market coordination

3 Technical details

3.1 Actors/Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
DG-DT	System	This system evaluates grid constraints in the distribution grid at different timescales.	
TG-DT	System	This system contains information from the wholesale market clearing results and evaluates grid constraints in the transmission grid at different timescales.	
LMO-platform	System	This system contains the clearing results of the Local Market and the list of local FSPs with their bids.	
FSP-EMS	System	This system provides bids to the LMO platform and receives clearing results from the LMO platform and activations from the DG-DT, if the FSP offer was activated from the local market, or receives activation from the TG-DT if the FSP offer was activated from the TSO balancing markets.	

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
System name	System owner	System description	Further information specific to this system use case

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Real-Time Technical restraints resolution	Market transactions in which flexibility is pulled from the offers by FSPs in the local	TG-DT, DG-DT, LMO-platform, FSP	Need of flexibility in order to fix sudden events on the supply or demand side	- Secure and reliable communication infrastructure should be in place for exchanging information.	- Delivery of the needed flexibility. - Financial settlements completed.

	including local FSPs	flexibility market, or from the mFRR offers, when it provides better techno-economic performance. to solve real-time technical constraints when needs arises.		that create grid constraints.	- Risk assessment and monitoring system. - Identification of the qualified market participants and their bids in the Local Flexibility Market and in the mFRR market. - Energy market regulations compliance.	

4.2 Steps – Scenarios

Scenario								
Scenario name:		Real-Time Technical restraints resolution cost						
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information Exchanged (IDs)	Requirement, R-IDs
1	Technical Restriction Detected	Detection and Reporting	The TSO identifies a technical restriction in the Grid, such as voltage rise or feeder overload.	Grid Monitoring	TG-DT		Info1	
2	Request Local Flexibility	Request Local Flexibility	Request of the Local available flexibility			DG-DT	Info2	
3	Flexibility Listing	Listing of local flexibility available	DG-DT validates the local flexibility that can be safely activated from the existing local reserves and lists them.	Grid monitoring	DG-DT	TG-DT	Info3	
4	Reserve selection	Techno economic analysis of reserves	The TSO performs the techno-economic analysis of the available flexibility to	Grid Monitoring	TG-DT		Info4	

			solve real-time technical constraints, including in the analysis the flexibility offers from FSPs in the local market.					
5	Activation	Communication of activation of FSPs offers in the local market	In case there are flexibility offers in the local market to be activated, the TSO informs the DSO of the FSPs to be activated, the amount of energy and direction of activation, to be activated by the DSO.	Activation request to the DSO	TG-DT	DG-DT	Info5	
6	Activation	Activation of FSPs offers in the local market	In case the DSO has received activation requests from the TSO, the DSO activates the FSPs in the amount of energy and direction of activation, and meters the response.	Activation signal	DG-DT	FSP-EMS	Info6	
7	Settlement	Metering of activated offers in the local market	In case an offer in the local flexibility market is activated, the DSO meters the response and informs the TSO of the metered amount and direction of energy	Metering	DG-DT	TG-DT	Info7	
8	Settlement	Service Settlement	The TSO settles the service computing the revenues and eventual	Settlement	TG-DT	DG-DT	Info8	

			penalties for each FSP. It informs the FSPs responsible for the activated offers in the balancing market and informs the DSO about the settlement results of the activations from the local market					
9	Settlement	Service Settlement	If the DSO receives settlement information from the TSO, it validates the information and informs the LMO	Settlement	DG-DT	LMO-platform	Info9	
10	Settlement	Service Settlement	In case the LMO received information from the DSO about the settlement of offers in the local market, the LMO informs each activated FSP in the local market.	Settlement	LMO-platform	FSP-EMS	Info10	
11	Update flexibility offers in the local market	Update local market	The LMO updates the offers in the local market and informs the DSO about the updated local market results	Local market clearing	LMO-platform	DG-DT	Info11	

5 Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	<i>Requirement, R-IDs</i>
Info1	Technical Restrictions details	Details of the detected technical restrictions.	
Info2	Local Flexibility	Details of the Local available flexibility.	
Info3	Flexibility Listing	Validation of the local flexibility that can be safely activated.	
Info4	Techno economic reserve analysis	To solve real-time constraints a techno-economic analysis is performed.	
Info5	Local Market offer activation Communication	The FSPs to be activated, the amount of energy and direction of activation in the Local Market, if needed to be activated.	
Info6	Local Market offer activation	The FSPs to be activated, the amount of energy and direction of activation in the Local Market.	
Info7	Metering of activated offers	Metering of the activated offers (amount and direction of energy).	
Info8	Service settlement (DSO)	Settlement information from TSO.	
Info9	Service settlement (LMO)	Settlement information from DSO.	
Info10	Service settlement (FSP)	Service Settlement for each of the activated FSPs.	
Info11	Flexibility offer update	Local market offers update from LMO and information of the updated results to DSO.	

6 Requirements (optional)

7 Common terms and definitions

DG-DT	Distribution Grid Digital Twin
TG-DT	Transmission Grid Digital Twin
LMO-platform	Local Market Operator
FSP-EMS	Flexibility Service Provider – Energy Management Service
mFRR	manual Frequency Restoration Reserve

8 Custom information (optional)

B.6.13 Enhancement of short-circuit models for operational planning [Ib13]**1 Description of the use case****1.1 Name of use case**

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Ib13	Operational Planning	Enhancement of short-circuit models and TSO/DSO information exchange for operational planning

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	12.07.2024	Gonalo Gl3ria (R&D NESTER)	All chapter 1.	
0.3	18.02.205	Gonalo Gl3ria (R&D NESTER)	Last revision	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	Address the technical validation of the short-circuit currents in the EHV/HV substations and the respective information exchange between TSO and DSO, focusing on the improvement of the short-circuit models for renewable energy sources.
<i>Objective(s)</i>	- Improved communication and data exchange between TSOs and DSOs to enable better grid management and planning. - Enhance TSO short-circuit models of RES generators for more accurate short-circuit currents estimation. - Improve TSO and DSO grid planning by taking into account each other's short-circuit contributions in the TSO/DSO interface - Improve security of operation and quality of service
<i>Related business case(s)</i>	

1.4 Narrative of Use Case

<i>Narrative of use case</i>
<i>Short description</i>
This Use Case presents the processes and information exchanged between TSO and DSO regarding short-circuit currents (three-phase short-circuits) foreseen in the EHV/HV substations in the short-term (day-ahead). Additionally, focus on improving the TSO short-circuit models of the RES generators to obtain estimates closer to reality.
<i>Complete description</i>

Short-circuit currents are among the most critical operational security parameters in power grids, making their monitoring essential. As Distributed Energy Resources (DERs) continue to proliferate, grid operators must increasingly monitor short-circuit currents, namely closer to real-time, to ensure system stability and reliability. In the TSO/DSO interface (in Portugal corresponds to the 63kV bays), is increasingly important to monitor the short-circuit currents due to the lack of observability from the SOs.

Therefore, the TSO/DSO interface must account for active contributions to short-circuit power from both transmission and distribution networks. Accurate measurement and computation of these contributions are crucial for effective operational planning and to avoid compromising the security of the grid.

To manage the complexities at the TSO/DSO interface, this Use Case outlines the process for computing and exchanging complete short-circuit currents at interface nodes. This process ensures that both transmission and distribution network contributions are considered, providing a comprehensive view of the short-circuit current for operational planning. The work proposed is to focus not only the definition of the communication flows but mainly on the improvement of the models used for the computation of the short-circuit currents using the steady state DT.

This UC addresses only the three-phase symmetrical short-circuit fault type because is the most severe scenario. Independently of the different topological arrangements of each country, the calculation of the short-circuit currents should follow a similar approach that is proposed in this UC.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
lb13-1	% deviation to the maximum planning short-circuit current forecasted	Computation of the deviation between the maximum planning estimated value of the short-circuit current in a certain EHV/MV substation and the maximum short-circuit current forecasted through the model	
lb13-2	% deviation between the short-circuit forecast with the rated short-circuit current of the circuit breaker in EHV/HV substations	Computation of the deviation between the rated short-circuit value of the circuit breaker in a certain EHV/MV substation and the maximum short-circuit current forecasted through the model	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	Only three-phase symmetrical short-circuit will be analysed
2	The technical validation of the short-circuit values is done after the wholesale market results (day-ahead)
Prerequisites	
1	Steady state model of the network is available
2	Have access to the reactance's from the machines

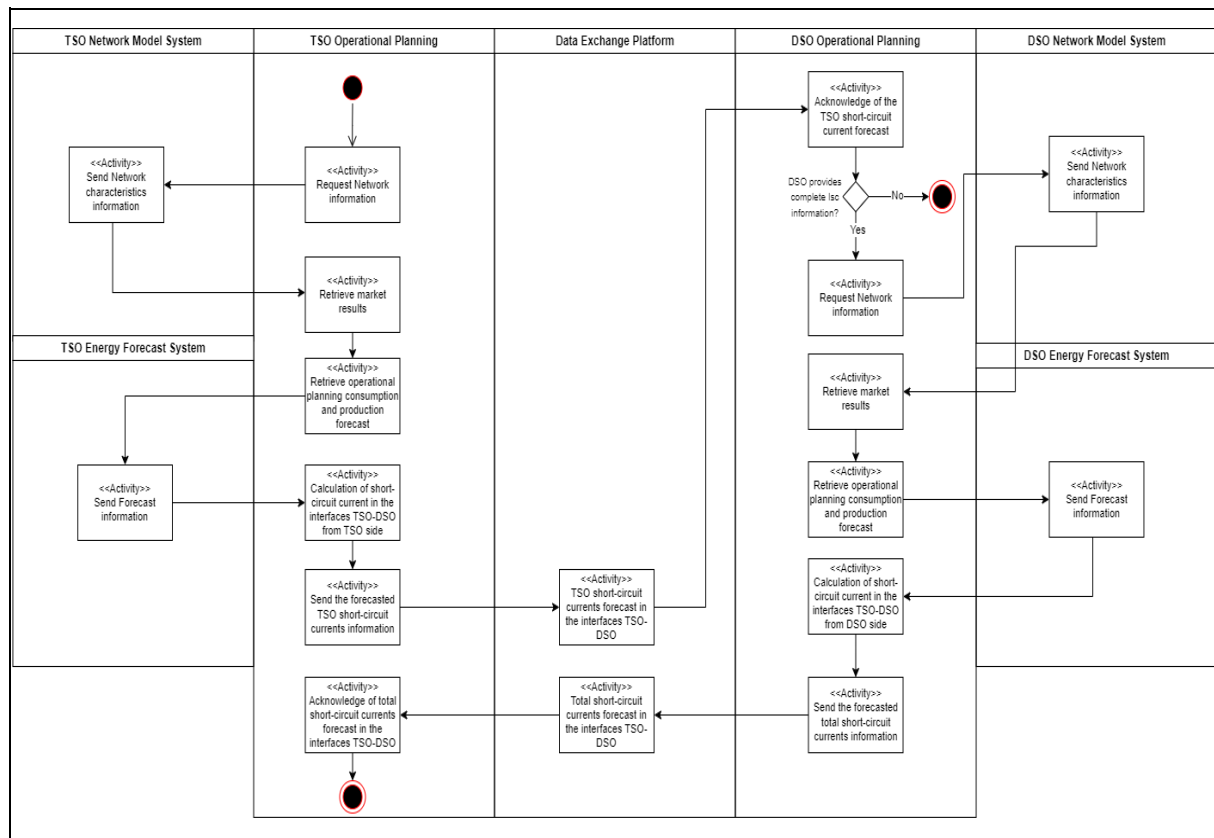
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Level of depth
System Use Case (TSO-DSO level)
Prioritisation
High
Generic, regional or national relation
Generic
Nature of the use case
SUC
Further keywords for classification
Operational Planning, Short-Circuit

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors/Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Network Model System	System	The Network Model System (NMS) manages information for establishing and maintenance of the functional description of the network grid that is provided by current installed asset (as-built model), planned installed asset (future model) or potential installation (what-if/ hypothetical model). The focus is to provide a mathematical model of the network grid that can be used in different analysis of the grid, including but not limited to steady state power flow, state estimation, contingency analysis as part of security assessment and stability analysis. It maintains master representations of the power system for network analysis functions, so that all analysis shares the same source information.	

		NMS handles both internal enterprise element and cross entity both in the horizontal and vertical domain, e.g. TSOs-TSOs and TSOs-DSOs coordination. In this SUC this is an internal System of each SO.	
Energy Forecast System	System	The Energy Forecast (EF) system involves the forecasting of one or more of the items consumption (load), production (primarily intermittent or price inelastic production), direct current and area inter-exchange. This also include energy forecast for intermittent or price inelastic production that is part of Distributed Energy Resources (DER).	
Data exchange platform	System	Data exchange platform is a generic system that can be used by several entities to exchange information for different proposes. The 3 type of data (Real-time; scheduled and structural data) can be exchanged in this platform. The operational/control data are not included in real-time type. The exchange of information related with the markets are included in the scheduled data. Data-agnostic ICT infrastructure that enables secured and reliable information exchange for different purposes and within different time scales. When information reaches this actor, the other SO is automatically notified.	
Operational Planning	System	The Operational Planning System involves forecasting future operational situations with an acceptable level of reliability, including the incorporation of "what-if" scenarios and risk assessments. This process includes adequacy management, which requires system operators and planners to account for both scheduled maintenance and the reasonably expected unscheduled availability of equipment, while maintaining a constant balance between supply and demand.	

3.2 Systems

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Short-Circuit Currents in TSO-DSO interfaces	In a first step the TSO provide the short-circuit currents information based on the EHV/HV transmission system and on the producers connected to these networks. Using the TSO information, the DSO compute the short-circuit currents also considering the impact of the DER, connected to		Once per day after the GCT		

		distribution network. In the end both SOs have the total short-circuit currents foreseen for the next day in the TSO-DSO interfaces.				

Scenario								
Scenario name		Short-Circuit Currents in TSO-DSO interfaces						
Step No	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)	Requirement, R-IDs
1.1		Request Network information	Request the network characteristics		Operational Planning	Network Model System	Info1-Request (internal) the Network characteristics information	
1.2		Send network characteristics information			Network Model System	Operational Planning	Info2-Network characteristics (internal) information	
1.3		Retrieve market results	This process should be executed after the Day-Ahead Market (DAM clear). The market results should be available and used in this process.		Operational Planning			
1.4		Retrieve operational planning consumption and production forecast	The consumption and production forecast information provided in operational planning by the SOs (TSOs and DSOs) should be take into account in the method.		Operational Planning			
1.5		Send forecast information	Send the production and consumption forecast that is needed to execute the method. The information should be provided by technology. Some quantiles can be provided if stochastic methods are used		Energy Forecasting	Operational Planning	Info4-Consumption and production forecast (internal) information	
1.6		Calculation of short-circuit currents in the			Operational Planning			

		TSO-DSO interfaces from TSO or DSO side						
1.7		Send the forecasted TSO or DSO short-circuit currents information	The SOs should send the information of the forecast short-circuit currents for the 24h of the next day		Operation Planning	Data exchange platform	Info5-Short-Circuit currents forecast	
1.8		TSO or DSO short-circuit currents forecast in the interfaces TSO-DSO			Data exchange platform			
1.9		Acknowledge of the TSO short-circuit current forecast	The DSO receives the information regarding the forecasted short-circuit currents in the TSO-DSO interface having just in consideration the TSO contributions		DSO Operational Planning			
1.10		Request Network information	Request the network characteristics		Operational Planning	Network Model System	Info1-Request (internal) the Network characteristics information	
1.11		Send network characteristics information			Network Model System	Operational Planning	Info2-Network characteristics (internal) information	
1.12		Retrieve market results	This process should be executed after the day-ahead market Day-Ahead Market (DAM clear). The market results should be available and use in this process.		Operational Planning			
1.13		Retrieve operational planning consumption and production forecast	The consumption and production forecast information provided in operational planning by the SOs (TSOs and DSOs) should be take into account in the method.		Operational Planning			
1.14		Send forecast information	Send the production and consumption forecast that is needed to execute the method. The information should be provided by technology. Some quantiles can be		Energy Forecasting	Operational Planning	Info4-Consumption and production forecast (internal) information	

			provided if stochastic methods are used					
1.15		Calculation of short-circuit currents in the TSO-DSO interfaces from TSO or DSO side			Operational Planning			
1.16		Send the forecasted total (TSO+DSO) short-circuit currents information	The DSO should send the information of the total forecast short-circuit currents for the 24h of the next day		Operation Planning	Data exchange platform	Info5-Short-Circuit currents forecast	
1.17		Total short-circuit currents forecast in the interfaces TSO-DSO			Data exchange platform	TSO Operational Planning	Info5-Short-Circuit currents forecast	
1.18		Acknowledge of total short-circuit currents forecast in the interfaces TSO-DSO			TSO Operational Planning			

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
Info1	Request (internal) the Network characteristics information	Request the structural information of the network characteristics are required to the computation process. This information is exchange between the SO systems. The focus of the UC will be in the improvement of these models	
Info2	Network characteristics (internal) information	Submit The structural information of the network characteristics are required to the computation process. This information is exchange between the SO systems. The focus of the UC will be in the improvement of these models	
Info3	Request (internal) the Consumption and production forecast	Request the submission of the day-ahead consumption and generation foreseen.	
Info4	Consumption and production forecast (internal) information	Submit the consumption and generation forecast.	
Info5	Short-Circuit currents forecast	Exchange of short-circuit currents in each node in the observability area.	

6 Requirements (optional)

7 Common terms and definitions

SO – System Operator

TSO – Transmission System Operator

DSO – Distribution System Operator

DAM – Day-Ahead Market

DER – Distributed Energy Resources

GCT – Gate Closure Time

EHV/HV - Extra High Voltage / High Voltage

Sc - short circuit

8 Custom information (optional)

B.6.14 DT-endorsed flexible connection grant through the settlement of a Local Flexibility Market to internally balance the production surplus in congestion-creation hours/scenarios. [Ib14]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
Ib14	Distribution	DT-endorsed flexible connection grant through the settlement of a Local Flexibility Market to internally balance the production surplus in congestion-creation hours/scenarios.

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	02.07.2024	Esteban Pastor Calatayud (ETRA)	New requirement. Name, scope and objectives, narrative, use case conditions and further information.	
0.2	19.07.2024	Esteban Pastor Calatayud (ETRA)	Concept update and KPIs definition	
0.3	30.08.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Diagrams of use and technical details	
0.4	27.09.2024	Esteban Pastor Calatayud (ETRA), Pablo Bort Gómez (ETRA)	Step-by-step analysis of the use case and information exchanged	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope of this UC is limited to grid planning purposes in the distribution network and, more specifically, related to the concession of flexible connection points to RES power plants developers, subject to the results of the simulations undertaken by the DT and the settlement of a LFM able to absorb surplus power without creating congestions.
Objective(s)	The objective of this use case is leveraging the interaction between the DT of the distribution system with the DT of the NEMO's LFM to validate the grid-exported power increase for a specific connection

	point for renewable energy plants subject to the opening of a LFM than can absorb the surplus power when forecasted. This use case is contributing to: O8: Demonstrate the TwinEU approach in real scenarios validating the complete energy and data value chains O9: Large adoption of the TwinEU approach creating the condition for a real implementation at European scale
Related business case(s)	Smart coordinated planning of the distribution grid

1.4 Narrative of Use Case

Narrative of use case
Short description
Collaboration between the DT of the distribution system, the dynamic forecasting models of the eventually deployed RES power plants and the DT of the NEMO's LFM to validate the viability of a new installation. The result of the Use Case will be a viability assessment for further deployment of RES systems with increased peak power capacities.
Complete description
Highly industry-populated areas are experiencing an increase in the use of electricity both at demand side (electrification of industrial processes towards meeting sustainability goals) and at generation side (deployment of PV self-consumption installations covering the maximum available roof). In this context, the classic methodology for calculating the available capacity at a specific node is obsolete, as it does not take into account the dynamic component that parametrizes the evolution of the grid use (power flows and congestion) over the year, but rather it obtains results based on a fix percentage of the maximum demand. TwinEU leverages the implementation of Digital Twins for the uptake, in terms of grid capacity planning, of distribution companies by analysing the impact that newly deployed commercial and utility-scale renewable power plants will have in their networks. When a PV installation connection point request is received, the DSO's DT makes a series of scenarios simulations to identify bottlenecks where the grid gets congested. Among the results of these simulations, the DSO will get the maximum power for which no congestions are generated in the grid at any time. This will be the base power granted for the plant. From there onwards, in increased power steps, additional result will be given stating, for each step, an estimation for the hours of the year that the flexible connection point could be increased to that export peak power. This way, the developer could choose, based on non-binding estimation, to what extent is profitable for them to deploy more power. This increased power granted can be due to the lack of a congestion or the establishment of a long-term local flexibility market. For such periods of time, the DSO's DT communicates with the NEMO's LFMs DT in order to open a session in the market for flexibility provision. Once the offers have been received (estimated based on the registered assets for the selected zones of the grid) and the market has been cleared, the DSO's DT runs once again the set of eventual scenarios to verify that all the power can be injected into the grid without causing further congestions. Once the grid status has been verified as suitable, the DSO increases the connection power capacity for the specific period of time where no congestions are generated.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
	Number of LFM sessions cleared	This KPI states the amount of sessions for local flexibility markets that are successfully	In relation to O9, this UCs tests the DT-enabled implementation of a scenario that so far

		cleared, generating an increased RES power export to the distribution grid.	couldn't be realised in real operating conditions in European distribution grids.
	Increased RES power	This KPI measures the increased RES generated power that could be exported to the grid thanks to the collaboration between the DSO's and the MO's digital twins.	In relation to O8, this KPI measures the increased power enabled by leveraging data and DTs interoperability.

1.6 Use case conditions

<i>Use case conditions</i>	
<i>Assumptions</i>	
1	A new connection point requested
2	After the analysis of maximum load in the respective node, the DSO states that the requested power that can be granted is diminished to a certain percentage (e.g., 80% of the maximum requested peak power)
3	Calculations consider hourly based data
<i>Prerequisites</i>	
1	The digital Twin of ANELL's distribution network (ÉTER + ANELL's Digsilent Model of the grid) is fully deployed and integrated.
2	The DT of ANELL's grid, provided with the simulation model services for the generation assets and flexible loads, must be integrated with the DT of OMIE's LFMs.

1.7 Further information to the use case for classification/mapping

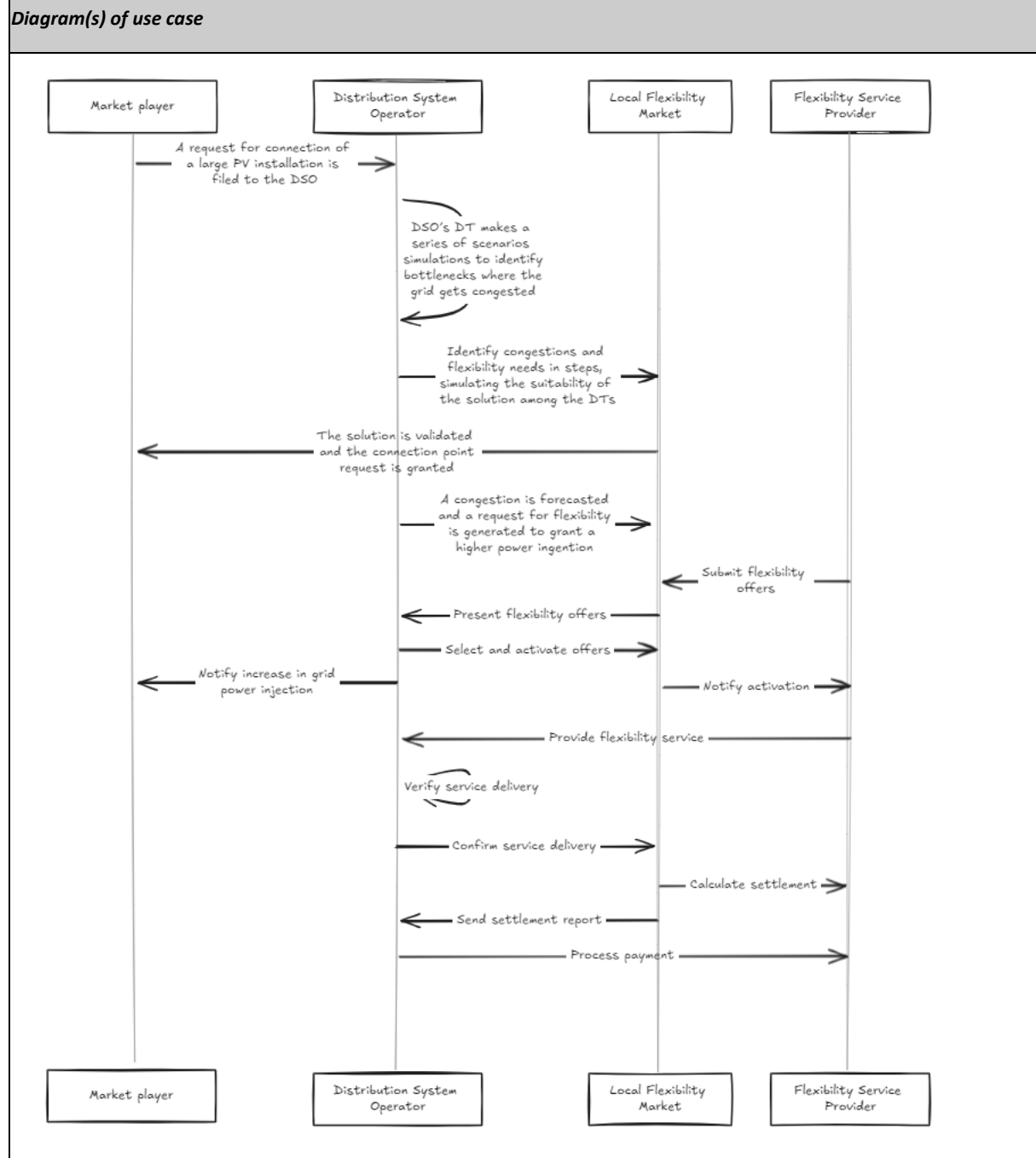
<i>Classification information</i>
<i>Relation to other use cases</i>
UC-Ib06: DT-enabled new RES integration validated plan in the MV grid
<i>Level of depth</i>
<i>Prioritisation</i>
High
<i>Generic, regional or national relation</i>
Regional – DSO-level relation

Nature of the use case
Grid planning towards maximising the deployment of RES power plants in the distribution level.
Further keywords for classification

1.8 General remarks

n.a.

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Zones of the Distribution System to be defined.		This use case is focused on the distribution level. The specific zones to be coordinated within the grid will later on be defined.	
Actor name	Actor type	Actor description	Further information specific to this business use case
Distribution System Operator (DSO)		Actor responsible for operating, maintaining and further developing the electricity distribution grid.	DSO operator will be responsible for the proper operation of the distribution grid and its DT.
Market Operator (MO)		Actor owning, operating maintaining and updating local flexibility markets	The MO operates and manages the services included in the LFMs
Flexibility Service Provider (FSP)		Actor providing flexibility services to the energy system.	FSP will participate to flexibility market and will provide congestion management services according to the activation signals of the DSO

3.2 Systems

Actors			
Grouping (e.g. domains, zones)		Group description	
Role		The group have been created depending on the role they undertake during the UC demonstration	
System name	System owner	System description	Further information specific to this system use case
Electricity Distribution System	DSO	Electricity Distribution network connected to transmission upstream and to final consumers or prosumers downstream	The DSO's system includes the DT of the grid as well as information from the SCADA and all RTU and other HW deployed.
RES electricity generation systems	Market players	Mainly PV plants at commercial scale.	Renewable electricity generation plants aiming at obtaining a dynamic grid connection.
Distributed energy resources	FSP	Flexibility assets owners	The flexibility assets must have enough capacity to participate in a local flexibility market. In essence, industrial prosumers with storage systems, other flexible assets or aggregators.

3.3 References

n.a.

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Connection point request	If the trigger is a connection point request, the market player requests for connection of a large PV installation is filed to the DSO	Market player (MP)	Connection request	No plant expected	New RES expected
2	Simulation and LFM opening request	The DSO's DT makes a series of scenarios simulations to identify bottlenecks where the grid gets congested. It identifies congestions and flexibility needs in steps, simulating the suitability of the solution among the DTs, it requests the collaboration of the LFM DT.	DSO	Capacity assessment	The plant can be deployed	A LFM is required
3	LFM validation	The solution is validated and the connection point request is granted	MO, DSO	LFM simulation	Impossibility to deploy PV plant	Deployment subject to conditions but possible
4	Extension of power injection cap	A congestion is forecasted and a request for flexibility is generated to grant a higher power injection at specific times when it can be absorbed by DERs as FSPs.	DSO, MO, MP	The full power of the plan can be injected with the facilitation of DERs as FSPs	Limited power available	Full power available
5	Market activation	The LFM is activated, cleared and executed	DSO, MO, MP	The full power of the plan can be injected with the facilitation of DERs as FSPs	Limited power available	Full power available

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
1	Connection point request	Information on power and plant characteristics	n.a.

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
2	Grid status and potential FSPs (DERs) information	All forecasted data	n.a.
3	Simulation based result of the LFM	Generated by the DTs	n.a.
4	Flexibility requests and offers	Actual data from DSO and FSPs	n.a.
5	Results of the market clearing	Final status of the local system	n.a.

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.7 Italian Pilot Site UCs

B.7.1 The Defence System [IT01]

1 Description of the use case

1.1 Name of use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
IT01	Transmission/Distribution	Analysis through DT of the TSO defence system

1.2 Version management

<i>Version management</i>				
<i>V. No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>	<i>Approval status</i>
0.1	30.04.2024	Andrea Porcu (TRI)	n.a.	
0.2	08.05.2024	Andrea Mazza (ENSIEL)		
0.3	13.05.2024	Andrea Porcu (TRI)	1.6 and 1.7	
0.4	17.07.2024	Andrea Porcu (TRI)	1.7	
0.5	19.07.2024	Andrea Porcu (TRI)	1.5	
0.6	27.07.2024	Andrea Mazza (ENSIEL)		
0.7	01.08.2024	Andrea Porcu (TRI)	1.6	
0.8	30.08.2024	Andrea Porcu (TRI)	2	
0.9	03.09.2024	Andrea Porcu (TRI)	3	
10	19/09/2023	Andrea Porcu (TRI) Andrea Mazza (ENSIEL)	5	

1.3 Scope and objectives of use case

<i>Scope and objectives of use case</i>	
<i>Scope</i>	Analysis of the performance of the defence system applied to a portion of the Sardinian transmission and distribution grids.
<i>Objective(s)</i>	Analysis of the power system stability and security

	Testing different scenarios triggering the TSO Defence System Testing in real-like conditions the Defence System, performing simulations using a Real Time Simulator (RTS) in Hardware in the Loop (HIL) configuration. Performing sensitivity analyses by considering the evolution of system parameters according also to future scenarios. With the aim of simulating even more complex systems, it will be considered the possibility to connect the RTS facilities of Terna and Ensiel (Politecnico di Torino) to simulate the complete grid framework by using a geographical distributed RTS approach.
Related business case(s)	System stability and security

1.4 Narrative of Use Case

Narrative of use case
Short description
This use case focuses on the developing a DT of a selected portion of the Sardinian high voltage grid to simulate and assess operational aspects specific of the TSO Defence System, devoted to managing power system stability and security and to prevent cascading effects and blackouts. The simulations will be carried out by using HIL techniques. The model, running on an RTS, will be interfaced with specific physical devices, to duly test protections and control logics, as well as operation strategies, in a protected environment and under real-like conditions. The primary objective is to obtain data from the simulation regarding the frequency and voltage behaviour after an event or a series of events. The second objective consists in interfacing real hardware (i.e., EAC relè – Equilibratore Automatico di Carico – “Automatic Load Balancer”) to the RTS in a HIL configuration, with the aim to duly test physical devices in a safe way, also varying the intervention thresholds. The third objective will be covered by a sensitivity analysis that will be carried out to analyse the performance of the defence system taking in to account the planned development of the HV network. In order to demonstrate the scalability of the experimental setup proposed, it will be taken into account the possibility to connect the RTS facilities of Terna and Ensiel (Politecnico di Torino).
Complete description

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI-1	Voltage profile comparison by evaluating the maximum error	Comparison of the simulated voltage profile with available historical data voltage profile.	
KPI-2	Current profile comparison by evaluating the maximum error	Comparison of the current profile of the simulated systems with available historical data.	

KPI-3	Frequency profile comparison by evaluating the maximum error	Comparison of the frequency of the simulated system with available historical data in case of relatively small unbalances.	
KPI-4	Defence system performance with different intervention thresholds and scenarios - Voltage	The voltage profile of a node during an event that triggered the Sardinian defence system is take as reference curve. The new simulated condition (scenario and/or intervention thresholds) will be compared in terms of duration of the voltage transient and the magnitude of the voltage variation.	
KPI-5	Defence system performance with different intervention thresholds and scenarios - Frequency	The frequency profile of the simulated system during an event that triggered the Sardinian defence system is take as reference curve. The new simulated condition (scenario and/or intervention thresholds) will be compared in terms of duration of the frequency transient and the magnitude of the frequency variation.	
KPI-6	Defence system performance with different intervention thresholds and scenarios – Net load at HV/MV substation	The net load at HV/MV substation during an event that triggered the Sardinian defence system will be compared with the simulated HV/MV substation using different simulation conditions.	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The simulated HV network event is able to trigger the defence system
2	The load underlying the relay EAC is greater than zero
Prerequisites	
1	RTS availability for SIL and HIL simulation (TRI and PoliTo)
2	Software licence (e.g. OPAL RT-Lab, Matlab/Simulink etc)
3	Availability of at least one EAC relay (Load balancer relay)
4	Availability of network data (both at HV and MV level)

1.7 Further information to the use case for classification/mapping

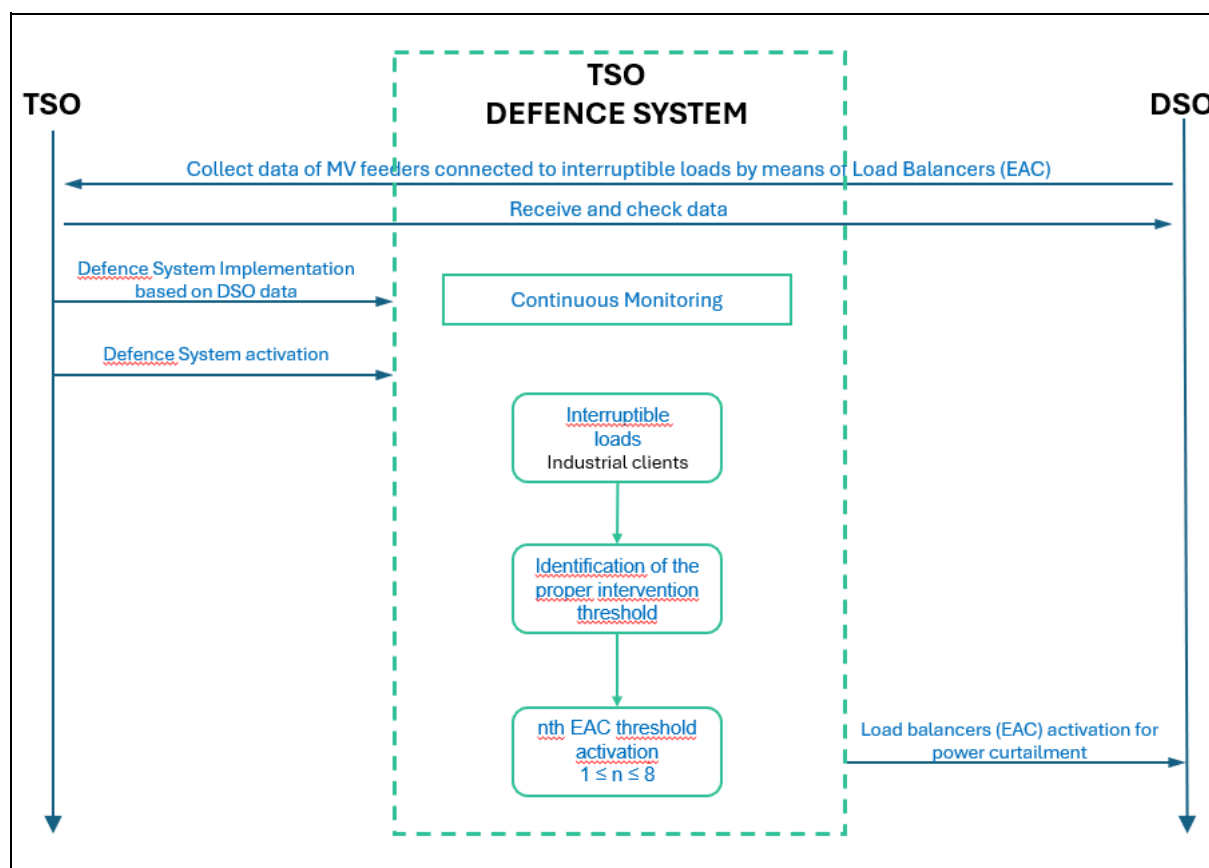
Classification information	
Relation to other use cases	

Level of depth
High level
Prioritisation
Medium
Generic, regional or national relation
National relation
Nature of the use case
HIL simulations
Further keywords for classification
Defence system, Network models, RTS, HIL

1.8 General remarks

2 Diagrams of use case

Diagram(s) of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Transmission System Operator (TSO)	Business	According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.	
Distribution System Operator (DSO)		A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.	

3.2 Systems

3.3 References

4 Step by step analysis of use case

4.1 Overview of scenarios

Scenarios will be implemented based on the foreseen TSO grid development.

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1	Voltage	Three-phase voltage signal at the HV/MV interface (i.e., at transformer level).	
ID2	Current	Three-phase current signal at the HV/MV interface (i.e., at transformer level).	
ID3	Apparent power	Three-phase apparent power exchanged at the HV/MV interface (i.e., at transformer level).	
ID4	Frequency	Frequency of the TS following the grid event.	

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.7.2 The Defence System [IT02]

1 Description of the use case

1.1 Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
IT02	Transmission/Distribution	Analysis through DT of the behaviour of aggregated distributed resources during a grid event in the TSO system

1.2 Version management

Version management				
V. No.	Date	Name of author(s)	Changes	Approval status
0.1	12.09.2024	Andrea Mazza & Giorgio Benedetto (ENSIEL)	First draft	
0.2	13.09.2024	Andrea Mazza (ENSIEL)	Completion of the draft	
0.3	19.09.2024	Andrea Porcu (TERNA)	Updates	
0.4	23.09.2024	Andrea Mazza (ENSIEL)	Definition of DERs	
0.5	24.09.2024	Andrea Mazza & Giorgio Benedetto (ENSIEL)	Update figure case study	

1.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Analysis of the impact of aggregated distributed resources on the distribution network with the participation of relevant shares of inverter-based resources
Objective(s)	Studying the impact of inverter-based resource operation on the distribution network after a transmission system grid events.
Related business case(s)	System secure operation

1.4 Narrative of Use Case

Narrative of use case
Short description

A key focus will be on studying the impact of inverter-based resource operation on the distribution network after a transmission system grid event.

The network model will be firstly validated by comparing its outputs with real-world data provided by the Distribution System Operator (DSO).

Afterwards, sensitivity analyses will be performed, creating scenarios with varying levels of Distributed Energy Resource (DER) penetration to evaluate the distribution system behaviour.

Complete description

This use case focuses on developing a Digital Twin (DT) of selected portions of the medium distribution grids, with a particular focus on integrating DERs, such as photovoltaic (PV) systems and electric vehicle (EV) charging stations. The objective is to evaluate operational challenges related to load and generation variability, ensuring secure grid operations, especially in high-density urban areas and rural zones.

Simulations will be carried out using Hardware in the Loop (HIL) techniques, focusing on the medium voltage (MV) network and aggregating data at the MV substation level. The model will run on a Real Time Simulator (RTS).

The primary goal is to gather data on voltage, frequency, and load profiles, validating the simulations based on real data obtained from selected primary substations, the selection will depend on the size of the substation.

Afterwards, the study will analyze the behaviour of the distribution network when working in (virtual) islanding mode, to understand the impact on the distribution system operation of the DER intervention. Finally, sensitivity analyses will be performed to assess the impact of future scenarios, considering the planned expansion of DERs.

This approach will offer critical insights for the future development of the grid, with a focus on high-density urban networks and rural areas with complex configurations.

1.5 Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI-1	Grid losses (Wh)	Grid losses result from difference between energy feed-in and withdrawal.	
KPI-2	Percentage grid losses (%)	Grid losses result from difference between energy feed-in and withdrawal.	
KPI-3	Reverse power flow (Wh), (min)	The reverse power flow represents the injection of energy to the transmission system through the HV/MV transformer	
KPI-4	Max power injected to/withdrawn from HV/MV substation (W)	Peak power	
KPI-5	Grid self-sufficiency (%)	Grid self-sufficiency represents the percentage of RES production that is used for supplying the loads and the energy of the loads	

KPI-6	Grid self-consumption (%)	Grid self-consumption represents the ratio between the RES production used for supplying the loads and the total RES production	
KPI-7	Voltage profiles (pu)	Voltage profiles can be used to evaluate voltage stability of the power system.	
KPI-8	Lines loading factor (pu)		
KPI-9	Max nadir	Maximum nadir reached during an extreme event (to be defined extreme event)	

1.6 Use case conditions

Use case conditions	
Assumptions	
1	The simulated HV network event is able to trigger the TSO request of support.
Prerequisites	
1	RTS availability for SIL and HIL simulation (TRI and PoliTo)
2	Software licence (e.g. OPAL RT-Lab, Matlab/Simulink etc)
3	Availability of network data (both at HV and MV level)

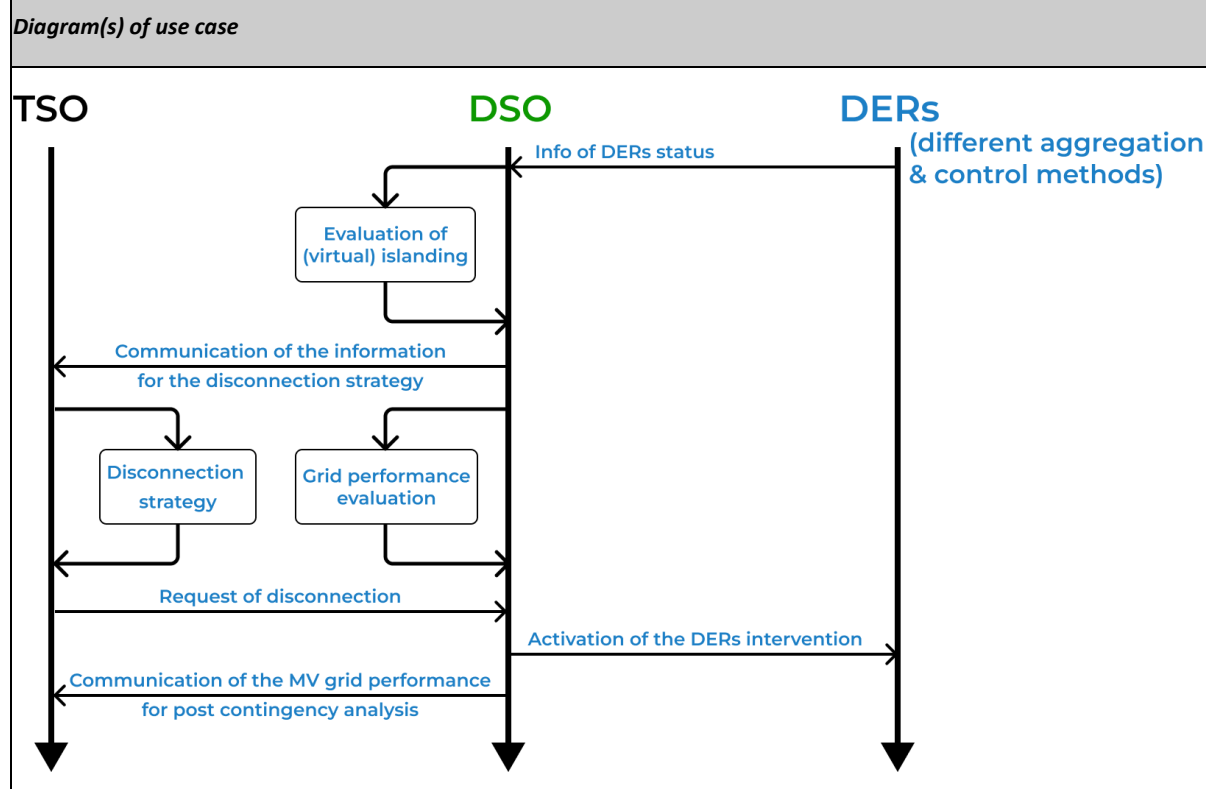
1.7 Further information to the use case for classification/mapping

Classification information
Relation to other use cases
Level of depth
High level
Prioritisation
Medium
Generic, regional or national relation
Regional relation
Nature of the use case

Simulations
Further keywords for classification
Grid event, Network models, RTS

1.8 General remarks

2 Diagrams of use case



3 Technical details

3.1 Actors

Actors			
Grouping (e.g. domains, zones)		Group description	
Actor name	Actor type	Actor description	Further information specific to this business use case
Transmission System Operator (TSO)	Business	According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid	

		users at the transmission level and connection of the DSOs within the TSO control area.	
Distribution System Operator (DSO)	Business	A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.	
Distributed Energy Resources (DERs)	Business	Distributed Energy Resources (DERs) are defined as energy resources comprised of generation and/or storage and/or controllable load which is connected at the low or medium voltage distribution level. The term “DER” may also indicate a collection of DER units. This collection may also be called a DER plant or a DER facility. In addition, DER plants may act as microgrids. These microgrids may be permanently disconnected from the main grid, but in most cases are normally connected, even though they are designed to disconnect and operate autonomously if necessary.	

3.2 References

4 Step by step analysis of use case

4.1 Overview of scenarios

The scenarios will be defined according to the future DS grid planning, on the basis of the indications provided by the DSOs. Hence, the table will be filled during the implementation phase of the model (step-by-step).

5 Information exchanged

Information exchanged			
Information exchanged, ID	Name of information	Description of information exchanged	Requirement, R-IDs
ID1	Voltage	Three-phase voltage signal at the HV/MV interface (i.e., at transformer level).	
ID2	Current	Three-phase current signal at the HV/MV interface (i.e., at transformer level).	
ID3	Apparent power	Three-phase apparent power exchanged at the HV/MV interface (i.e., at transformer level).	
ID4	Frequency	Frequency of the TS following the grid event.	

6 Requirements (optional)

7 Common terms and definitions

8 Custom information (optional)

B.7.3 Digital Twin for definition of data model [EACL-IT-01]

1 Description of the use case

1.1 Name of use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area(s)/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
EACL-IT-01	Connection	Digital Twin for definition of data model

B.8 Slovenian Pilot Site UCs

B.8.1 BUC 1: Dynamic RMS Analysis with Upgraded Transmission System Model

1 Description of the Use Case

1.1 Name of Use Case

Use Case Identification		
ID	Area / Domain(s)/ Zone(s)	Name of Use Case
SLO-BUC-1	System dynamic analysis	Dynamic RMS Analysis with Upgraded Transmission System Model

1.2 Version Management

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
1	2024-04-30	N. Suljanović, L. Herman, J. Lasnik		First draft
2	2024-05-22	N. Suljanović	DSO included in the information exchange	
3	2024-12-24	N. Suljanović, L. Herman, J. Lasnik, G. Omahen	KPI 3 added	

1.3 Scope and Objectives of Use Case

Scope and Objectives of Use Case	
Scope	Dynamic power system analysis with inclusion of distributed generation connected to the distribution grid.
Objective(s)	Enhance the dynamic modelling capabilities of the transmission system by integrating an improved distribution system model. Improve the accuracy of the dynamic analysis of the power system for operational planning and dynamic security assessments, by inclusion of the impact of generation connected to the distribution network. Increase system security and the quality of supply. Enable the exchange of network models between DSOs and TSO in a standardized and interoperable way.

<i>Related business case(s)</i>	

1.4 Narrative of Use Case

<i>Narrative of Use Case</i>
<i>Short description</i>
This use case defines the process of upgrading system dynamic model of the transmission system by the distribution system to increase the accuracy of the dynamic RMS analysis. The distribution system is represented by an equivalent that contains the generation aggregated by different types (synchronous, asynchronous and PV) and a aggregated dynamic consumption model.
<i>Complete description</i>
This use case describes the development of an extended/improved dynamic power system model with the distribution system, aiming to facilitate more precise analyses. The improved system model replaces existing PQ nodes used to represent distribution system with more detailed equivalent comprising of aggregated production units of different types (synchronous, asynchronous and PV) as well as frequency and voltage dependent models of consumption. Furthermore, model variations due to seasonality and day-of-the-week are taken into account at the distribution level. Power system analysts can use the upgraded model to recreate and analyse the events and transients observed in the power system with enhanced accuracy. More detailed distribution system modelling is especially important for analyses of local, islanded parts of the power system (e.g. after separation from the rest of the power system or during black start). The upgraded model will also enable more accurate dynamic security assessment during the operational planning stage. With an assumption that distribution system equivalent is defined and that distribution grid model is available as CIM RDF/XML format, the use case incorporates the following processes: 1. Determination of the distribution system equivalent parameters. The distribution grid model in CIM RDF/XML format is processed to determine all needed data for the aggregated production per types (synchronous, asynchronous, PV). Process measurement data to determine frequency and voltage dependent models of aggregated consumption. 2. Use of accurate transmission system model for the extension with the distribution system equivalent. For this purpose, SCADA/EMS state estimators are leveraged to maintain an updated transmission system load/generation/topology database. 3. Prepare full CIM model of the transmission system extended with the distribution system equivalent. This shall be done in fully automatize way, utilizing original transmission system model and extending it with the distribution equivalents (results of step 1). 4. Import full CIM model in power system analysis tool (e.g. PowerFactory), to enable detailed load flow calculations and subsequent dynamic RMS analyses. The results should demonstrate enhanced accuracy in conducting RMS dynamic analysis. In this use case, DSO provides the distribution system model in CIM RDF/XML format and metering data (e.g. metering time series), and creates equivalent distribution network model with the aggregated generation and consumption models. TSO extends transmission grid model in CGMES with the equivalent distribution grid model.

1.5 Key performance indicators (KPI)

<i>Key performance indicators</i>

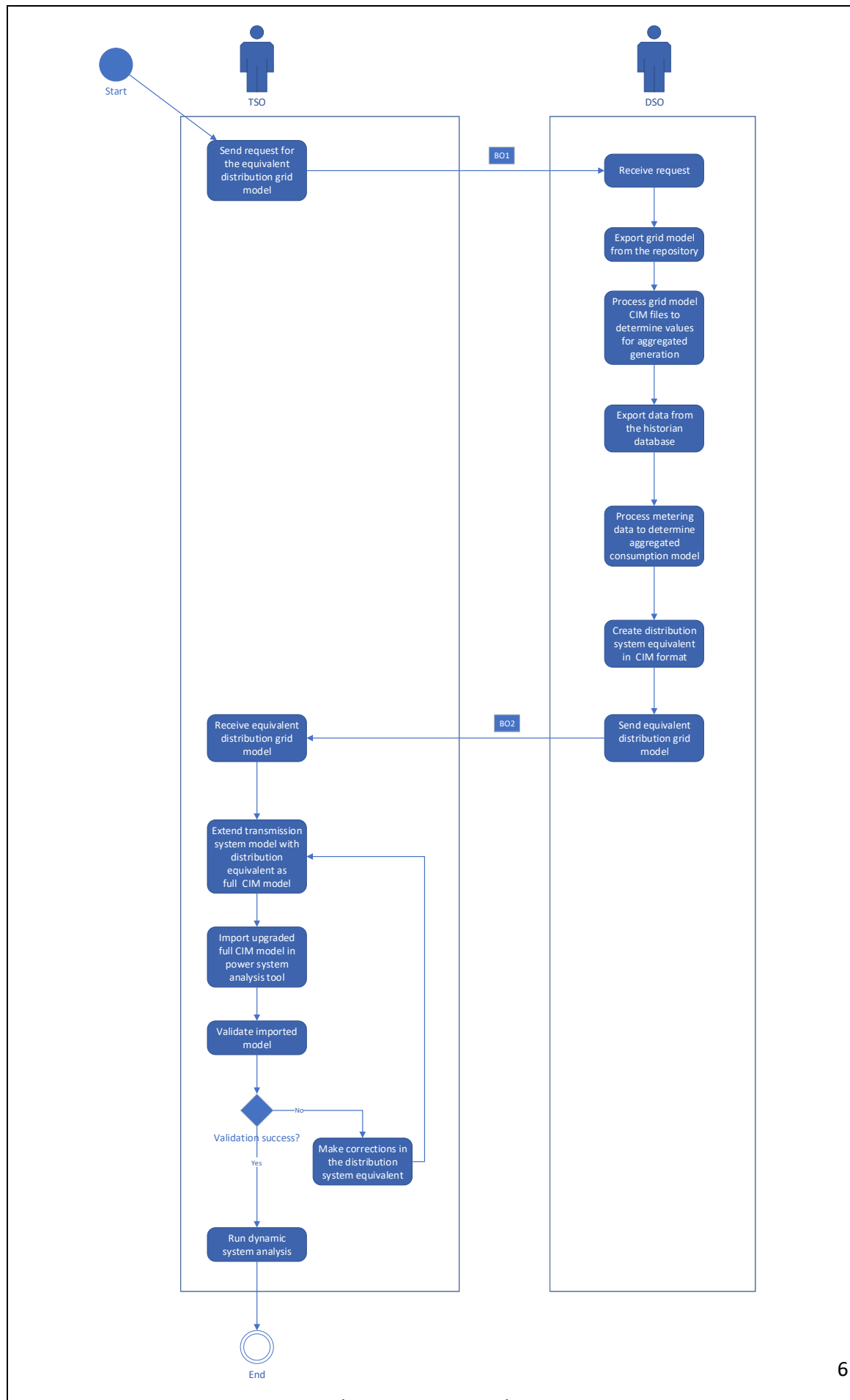
ID	Name	Description	Reference to mentioned use case objectives
1	Equivalent dynamic network model is successfully merged with dynamic transmission network model.		Enhance the dynamic modelling capabilities of the transmission system by integrating an improved distribution system model. Enable the exchange of network models between DSOs and TSO in a standardized and interoperable way. Improve the accuracy of the dynamic analysis of the power system for operational planning and dynamic security assessments, by inclusion of the impact of generation connected to the distribution network.
2	Successful run of dynamic RMS analysis with included equivalent distribution model.		Improve the accuracy of the dynamic analysis of the power system for operational planning and dynamic security assessments, by inclusion of the impact of generation connected to the distribution network. Increase system security and the quality of supply.
3	Voltage and frequency dependency of the load model in the distribution grid		Current distribution grid model includes only simple voltage and frequency dependence of the load in the distribution grid. Evaluation will be done based on the MSE calculation between simulations results with current and improved models.

1.6 General Remarks

General Remarks

2 Diagrams of Use Case

Diagram(s) of Use Case



3 Technical Details

3.1 Actors

Actors			
Grouping		Group Description	
Actor Name <i>see Actor List</i>	Actor Type <i>see Actor List</i>	Actor Description <i>see Actor List</i>	Further information specific to this Use Case
Transmission System Operator (TSO)	Business	According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.	
Distribution System Operator (DSO)	Business	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long term ability of the system to meet reasonable demands for the distribution of electricity or gas. That definition is provided for by art. 2 n. 6 Dir 2007/72/EC with regards to electricity and by art. 2 (6) Dir 2007/73/EC with regards to gas. In the electricity sector distribution means the transport of electricity on high-voltage, medium-voltage and low-voltage distribution systems with a view to its delivery to customers, but does not include supply according to art. 2 (5) Dir, 2007/72/EC. DSOs have to act according to art. 25, 26, 27 Dir. 2007/72/EC (with regards	

		to electricity) and to art. 25, 26, 27 Dir. 2007/73/EC (with regards to gas). The aforementioned provisions provide the tasks and duties of DSOs.	

3.2 Triggering Event, Preconditions, Assumptions

Use Case Conditions			
Actor/System/Information/ Contract	Triggering Event	Pre-conditions	Assumption
DSO	Request for equivalent model of distribution grid	Equivalent model of distribution grid is defined	Distribution grid model is available in CIM format and can be used for the creation of the distribution system equivalent.

3.3 References

References						
No.	References Type	Reference	Status	Impact on Use Case	Originator Organisation /	Link

3.4 Further Information to the Use Case for Classification / Mapping

Classification Information
Relation to Other Use Cases
Level of Depth
Business Use Case - High level
Prioritisation
Medium
Generic, Regional or National Relation
Generic
Viewpoint

Further Keywords for Classification

4 Step by Step Analysis of Use Case

4.1 4.1 Overview of Scenarios

Scenario Conditions					
No.	Scenario Name	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1	TSO retrieves distribution grid model from DSO in CIM format	DSO	TSO includes distribution grid in dynamic system analysis	DSO can create equivalent model in CIM	TSO use power analysis tool which can import grid model in CIM

4.2 Steps – Scenarios

Scenario								
Scenario Name :		No. 1 - ...						
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged	Requirements, R-ID
1		Send request for the equivalent distribution grid model		REQUEST	TSO	DSO	BO	R1
2		Export grid model from the repository	DSO exports distribution grid model from CIM repository	EXECUTE	DSO	DSO		
3		Process grid model CIM files to determine		EXECUTE	DSO	DSO		R2

		values for aggregated generation.						
4		Export data from the historian database	Obtain metering data for the equivalent consumption model.	EXECUTE	DSO	DSO		R3
5		Process metering data to determine aggregated consumption model		EXECUTE	DSO	DSO		R2
6		Create distribution system equivalent in CIM format		CREATE	DSO	DSO		R2, R4
7		Send equivalent distribution grid model		REPORT	DSO	TSO		R5
8		Receive equivalent distribution grid model		GET	TSO	TSO		R5
9		Extend transmission system model with distribution equivalent as full CIM model		EXECUTE	TSO	TSO		R6
9		Import upgraded full CIM model in power system analysis tool		EXECUTE	TSO	TSO		R6

10	Validation fails	Make corrections in the distribution system equivalent	Go back to the step 8	REPEAT	TSO	TSO		
11	Validation success	Run dynamic system analysis		EXECUTE	TSO	TSO		

5 Information Exchanged

Information Exchanged		
Name of Information (ID)	Description of Information Exchanged	Requirements to information data
BO1	Request for the equivalent distribution grid model	This request is json or xml file that contains information about the requested equivalent model.
BO2	Equivalent distribution grid model	CIM RDF/XML file compliant with CGMES profile

6 Requirements (optional)

Requirements (optional)	
Categories for Requirements	Category Description
Requirement ID	Requirement Description
R1	DSO has distribution grid model in CIM and is able to create equivalent model with the aggregated consumption and distributed generation connected to the distribution grid.
R2	The methodology how to create equivalent distribution grid model and necessary data were defined.
R3	Smart metering data and power quality measurements are available for the determination of the equivalent consumption model.
R4	DSO uses appropriate tool to create equivalent distribution grid model in CIM, compliant with CGMES.

R5	Reliable and secure channel for file exchange is established between TSO and DSO (e.g. ECCo SP).
R6	TSO uses appropriate power system analysis tool that can import and manage grid models in CIM CGMES format.

7 Common Terms and Definitions

Common Terms and Definitions	
Term	Definition

8 Custom Information (optional)

Custom Information (optional)		
Key	Value	Refers to Section

B.8.2 BUC 2: Real-time Dynamic RMS Analysis with Transmission System Model improved with the dynamic parameters of generators and control models of the neighbouring TSOs

1 Description of the Use Case

1.1 Name of Use Case

Use Case Identification		
ID	Area / Domain(s)/ Zone(s)	Name of Use Case
SLO-BUC-2	System dynamic analysis	Real-time Dynamic RMS Analysis with Transmission System Model improved with the dynamic parameters of generators and control models of the neighbouring TSOs

1.2 Version Management

Version Management				
Version No.	Date	Name of Author(s)	Changes	Approval Status
1	2024-10-23	N. Suljanović		First draft
2	2024-10-25	J. Lasnik, N. Suljanović	Description of exchanged data	Submitted
3	2024-12-24	N. Suljanović, L. Herman, J. Lasnik, G. Omahen	KPI 4 added	

1.3 Scope and Objectives of Use Case

Scope and Objectives of Use Case	
Scope	Dynamic power system analysis in real-time incorporating detailed dynamic models of neighbouring transmission system operators (TSOs)
Objective(s)	Enable real-time stability analysis and dynamic state monitoring of power system. Establish generator dynamic data exchange between TSOs. Enhance dynamic modelling capabilities of the transmission system by integrating network models from neighbouring TSOs. Improve the accuracy of dynamic power system analysis for dynamic security assessments by accounting for the impact of interconnections. Strengthen system security and ensure higher quality of supply.

	Facilitate the standardized and interoperable exchange of network models between neighbouring TSOs.
Related business case(s)	

1.4 Narrative of Use Case

Narrative of Use Case
Short description This use case defines the process that enables the TSO to perform dynamic security assessments of the power system in real-time. The analysis tool is based on the power system numerical simulation and analysis tool (e.g. DigSILENT PowerFactory) and real-time data exchange with SCADA/EMS. The TSO's dynamic RMS network model is merged with the dynamic RMS network models of neighbouring TSOs (within the TSO's observability area) to enable accurate dynamic RMS analyses. The neighbouring network models include detailed dynamic characteristics of generators connected to the transmission grid. In this use case, neighbouring TSOs exchange dynamic parameters of generators and models of controllers with the set-up parameters via TwinEU federated data exchange.
Complete description This use case describes in detail the dynamic security assessment of the power system in real time, utilising data from SCADA/EMS about the current state of the power system. For the sake of the assessment accuracy, influences from the rest of the continental Europe interconnection on transient states are incorporated in the analysis. According to NC RfG and SO GL, producers are obliged to provide TSOs with accurate and detailed models of power generating modules. TSOs includes these models into the network models of their responsibility area for static and dynamic power system analyses. Each TSO access the dynamic network model of the neighbouring TSOs through the common TwinEU federated data exchange. The use case incorporates the following steps: 1. TSO develops and maintains dynamic RMS power system model in a power system numerical simulation tool (e.g. DigSILENT PowerFactory), appropriate for stability analyses. 2. Static network model of the observability area from SCADA/EMS is exported and imported in the analysis tool. 3. Dynamic internal TSO network model is merged with the model of the observability area. 4. Modifications of the power system model (e.g. correcting generator setpoint with the setpoint outside the operational diagram) and parametrisation of equivalents on the boundary of the model. 5. Retrieval of dynamic parameters of generators and controller models with the set-up data of the neighbouring TSOs via TwinEU federated data exchange middleware. 6. Adding dynamic characteristics (dynamic parameters and control systems) for generators in the observability area. 7. Request the current operational state of the TSO responsible network and observability area from SCADA/EMS and import files in the dynamic security assessment tool. 8. Run power flow analysis and validate results using actual measured power flows and voltages in the network. 9. If validation is successful, run the pre-defined list of dynamic RMS simulations. 10. Calculate network stability indices using RMS simulation results. 11. Visualise network stability indices. In this use case, all processing and analysis is done by TSO. Neighbouring TSOs provide dynamics-related data for generators within their control area.

1.5 Key performance indicators (KPI)

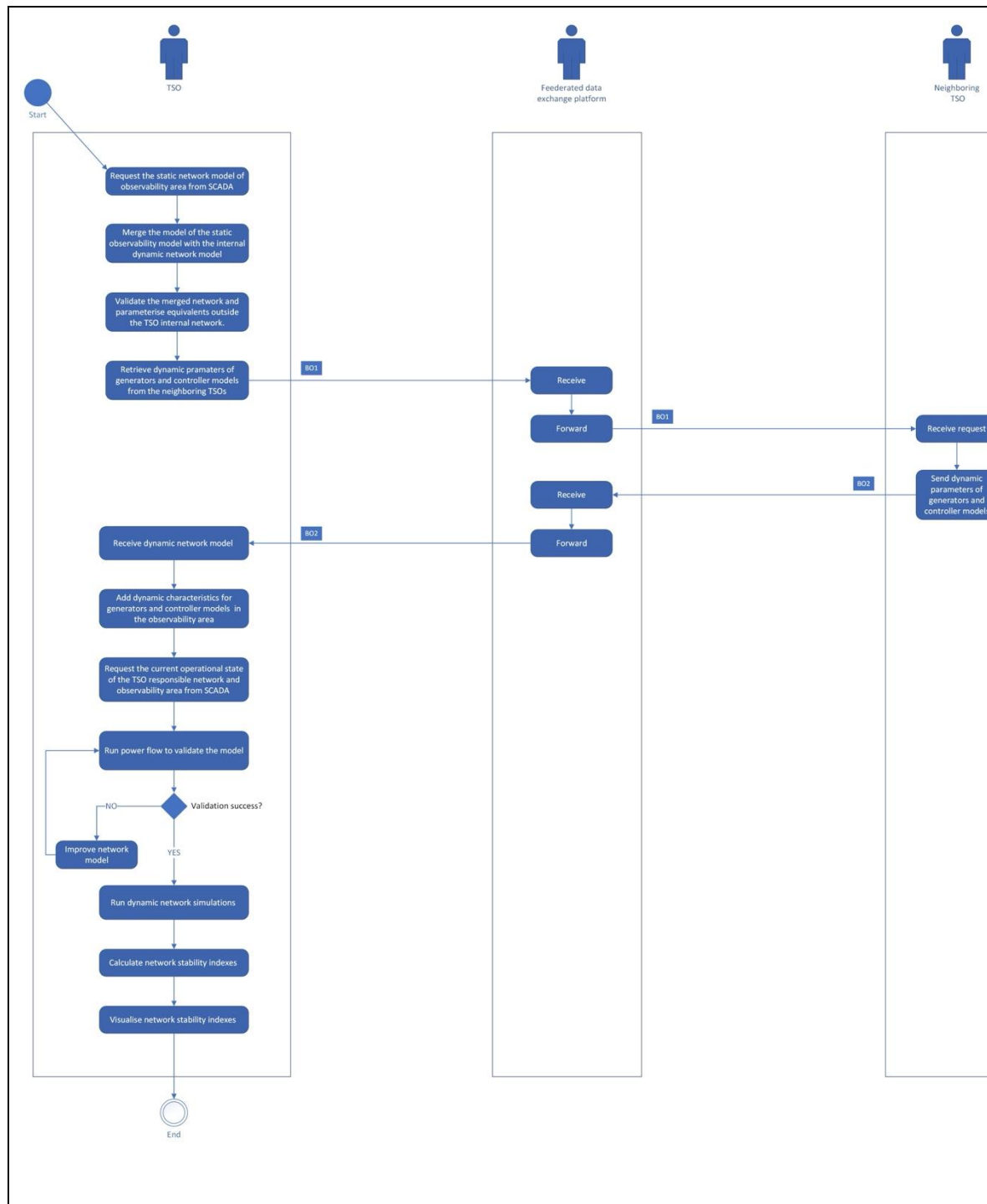
<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
1	Dynamic network models exchange.		Establish dynamic network model exchange between TSOs.
2	Dynamic network model of the transmission grid with observability area is developed.		Enhance dynamic modelling capabilities of the transmission system by integrating network models from neighbouring TSOs. Improve the accuracy of dynamic power system analysis for dynamic security assessments by accounting for the impact of interconnections.
3	Run dynamic network analysis on the extended network model with operational data retrieved from SCADA		Enable real-time stability analysis and dynamic state monitoring of power system. Strengthen system security and ensure higher quality of supply. Facilitate the standardized and interoperable exchange of network models between neighbouring TSOs.
4	Number of TSOs for dynamic data exchange		Data about dynamic generator models are exchanged between neighbouring TSOs. Improve accuracy of dynamic security assessment.

1.6 General Remarks

<i>General Remarks</i>
Business Use Case

2 Diagrams of Use Case

<i>Diagram(s) of Use Case</i>



3 Technical Details

3.1 Actors

Actors	
Grouping	Group Description

Actor Name <i>see Actor List</i>	Actor Type <i>see Actor List</i>	Actor Description <i>see Actor List</i>	Further information specific to this Use Case
Transmission System Operator (TSO)	Business	According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.	
Federated data exchange platform	Business	Federated Data Exchange Platform refers to a software layer (middleware) that facilitates the secure and efficient exchange of data across multiple, distributed systems or organizations in a federated architecture. It serves as an intermediary that enables interoperability between different systems, ensuring that data can be shared, accessed, and integrated without centralizing it in a single repository. This middleware typically supports standardized data formats, ensures data security and compliance with regulations, and manages access control, data transformation, and communication protocols, allowing organizations to collaborate and share data while maintaining control over their own datasets.	

3.2 Triggering Event, Preconditions, Assumptions

Use Case Conditions			
Actor/System/Information/Contract	Triggering Event	Pre-conditions	Assumption

TSO	Request for dynamic network model or data of the neighbouring TSOs	Each European TSO published its dynamic network model/data	Dynamic network model is available in CIM CGMES or Power Factory format.

3.3 References

<i>References</i>						
<i>No.</i>	<i>References Type</i>	<i>Reference</i>	<i>Status</i>	<i>Impact on Use Case</i>	<i>Originator / Organisation</i>	<i>Link</i>
1	regulation	Network Code on Requirements for Generators	Active	Defines data needed for exchange	ENTSO-E	
2	regulation	System Operation Guidelines (articles 41 and 45)	Active	Defines the exchange of generator data between TSOs	ENTSO-E	

3.4 Further Information to the Use Case for Classification / Mapping

<i>Classification Information</i>
<i>Relation to Other Use Cases</i>
<i>Level of Depth</i>
Business Use Case (BUC) - High level
<i>Prioritisation</i>
Medium priority
<i>Generic, Regional or National Relation</i>
Regional
<i>Viewpoint</i>
<i>Further Keywords for Classification</i>
BUC, dynamic system security assessment

4 Step by Step Analysis of Use Case

4.1 4.1 Overview of Scenarios

Scenario Conditions					
No.	Scenario Name	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	TSO request dynamic parameters of generators and controller models	TSO	Need to improve accuracy of dynamic security assessment	Dynamic parameters of generators and controller models are available.	Improved dynamic model of power system.

4.2 4.2 Steps – Scenarios

Scenario								
Scenario Name :		No. 1 - TSO request dynamic parameters of generators and controller models						
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged	Requirements, R-ID
1		Request the network model	Request the static network model of observability area from SCADA	REQUEST	TSO	Federated data exchange platform	BO1	
2		Forward request		FORWARD	Federated data exchange platform	Neighbouring TSO	BO1	
3		Send data	Send dynamic parameters of generators and controller models	REPORT	Neighbouring TSO	Federated data exchange platform	BO2	
4		Forward data		FORWARD	Federated data exchange platform	TSO	BO2	

5		Add dynamic characteristics for generators and controller models in the observability area		EXECUTE	TSO			
6		Request the current operational state of the TSO responsible network and observability area from SCADA		EXECUTE	TSO			
7		Run power flow to validate the model	Repeat until success	EXECUTE	TSO			
8		Run dynamic network simulations		EXECUTE	TSO			
9		Calculate network stability indexes		EXECUTE	TSO			
10		Visualise network stability indexes		EXECUTE	TSO			

5 Information Exchanged

Information Exchanged		
Name of Information (ID)	Description of Information Exchanged	Requirements to information data

BO1	Request for the dynamic parameters of generators and controller models of the neighbouring TSO	Since data is exchanged via federation-based data exchange platform, some messaging mechanism shall be used to address proper TSO.
BO2	Dynamic parameters of generators and controller models with the setup data	It includes all the data necessary for the dynamic simulations, such as dynamic parameters of generation and control systems.

6 Requirements (optional)

Requirements (optional)	
Categories for Requirements	Category Description
DNM	Dynamic network model
Requirement ID	Requirement Description
DNM-1	Each TSO maintains it's dynamic network model, which includes dynamic parameters of generators and controller models, in accordance with RfG.

7 Common Terms and Definitions

Common Terms and Definitions	
Term	Definition

8 Custom Information (optional)

Custom Information (optional)		
Key	Value	Refers to Section

B.8.3 SUC 1: Power system analysis tool retrieves operational data from SCADA/EMS

1 Description of the Use Case

1.1 Name of Use Case

<i>Use Case Identification</i>		
<i>ID</i>	<i>Area / Domain(s)/ Zone(s)</i>	<i>Name of Use Case</i>
SLO-SUC-1	Power system analysis	Power system analysis tool retrieves operational data from SCADA/EMS

1.2 Version Management

<i>Version Management</i>				
<i>Version No.</i>	<i>Date</i>	<i>Name of Author(s)</i>	<i>Changes</i>	<i>Approval Status</i>
1	2024-11-06	N. Suljanović		First draft
2	2024-11-06	J. Lastnik	Changes in the SUC description and information exchange	Second draft

1.3 Scope and Objectives of Use Case

<i>Scope and Objectives of Use Case</i>	
<i>Scope</i>	Power system numerical simulations and analysis
<i>Objective(s)</i>	Provide numerical analysis and simulation tools with operational data from SCADA/EMS for various purposes, such as dynamic security assessment.
<i>Related business case(s)</i>	SLO-BUC-2: Real-time Dynamic RMS Analysis with Transmission System Model improved with the dynamic parameters of generators and control models of the neighbouring TSOs

1.4 Narrative of Use Case

<i>Narrative of Use Case</i>
<i>Short description</i>
This use case defines the procedure in which power system analysis and simulation tool (such as DigSILENT PowerFactory) retrieves operational data from SCADA/EMS. The SCADA/EMS system periodically dumps snapshots of the current operation state of the power system and these data are stored on the shared disk. Power system analytic tool (such as DigSILENT PowerFactory) accesses these data and imports it for further analysis.

Complete description

This use case describes how a power system simulation and analysis tool (e.g., DigSILENT PowerFactory) accesses operational data required for various analyses and assessments. The SCADA/EMS system periodically generates snapshots of the current operational state of the power system in various formats (CIM, PSS/E, TXT). These files contain essential data such as generation and consumption values, the operational state of circuit breakers and disconnectors, and measurements of power flows, voltages, and currents.

The SCADA/EMS system periodically saves the snapshots to a shared disk. The power system simulation and analysis tool is granted authorization to access this disk and retrieve the data. Once the data is retrieved, it is imported into the simulation tool for further analysis.

1.5 Key performance indicators (KPI)

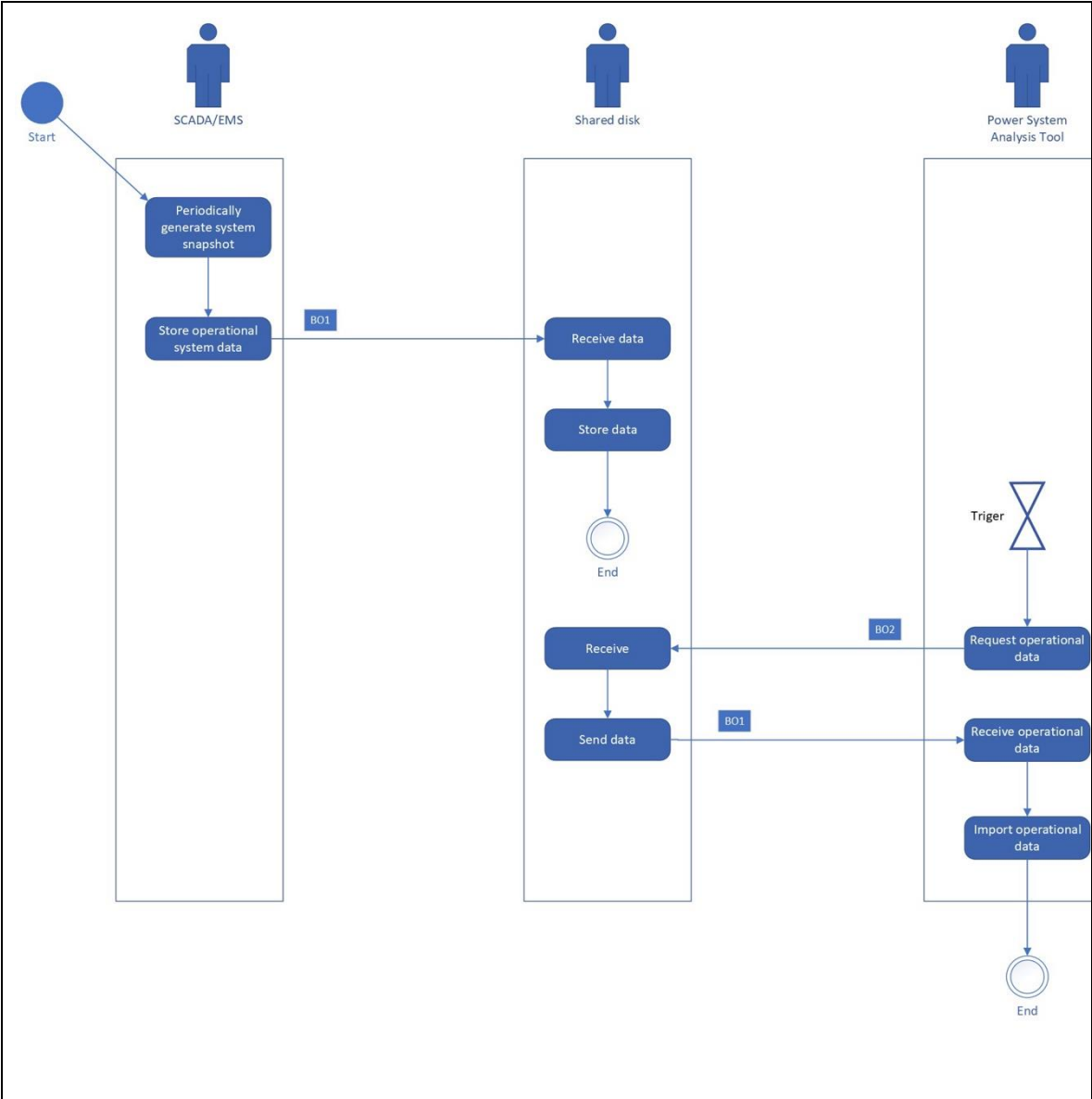
<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
1	Operational data are successfully retrieved and imported in the simulation tool.		Provide numerical analysis and simulation tools with operational data from SCADA/EMS for various purposes, such as dynamic security assessment.

1.5 General Remarks

<i>General Remarks</i>
System Use Case (SUC)

2 Diagrams of Use Case

<i>Diagram(s) of Use Case</i>



3 Technical Details

3.1 Actors

Actors			
Grouping		Group Description	
Actor Name	Actor Type	Actor Description	Further information specific to this Use Case
see Actor List	see Actor List	see Actor List	
SCADA/EMS	System	A supervisory control and data acquisition/energy management system that enables real-time	

		monitoring, control, and data collection from field devices, providing operators with a centralized view of system performance. It plays a critical role in ensuring safe and reliable operation by allowing remote command execution, alarm management, and data analysis to support decision-making and maintain operational stability.	
Power System Analysis Tool	System	A software application used to model, simulate, and analyse electrical power systems. It helps engineers and operators assess network stability, optimize performance, and predict the behaviour of the system under various conditions, including load variations, faults, and contingency scenarios. This tool plays a crucial role in planning, operation, and reliability assessment by providing insights into power flow, voltage stability, and system dynamics, enabling informed decisions to ensure efficient and secure power delivery.	
Shared disk	System	A storage device accessible by multiple computers or servers within a network, allowing them to read and write data concurrently. This setup facilitates data sharing and collaboration across systems while maintaining a centralized data repository.	

3.2 Triggering Event, Preconditions, Assumptions

Use Case Conditions			
Actor/System/Information/ Contract	Triggering Event	Pre-conditions	Assumption
Power System Analysis Tool	Request for operational data	SCADA/EMS dumps snapshots of the system on the shared disk.	Power System Analysis Tool can reach data on the shared disk.

3.3 References

<i>References</i>						
<i>No.</i>	<i>References Type</i>	<i>Reference</i>	<i>Status</i>	<i>Impact on Use Case</i>	<i>Originator Organisation /</i>	<i>Link</i>

3.4 Further Information to the Use Case for Classification / Mapping

<i>Classification Information</i>
<i>Relation to Other Use Cases</i>
<i>Level of Depth</i>
System Use Case (SUC) - High level
<i>Prioritisation</i>
Medium priority
<i>Generic, Regional or National Relation</i>
Regional
<i>Viewpoint</i>
<i>Further Keywords for Classification</i>
SUC, SCADA, operational data access

4 Step by Step Analysis of Use Case

4.1 Overview of Scenarios

<i>Scenario Conditions</i>					
<i>No.</i>	<i>Scenario Name</i>	<i>Primary Actor</i>	<i>Triggering Event</i>	<i>Pre-Condition</i>	<i>Post-Condition</i>

4.2 Steps – Scenarios

Scenario								
Scenario Name :		Access to power system operational data						
Step No.	Event	Name of Process/ Activity	Description of Process/ Activity	Service	Information Producer (Actor)	Information Receiver (Actor)	Information Exchanged	Requirements , R-ID
1		Periodically generate system snapshot	Generate operational data set	EXECUTE	SCADA/EMS	SCADA/EMS		OD-1
2		Store operational system data	SCADA dumps operational data to the shared storage	FORWARD	SCADA/EMS	Shared disk	BO1	OD-1
3		Receive and store data	Power system snapshot is stored on the shared storage	EXECUTE	Shared disk	Shared disk		
4		Request operational data	Power system analysis tool access operational data	REQUEST	Power system analysis tool	Shared disk	BO2	
5		Send operational data	Power system tool retrieves operational data	REPORT	Shared disk	Power system analysis tool	BO1	

5 Information Exchanged

Information Exchanged		
Name of Information (ID)	Description of Information Exchanged	Requirements to information data

BO1	Snapshot of the power system in a given moment. It includes generation, load, voltages and states of switching elements. Data is stored in various formats (CIM, PSS/E, TXT).	Power system analysis tool is interoperable with data in CIM CGMES and PSS/E format.
BO2	Request for operational data	This is not a message, but rather a part of the SFTP protocols to retrieve data from the shared disk.

6 Requirements (optional)

Requirements (optional)	
Categories for Requirements	Category Description
OD	Operational data
IO	Interoperability
Requirement ID	Requirement Description
OD-1	The SCADA/EMS system periodically generates power system snapshot in various formats (CIM XML format, PSS/E, TXT).
IO-1	Power system analysis tool is able to import and export data in CIM CGMES and PSS/E format.

7 Common Terms and Definitions

Common Terms and Definitions	
Term	Definition

8 Custom Information (optional)

Custom Information (optional)		
Key	Value	Refers to Section