Use Cases & Digital Twin Solutions

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DSO ENTITY
DSOs FOR EUROPE

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Acronyms

AC	Alternating Current
ADMS	Advanced Distribution Management System
AG	Average Grade
AI	Artificial Intelligence
ANS	Advanced National Solution
APM	Asset Performance Management
BIM	Building Information Model
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
CENELEC	European Electrotechnical Committee for Standardisation
CGM	Common Grid Model
CGMES	Common Grid Model Exchange Standard
CIM	Common Information Model
CPS	Cyber-Physical System
DAR	Dynamic Asset Rating
DER	Distributed Energy Resources
DESAP	Digitalisation of Energy System EU Action Plan
DLR	Dynamic Line Rating
DSO	Distribution System Operator
DSR	Demand-Side Response
DT	Digital Twin
EU	European Union
EV	Electric Vehicle
FMM	Fundamental Market Model
GIS	Geographic Information System
HiL	Hardware in the Loop
HILF	High Impact Low Frequency
HV	High Voltage
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Committee
IGM	Individual Grid Model
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technology
JTF	Joint Task Force
LV	Low Voltage
MARI	Manually Activated Reserves Initiative
MTU	Market Time Unit
MVS	Minimum Viable Solution
MV	Medium Voltage
OPC/STA	Outage Planning Coordination/ Short-Term Adequacy
OPDM	Outage Planning Data Management
OT	Operational Technology
PMU	Phasor Measurement Unit
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
PV	Photovoltaic
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SGAM	Smart energy Grid Architecture Model
SGI	Smart Grid Indicators
SoS	System of Systems
SOTA	State-of-the-Art
TC	Technical Committee
TSO	Transmission System Operator
UC	Use Case
VAMOS	Varied Market-Model Operating System
WAMPAC	Wide Area Monitoring, Protection, and Control
WP	Work Package

Contents

Executive Summary

Europe's electricity system is at a pivotal moment, transitioning towards a low-carbon, integrated future. Digitalisation is one of the cornerstones of this transformation, enabling smarter planning, real-time operations, and consumer engagement. Building on the previous Digitalisation of Energy System EU Action Plan (DESAP) report on TSO–DSO challenges, this study moves from analysis to action, defining strategic goals, identifying gaps, and presenting concrete solutions through digital twin (DT) use cases (UCs) and integration requirements.

The previous DESAP report identified fragmented data systems, limited forecasting accuracy, and regulatory constraints as major obstacles to digitalisation. It emphasised the need for a harmonised approach to DT adoption, supported by clear governance structures, interoperability standards, and high-quality data to enable effective decision-making. The report also identified high-level goals into clusters that serve as a starting point for this work.

High-Level Goals

PRIORITIES ARE GROUPED INTO THREE CLUSTERS

- **Cluster 1 – Customers, business, market, data and information exchange:**
  Enable active consumer participation in explicit flexibility markets through standardised interfaces and improve real-time grid visibility across all voltage levels.

- **Cluster 2 – System planning, future flexibility, and asset lifecycle:**
  Use predictive analytics for anticipatory investments, optimise hosting capacity, and strengthen resilience with advanced measures like microgrids and islanding.

- **Cluster 3 – System operations, dynamics, and control rooms of the future:**
  Enhance forecasting and data aggregation, enable coordinated security analysis between transmission system operators (TSOs) and distribution system operators (DSOs), and provide shared decision-support tools for control rooms.

This report responds by outlining actionable steps to accelerate digitalisation across Europe's electricity system to achieve these goals, combining a landscape assessment with a gap analysis to identify shortcomings in current DT development. Based on these insights, UCs were developed, ensuring scalability from national minimum viable solutions (MVSs) to pan-European implementations. To facilitate implementation, the MVS is further detailed and provided in the IEC 62559 standard. This approach links strategic goals to actionable solutions, guiding operators towards harmonised, future-proof digitalisation.

As part of the landscape assessment, it was recognised that European initiatives like TwinEU and Integrated Network for Data Space and Interoperable Energy Management in Europe (INSIEME) have made strong progress in creating secure data spaces and piloting DT applications, yet most pilots remain fragmented and focused on local UCs. From the assessment, the Joint Task Force (JTF) identified key gaps across all domains that can inform future goals.

First, **consumer flexibility** is treated as disconnected processes with low-voltage levels of observability and undefined aggregator interfaces. Second, **grid planning** lacks essential sector coupling and cross-operator alignment, while distributed energy resource (DER) capabilities like islanding and black-start for increased resilience remain underused or unexplored. Finally, **operational security** remains limited to isolated studies, missing the continuous, real-time coordination required for joint TSO–DSO decision-making.

Detailed Use Cases

- **Cluster 1 – Consumer Flexibility**
  UC1 enables aggregators to manage and value consumer explicit flexibility (for all types of technologies) through standardised DT interfaces, real-time data, and advanced analytics. Implementation ranges from foundational national solutions to fully integrated European platforms for automated cross-border flexibility trading.

- **Cluster 2 – Grid Planning & Resilience**
  UC2.1 supports joint TSO–DSO planning through shared data, scenario-based methodologies, as well as harmonised assumptions, enabling anticipatory investment and optimised hosting capacity.

  UC2.2 addresses resilience against high-impact, low-frequency (HILF) events by modelling and simulating coordinated restoration strategies using DER-based flexibility. Both UCs progress from basic coordination to pan-European DT environments for harmonised planning and recovery.

- **Cluster 3 – Operational Security**
  UC3.1 enables coordinated TSO–DSO security assessments for congestion management, voltage control, and dynamic stability. It evolves from secure data exchange and offline simulations to federated European platforms for real-time cross-border security coordination.

To translate these UCs into operational reality, operators must define specific functional and non-functional integration requirements. With this in mind, this report also highlights different layers – Data & Information, Communication & Interfaces, Application & Processing, and Governance & Security – and assesses local and common requirements in relation to the European framework.

By combining strategic goals, actionable UCs, and clear integration guidelines, this report provides the foundation for a roadmap to accelerate digitalisation and DT adoption, which will be part of the following deliverable 4.1. It will describe a harmonised, interoperable approach that strengthens resilience and enhances flexibility, addressing current and future challenges of Europe's electricity system.

CHAPTER 1

Introduction and Background

Definition of a Digital Twin

A Digital Twin (DT) is best understood as a dynamic, virtual counterpart of a physical system, asset, or process within the electricity grid. Unlike traditional simulation models, a DT is continuously and intimately connected to the physical world equivalent through electricity data exchange. This connection allows the DT to mirror the evolving state of the physical system, adapting to changes and providing a living model that supports advanced analysis, prediction, and optimisation.

While real-time data exchange is a hallmark and often the most valuable feature of DTs, enabling immediate diagnostics, predictive maintenance, and control, a DT can also utilise near-real-time and historical / static data depending on the specific application (monitoring, optimisation, or planning).

In the context of the European electricity system, DTs are emerging as a cornerstone technology for TSOs and DSOs. DTs enable system operators to assimilate vast streams of observational data, whether from sensors, smart meters, or manual inspections, and use this information to update internal models. These models do not merely replicate physical characteristics; they actively support decision-making by forecasting potential issues, simulating operational scenarios, and optimising asset performance across the entire life cycle, from initial design and planning to maintenance and real-time operation.

> "A Digital Twin (DT) is best understood as a dynamic, virtual counterpart of a physical system, asset, or process within the electricity grid."

DTs can be deployed at different scales. Some are **local**, focusing on specific assets or UCs, such as a high-voltage substation or modelling customer behaviour in response to real-time pricing.

Others are **integrated**, encompassing entire transmission or distribution networks and providing a comprehensive digital model of infrastructure. It is important to note that in practice, these integrations are largely limited to conceptual design and proof-of-concept pilots. At the highest level, DTs can form a **"system of systems"**, where independently managed DTs, often operated by different organisations, are interconnected through standardised data exchange and governance frameworks. This enables collaboration across TSOs, DSOs, and other stakeholders, supporting shared goals such as grid resilience, flexibility, and efficient market integration.

Ultimately, a DT is more than a technical tool; it is a strategic enabler for the digitalisation of the European electricity system. By providing enhanced observability, predictive capabilities, and interoperability, DTs empower operators to address the challenges of integrating distributed energy resources, managing increasing demand, responding to weather anomalies, and safeguarding against cyber threats. In doing so, they help create a more sustainable, secure, and competitive energy market for Europe.

About the Report

ENTSO-E and EU DSO Entity work in collaboration on the JTF for DESAP. The initiative is driven by the European Commission's action plan for [Digitalising the energy system – EU action plan] (COM/2022/552).

The European digital plan is helping achieve parts of the EU's energy policy and aims to develop a sustainable, secure, transparent, and competitive market for digital energy services [1].

Digitalisation of Energy System EU Action Plan

JTF DESAP's main goal is to develop a DT of the electricity grid of adequate granularity and develop guidance and support for network operators on sustainable and cost-effective smart investments using smart grid indicators (SGIs) [2].

To meet these goals, it plans to [2]:

- Enlist a set of business user requirements for the DT, addressing present and future energy system challenges from both the TSO and DSO perspectives.
- Define a set of conceptual UCs addressing the current and future challenges of a digitalised European electricity grid and helping to enhance the grid's smartness.
- Identify the current state of implementation of DT technologies in the power sector to prioritise challenges and develop requirements.
- Define the interoperability requirements based on the Smart Energy Grid Architecture Model (SGAM) reference architecture, which will support the implementation of the DT UCs.
- Provide a shared definition of DT platforms for the TSO/DSO sector.
- Define a set of smart indicators depicting the level of smartness and effectiveness of network operations.

This report is a deliverable from work package (WP) 3 of the JTF DESAP project, denoted as D3.1 (deliverable 1 in WP3) in Figure 3. WP1 focuses on administration and management, while WP2 is dedicated to identifying challenges and opportunities in DT development, including conducting a state-of-the-art (SOTA) and gap analysis. WP3 concentrates on creating UCs, DT solutions, and SGIs. Finally, WP4's main task is to develop a roadmap for digitalisation and enhance DT capabilities.

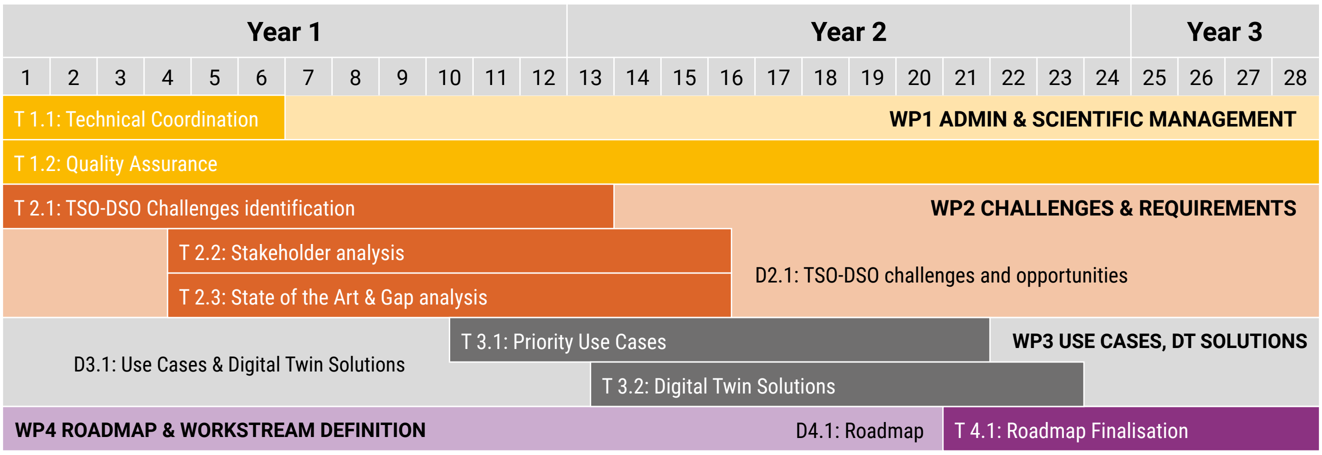


Figure 1: JTF DESAP work programme

According to the DESAP project plan, this deliverable (D3.1) shall provide [2]:

"A report with a compilation of concrete UCs derived from identified real-world challenges, enhancing the smartness of the electricity system, prioritised based on impact, urgency, and feasibility, with tangible results. The report outlines DT technical specifications, functionalities, and integration prerequisites.

The report also includes a definition of DT solutions harnessing advanced technologies, offering innovative approaches to tackle identified issues and enhance the energy system".

This report is the deliverable for this objective in JTF DESAP.

Structure of the Report

Chapter 1 outlines the background and context of this report in the DESAP programme and provides an overview of the report. Chapter 2 describes the high-level goals that guided the rest of the work, while Chapter 3 presents the methodology and approach used to develop the UCs. Chapter 4 presents and analyses different DT initiatives in the context of European system operators and performs a gap analysis in relation to the high-level goals.

Chapter 6 builds on these proposed UCs to outline how system operators can define their specific requirements for DT deployment, while also highlighting key common integration challenges. Finally, Chapter 7 summarises the main conclusion and key insights.

CHAPTER 2

High-level Goals

The transformation of Europe's electricity system is at a pivotal moment, driven by the urgent need for digitalisation to meet decarbonisation targets, integrate renewables, and empower consumers. The ENTSO-E–DSO ENTITY TSO-DSO Challenges & Opportunities for the Digital EU Electricity System report, a previous DESAP deliverable, identified the deployment of DT technologies as a cornerstone for future grid operation, planning, and customer integration.

DTs are not just advanced simulation tools; they are dynamic, virtual counterparts of physical grid assets and processes, continuously updated through real-time data exchange. Their implementation is essential for improved monitoring, prediction, and decision-making across the entire life cycle of grid assets: from planning and development to operational monitoring, predictive maintenance, asset management, replacement planning, and scenario simulation.

The European power system is undergoing a profound transformation, shaped by a convergence of complex challenges. At the forefront is the rapid expansion of DER and renewables, which is fundamentally altering the grid's architecture and demanding new, coordinated approaches to planning and operational management. As electrification accelerates across sectors like transport and heating, the pressure on grid capacity intensifies, making timely and accurate investment decisions more critical than ever.

This evolving landscape is further complicated by increasing weather anomalies and climate-driven variability. Fluctuations in production and consumption, driven by unpredictable weather patterns, require advanced forecasting capabilities to maintain secure and optimal grid operations.

Meanwhile, the sector must also contend with a shifting geopolitical environment and the growing threat of cyber risks. These realities underscore the necessity for robust, data-driven resilience strategies and security measures to safeguard the grid against both physical and digital disruptions.

Together, these challenges highlight the urgency of digitalisation and the strategic importance of deploying DT technologies. By enabling real-time monitoring, predictive analytics, and informed decision-making, DTs offer a pathway to a more flexible, resilient, and future-ready European electricity system – one that can adapt to rapid change, empower consumers, and support Europe's decarbonisation ambitions.

Against this backdrop of accelerating complexity and rising system demands, the DESAP project organises these needs into a set of thematic clusters that translate high-level challenges into concrete, actionable areas for DT development. The following sections introduce these clusters, beginning with the one most closely linked to consumer engagement and system observability.

Cluster 1:
Customers, Business, Market, Data and Information Exchange

The evolving energy landscape calls for a more active role for consumers and a deeper, real-time understanding of grid behaviour across all voltage levels. As electricity systems become increasingly decentralised and dynamic, the ability to integrate consumer flexibility (for all technology types) and ensure seamless data exchange between actors is no longer optional – it is foundational. This cluster focuses on enabling end-users to participate meaningfully in flexibility markets, supported by intuitive digital interfaces and interoperable platforms.

At the same time, it addresses the need for enhanced observability and coordination across transmission and distribution networks, ensuring that system operators can anticipate and respond to grid needs with precision. These priorities reflect a broader shift towards a more interactive, transparent, and resilient electricity system – one that is capable of adapting to fluctuating demand, integrating distributed resources, and unlocking the full potential of digitalisation.

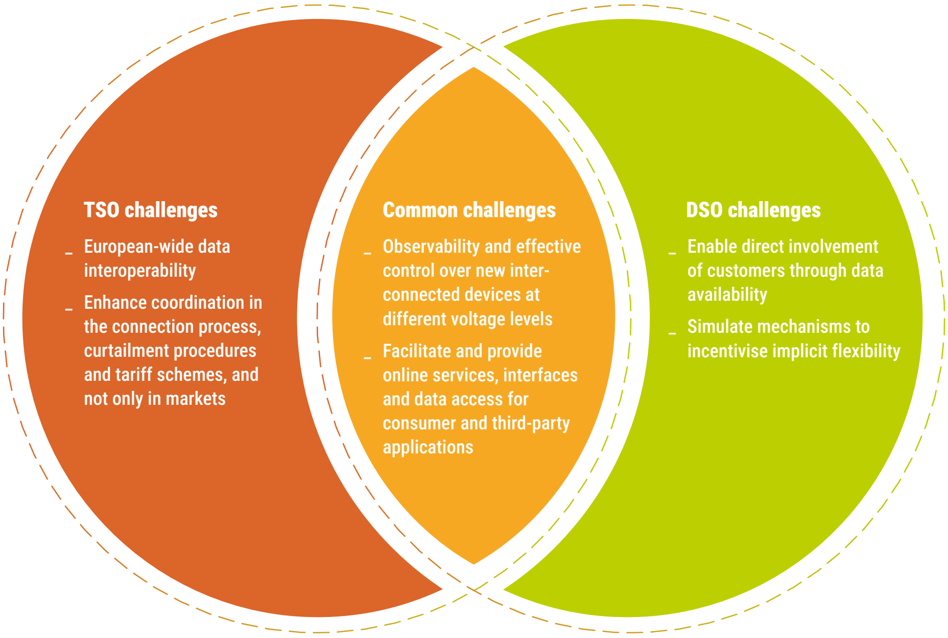


Figure 2: Cluster 1 mapping of TSO–DSO challenges

High-level definition

The DT enables consumer-centric flexibility, enhances grid observability across high voltage (HV), medium voltage (MV), and low voltage (LV) with new interfaces. It enables the identification of grid needs for flexibility.

With an easy, standardised interface, this will be possible with scalable, responsive flexibility services to the market and system operators to increase grid capacity and utilisation.

Sub-areas

Enhanced consumer-centric flexibility:

This sub-UC focuses on empowering consumers to actively engage by providing them with tools and standardised interfaces that enable flexibility across technologies. Since individual households and small businesses have limited flexible resources, activating them at scale requires intermediaries such as aggregators, which can pool flexibility from many small units and make it useful for both DSO and TSO needs. To secure aggregator participation, it is essential to provide data and build efficient processes. DTs and available data can support TSOs and DSOs in defining flexibility requirements and UCs that ensure operational reliability, while providing aggregators with the visibility they need to develop their business.

Integrated observability across all voltage levels:

Improved observability allows for continuous monitoring of grid performance at all voltage levels. The integration of real-time data feeds ensures improved identification of grid stress points, faults, and inefficiencies.

Flexibility assessment (system and grid needs) and market integration:

This sub-UC focuses on identifying and quantifying flexibility requirements within the grid. It provides a dynamic view of the grid's operational needs, allowing TSOs and DSOs to pinpoint specific areas where flexibility is needed, whether due to congestion or voltage issues, renewable energy variability, or shifting demand. This information is then used to seamlessly integrate flexibility services into energy markets through standardised platforms, enabling demand response aggregators, energy service providers, and prosumers to offer their resources.

These objectives for consumer-centric flexibility, enhanced observability, and market integration are closely informed by the insights of DESAP's Deliverable 2.1. Consumer-centric flexibility focuses on the user experience – measured not only by operational efficiency but primarily by customer satisfaction and convenience (for all technology types). The report emphasises the need for digital solutions that foster flexibility across grid users, facilitate seamless data exchange, and support active participation in flexibility markets. It also highlights the importance of standardised, interoperable interfaces and real-time data integration, which enable more accurate and timely system information – a prerequisite for improved grid visibility and operational responsiveness. By aligning DT capabilities with these priorities, system operators can address evolving market demands and foster a more interactive, resilient, and efficient electricity system.

Cluster 2:
System Planning, Future Flexibility, and Asset Lifecycle

As Europe's electricity system evolves, proactive planning and adaptive asset management become essential. This cluster focuses on equipping system operators with digital tools to anticipate future flexibility needs, optimise grid investments, and extend asset life cycles. By integrating predictive analytics, spatial planning, and interoperable data models, operators can better align infrastructure with long-term system goals, ensuring resilience, efficiency, and readiness for a digital energy future.

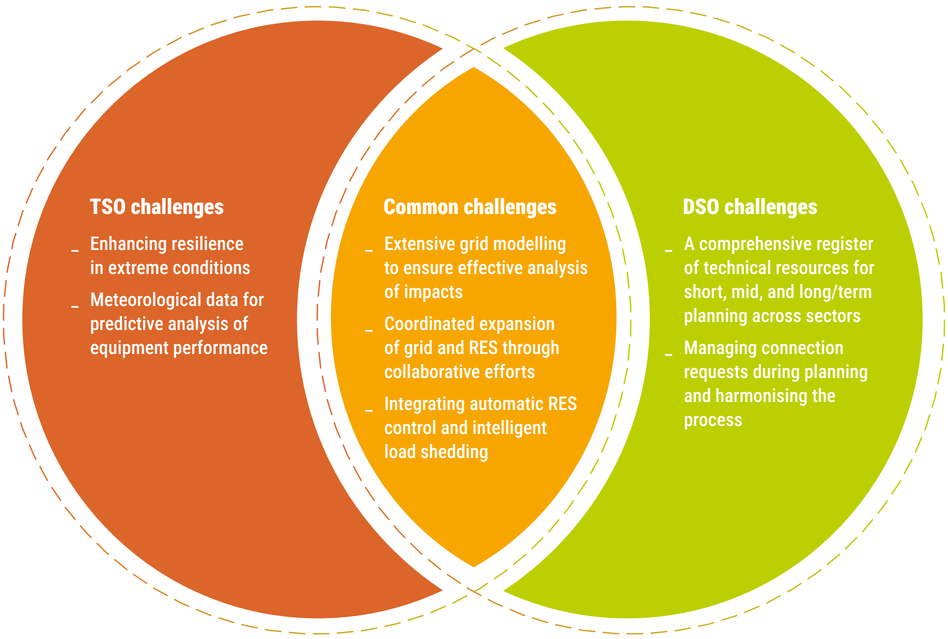


Figure 3: Cluster 2 mapping of TSO–DSO challenges

High-level definition

The DT employs granular, high-resolution data analysis to ensure anticipatory investment, hosting connections, and resilience. A proactive approach supports anticipatory investments, i. e. by being aware of potential new connections early. The DT performs assessments of flexibility and non-conventional measures to increase resilience, i. e. microgrids, in case of outages or special weather events.

Sub-areas

Data-driven anticipatory investment planning:

The DT leverages granular, high-resolution data to forecast emerging energy demands, such as electrified transport nodes, industrial growth areas, etc. By identifying these trends early, the DT enables proactive planning of infrastructure upgrades, reducing costs and preventing bottlenecks. This ensures investments are made efficiently, minimising the risks of underutilisation or overcapacity.

Hosting capacity optimisation:

The DT continuously assesses grid capacity to host new connections, including renewable energy sources (RES), electric vehicles (EVs), and distributed energy systems. Through detailed simulations, it identifies weak points and suggests upgrades to ensure that connections are managed seamlessly, avoiding overloading existing infrastructure and maximising the efficiency of decentralised energy integration.

Resilience enhancement through advanced measures (islanding, flexibility, black-start):

This sub-UC evaluates advanced measures like islanding, black-start capabilities, and flexibility solutions such as microgrids and demand-side response to strengthen grid resilience. By simulating contingency scenarios, it identifies vulnerabilities and recommends pre-emptive actions to mitigate disruptions caused by extreme weather, equipment failures, or other external factors. All these efforts ensure recovery and service continuity while minimising reliance on traditional infrastructure reinforcements.

These ambitions for anticipatory investment, hosting capacity, and resilience are strongly supported by the insights of the ENTSO-E–DSO ENTITY TSO-DSO Challenges & Opportunities for the Digital EU Electricity System report. The report emphasises the importance of leveraging granular, high-resolution data and advanced modelling to forecast emerging energy demands, optimise infrastructure upgrades, and coordinate the integration of renewables and new technologies. It also highlights the need for proactive planning and innovative resilience measures, such as microgrids, islanding, and black-start capabilities, to ensure the grid can withstand extreme weather events and evolving operational risks. By aligning DT solutions with these priorities, system operators can address both immediate and long-term challenges, making the grid more adaptive, efficient, and robust.

Cluster 3:
System Operations, Dynamics, and Control Rooms of the Future

As the electricity system becomes more complex and interconnected, real-time operational excellence is critical. This cluster focuses on enhancing system dynamics, control room capabilities, and cross-sector coordination.

It prioritises advanced forecasting, artificial intelligence (AI)-driven decision support, and resilient system design to manage volatility and integrate emerging technologies. These efforts reflect a broader push towards smarter, interoperable operations that can adapt to HILF events and ensure stability in a digitalised energy landscape.

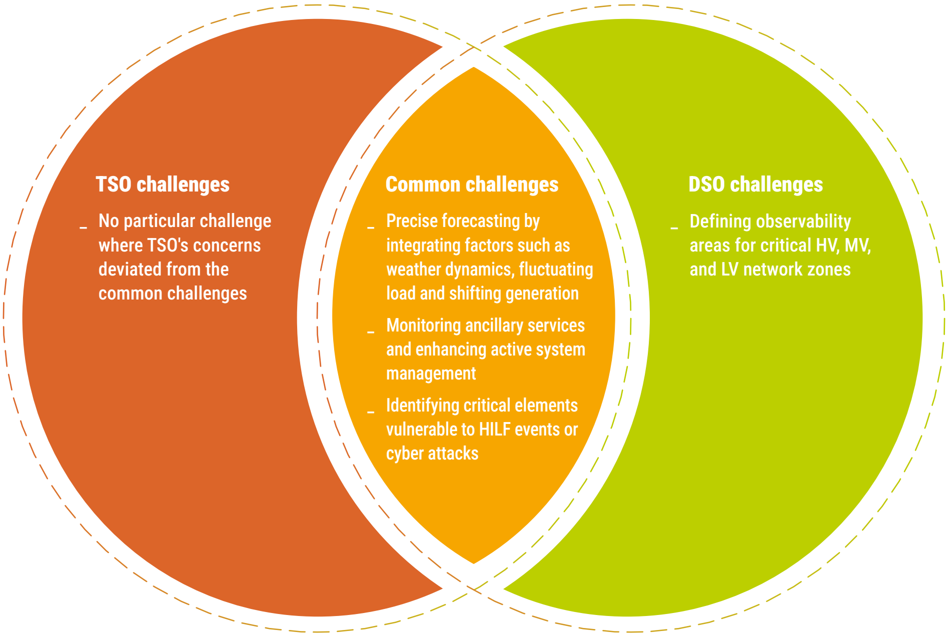


Figure 4: Cluster 3 mapping of TSO–DSO challenges

High-level definition

The DT aims to enable macro-level data utilisation/aggregation/post-processing to support informed decision-making in control rooms.

Coordinated security analysis can help optimise system operations. The uncertainty of solar production and load makes the estimated power flow uncertain.

A coordinated security analysis using aggregated data from DSOs and balancing responsible party (BSPs)/balancing service providers (BRPs) could enhance the security analysis. More precise analysis based on data and forecasts would enable more accurate optimisation of the power flow and remedial actions in advance.

Sub-areas

Advanced forecasting and data aggregation:

To address uncertainties in generation and load demand, accurate forecasting models that integrate real-time, historical, and environmental data are essential. Aggregating this information from DSOs, BRPs, BSPs, local service providers, or active citizen energy communities ensures a comprehensive view of grid conditions. AI could play a crucial role in post-processing and aggregating data by automating data cleansing, harmonisation, and synthesis from multiple stakeholders. Machine learning models enhance forecasts by analysing patterns and uncertainties in production and load, while predictive analytics quantify power flow uncertainties for more accurate security assessments. By incorporating uncertainty quantification techniques, this sub-UC provides a foundation for creating reliable input data for coordinated security analyses.

Coordinated TSO–DSO security analysis framework:

The coordinated security analysis framework allows for advanced simulations of power flows across interconnected grid systems. This framework integrates data from both transmission and distribution networks to perform dynamic power flow analyses, identify contingencies, and assess grid needs at various levels. By linking operational models across the TSO and DSO domains, this sub-UC ensures a unified approach to securing grid operations against uncertainties.

Precision support for control rooms:

Through the TSO–DSO DT, control rooms gain a shared decision-support platform that bridges operational silos between the transmission and distribution levels. It enables TSOs and DSOs to analyse vulnerabilities and synchronise coordinated responses effectively (e.g. optimised remedial actions like redispatching and activation of flexibilities). By offering scenario-based simulations and real-time coordination, the DT enhances operators' ability to implement strategies that stabilise grid operations.

These ambitions for advanced data aggregation, coordinated security analysis, and decision support are strongly reflected in the insights of the ENTSO-E–DSO ENTITY TSO-DSO Challenges & Opportunities for the Digital EU Electricity System report. The report highlights the growing complexity of system operations and the need for integrated, data-driven approaches to forecasting, security assessment, and control room decision-making. By leveraging DT technologies to unify data sources, automate analytics, and enable real-time coordination between TSOs and DSOs, system operators can address uncertainties in power flow, enhance resilience against operational risks, and optimise remedial actions – fully in line with the strategic priorities outlined in the report.

CHAPTER 3

Methodology & Approach

To effectively bridge the gap between the strategic **high-level goals** outlined in Chapter 2 and tangible, implementable **DT solutions** this report aims to provide, a structured methodology is essential. For this reason, the top-down approach shown in Figure 5 was selected to develop **UCs that are both specialised and adaptable** – technologically relevant yet flexible enough to be applied by different system operators.

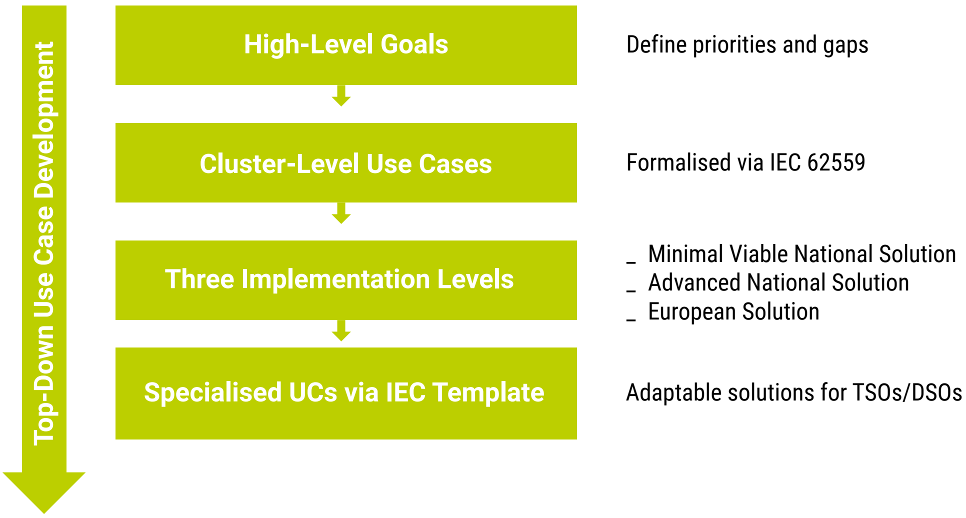


Figure 5: UC methodology

This methodology ensures that all technical development is directly traceable to a strategic business need. The process, as depicted above, begins with the **high-level goals** established in Chapter 2. These clusters (e.g. consumer-centric flexibility, anticipatory investment) represent the core "why" for any subsequent DT development and serve as the direct input for the UC definition process.

From these broad goals, we first derive **generic UCs** using landscape and gap analyses. For the gap analysis, a comprehensive repository of DT initiatives and studies in Europe was created, complemented by current DT solutions collected from TSOs and DSOs. These inputs were consolidated into a comprehensive repository of solutions and findings.

Next, selected existing solutions were mapped to the high-level goals, enabling a gap analysis between current capabilities and the desired objectives.

Finally, the UCs were defined with those gaps in mind and detailed to ensure consistency and interoperability.

UCs were defined based on the identified priorities and gaps, ensuring alignment with the identified strategic objectives. Each UC was then examined across relevant operational and functional areas, taking into account the specific conditions and constraints faced by TSOs and DSOs.

To ensure a common language and consistent structure understandable by all stakeholders (TSOs, DSOs, vendors, regulators), we utilised the **IEC 62559** "UC Management" standard. This template transforms a strategic aim into a formal description, outlining actors, objectives, high-level requirements, and information flows. This creates a reusable, interoperable, and technology-agnostic "blueprint" that captures the essence of the required functionality.

For each cluster introduced in Chapter 2, a dedicated UC was developed to address one or more high-level goals. The only exception was Cluster 2, where resilience enhancement was separated into its own UC, reflecting both the advanced nature of its functional requirements and the high priority of resilience-related capabilities.

Each UC is presented through three progressive levels of implementation maturity, offering a modular pathway from initial deployment to fully integrated operation:

- **National Minimum Viable Solution (MVS):** Focused on establishing essential data infrastructure, basic interfaces, and initial collaboration mechanisms
- **Advanced National Solution (ANS):** Incorporates increased automation, analytical capabilities, and operational integration
- **European Solution:** Enables interoperability and cross-border cooperation at a continental scale

This tiered structure ensures that TSOs and DSOs at different levels of digital maturity can identify UCs suitable for implementation within their organisations. The consistent framework across UCs facilitates comparison of readiness, ambition, and expected impact, while supporting the growth of DT solutions from local pilots into a federated European ecosystem.

The MVS for each UC is further detailed in the Annex, using the IEC 62559 template. This provides a practical starting point for implementation and illustrates how adaptable UCs can be translated into specific solutions. This approach balances technical detail with the adaptability needed for adoption by a diverse range of operators.

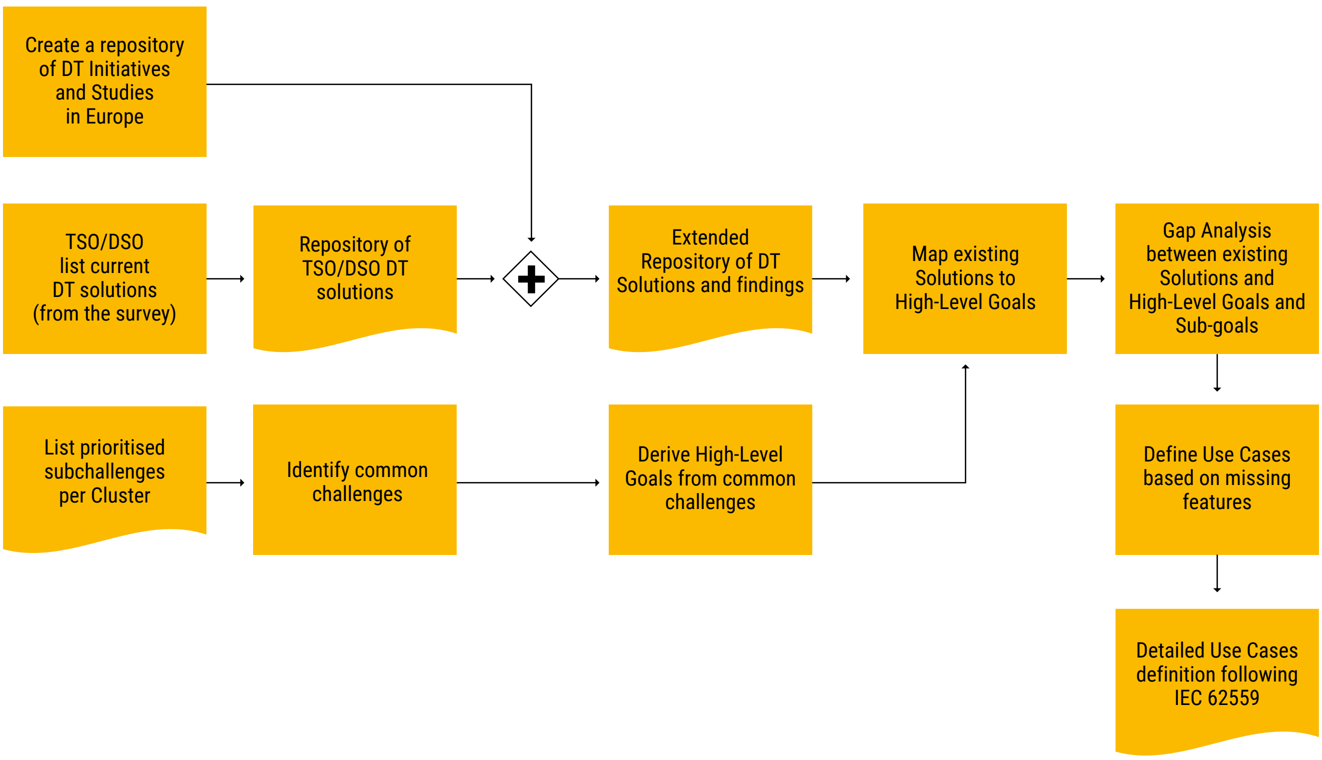


Figure 6: Gap analysis flow diagram

The description of the different levels of maturity and viable solutions and the IEC templates in the appendix form the core deliverables of this methodology, offering a structured and actionable framework for stakeholders to implement DT capabilities in alignment with their operational context and strategic goals.

The final step shown in the methodology is the **individual UC**. This stage is outside the primary scope of this report. An individual UC represents the final implementation by a specific TSO, DSO, or regional partnership, which adapts a specialised UC to its unique local conditions (e.g. integrating with specific legacy systems, adhering to local market rules, and using exact network models). The specialised UCs developed here serve as the common, robust foundation for all future individual implementations.

CHAPTER 4

Landscape Assessment & Gap Analysis

Landscape Assessment

The development of DTs for the European electricity grid is not occurring in a vacuum. A significant number of relevant DT initiatives and projects are already ongoing in the European DSO / TSO context, driven by European-level funding, national research, and direct efforts by system operators. A thorough landscape assessment is therefore necessary to correctly define the scope and guarantee the relevance of the UCs developed in this report.

This analysis ensures that our work does not duplicate existing efforts. Instead, it allows us to focus on what is needed to advance, while incorporating current learning and technologies. By building on this foundation, the UCs defined in the subsequent chapters will provide targeted, high-value contributions to the digitalisation of the European energy system.

Data Spaces: A **data space** is a federated data ecosystem built on a foundation of shared policies, standards, and rules. It is fundamentally different from a data lake. Instead of collecting all data into one massive, central repository, a data space allows data to remain with its owner (e.g. a DSO, aggregator, or TSO). It then creates a trusted framework for these independent parties to **share or access data in a secure, transparent, and sovereign manner**. The core principle is **data sovereignty**: data owners never lose control, but can grant specific, purpose-driven, and auditable access to their data based on common governance rules.

A data space is not a DT itself, but a **fundamental data-sharing infrastructure** to which a DT can be integrated to make high-fidelity DTs scalable across organisations as discussed in works such as Guidance for the Integration of Digital Twins in Data Spaces [3]. Data Spaces are an important and growing concept not only in the Energy sector, but also in other economy areas like transport, finance, health and potentially also across sectors. Moreover, any future integration of DT solutions must be aligned with ongoing discussions on governance frameworks and interoperability standards to deliver secure, scalable, and harmonised deployment across organisations, achieving semantic interoperability, which ensures that data exchanged between Digital Twins and Data Spaces maintains a consistent meaning across different platforms and organisations [4].

There are currently multiple data spaces initiatives in the European energy sector. At this stage, these initiatives address the relevance to exchange data. However, significant work is still needed to scale them up in an industrial and robust framework, from the technical, governance and funding, and accountability, responsibility and liability perspectives.

- **EDDIE:**
  A pan-European open source energy data infrastructure designed for service providers. It streamlines integration by providing distributed access to household, DER, and consumption data, enabling cross-border energy services and low-cost development. https://eddie.energy/

- **OMEGA X:**
  A federated, multi-vector energy data and service marketplace covering electricity, gas, and heat. It serves DSOs, TSOs, small and medium-sized enterprises (SMEs), and large operators with standards-aligned data exchange and multi-vector flexibility solutions. https://omega-x.eu/

- **SYNERGIES:**
  A reference energy data ecosystem focused on prosumers, network operators, and sector-coupling UCs. It combines building, mobility, smart metering, and operator data to enable flexibility services and TSO–DSO coordination. https://synergies-project.eu/

- **DATA CELLAR:**
  A federated data space tailored for local energy communities. It brings together smart metering, weather, load, production, and price data with AI tools and participation incentives for community-level energy services. https://datacellarproject.eu/

- **ENERSHARE:**
  Real-world pilots to demonstrate how energy data spaces can enable operational grid management, mobility / EV flexibility services, and cross-sector asset participation (e.g. water systems) all under secure, standardised, sovereign data frameworks. https://enershare.eu/

- **INSIEME:**
  INSIEME goes a step beyond the aforementioned examples, aiming to connect and improve these partial solutions in a Common European Energy Data Space (CEEDS) using a federative architecture to link existing data exchange platforms and organisations across Europe. Positioning itself as an integrator of integrators, INSIEME will implement core CEEDS components and deploy them for multiple UCs and in pilots across at least 16 EU countries, covering areas like energy efficiency, flexibility management, collective self-consumption, grid services, electromobility, renewable integration, and sector coupling. This ambitious project brings together more than 60 partners from at least 16 European countries, including DSOs, TSOs, associations, agencies, universities, start-ups, and established companies in the energy sector to achieve this goal. https://insieme.energy/

- **TwinEU:**
  The TwinEU project represents a critical strategic investment by the European Union to address the profound challenges of decarbonisation and energy sovereignty. The core goal is to develop a pan-European DT architecture for the electricity grid. Rather than attempting to build a single, centralised, and monolithic twin, the project's innovative strategy is to **federate** (or interconnect) the diverse local DTs already being developed by stakeholders across the continent, including TSOs, DSOs, and market operators. https://twineu.net/

The project's strategy is being proven in the real world through eight large-scale pilots. These pilots combine strategically chosen groups of stakeholders (TSOs, DSOs, market operators, and technology providers) collaborating to solve specific, high-priority local and regional challenges. While each pilot validates its own set of UCs, they are all designed to contribute their findings, models, and data to the wider pan-European scenarios.

Bulgarian Pilot Site

The Bulgarian pilot site includes **eight UCs (BG01–BG08)** focused on achieving full interoperability between the transmission, distribution, and market domains in Bulgaria. The pilot establishes a foundation for federated data exchange between **ESO (TSO)** and the national DSOs, introducing AI-based forecasting and flexibility management tools.

The UCs are structured in three progressive thematic groups:

- **Interoperability and data exchange (BG01–BG02):** Definition and implementation of standardised data models and secure data exchange protocols between ESO and DSOs
- **Forecasting and predictive analytics (BG03–BG05):** Application of AI models for wind and solar generation forecasting and short-term load prediction
- **Flexibility and asset management (BG06–BG08):** Integration of predictive maintenance and local flexibility activation into operational workflows

Dutch-French Pilot Site

The Dutch–French pilot site contains **three UCs (NL01–NL02, FR01)** and demonstrates **cross-border federation and interoperability** between **TenneT** and **RTE**. The pilot focuses on how DTs can exchange models and operational data securely to improve system stability and operator training.

Its UCs address:

- **Interoperable data exchange (NL01):** Establishment of cross-border data interfaces between the Dutch and French TSO DTs
- **Grid stability and observability (NL02):** Real-time voltage and frequency stability simulation for interconnected grids
- **Simulation and training environment (FR01):** Use of RTE's system twin for operator training and situational awareness enhancement

Eastern Mediterranean Pilot Site

The Eastern Mediterranean pilot site includes **six UCs (EM-GR-01 to EM-GR-03, EM-CY-01 to EM-CY-03)** connecting **Greece and Cyprus** through federated DTs of their power systems and markets. The pilot focuses on **high voltage direct current (HVDC) interconnection, system operation, and flexibility management** across grids from geographical islands.

The UCs can be grouped as follows:

- **Interoperability and federation (EM-GR-01, EM-CY-01):** Development of data interfaces between the Greek and Cypriot TSOs and DSOs
- **Forecasting and frequency control (EM-GR-02, EM-CY-02):** Use of DTs to improve renewable forecasting, balancing, and frequency support
- **Market and flexibility integration (EM-GR-03, EM-CY-03):** Simulation of joint market operation and flexibility exchange across the HVDC link

German Pilot Site

The German pilot site includes **eight UCs (GE01–GE08)** and is coordinated by **E.ON One**, **Westnetz**, and the **TSO Amprion**. It demonstrates how DTs can support **grid planning, hosting capacity, and multi-level coordination** between DSOs and the TSO.

The UCs follow three main thematic streams:

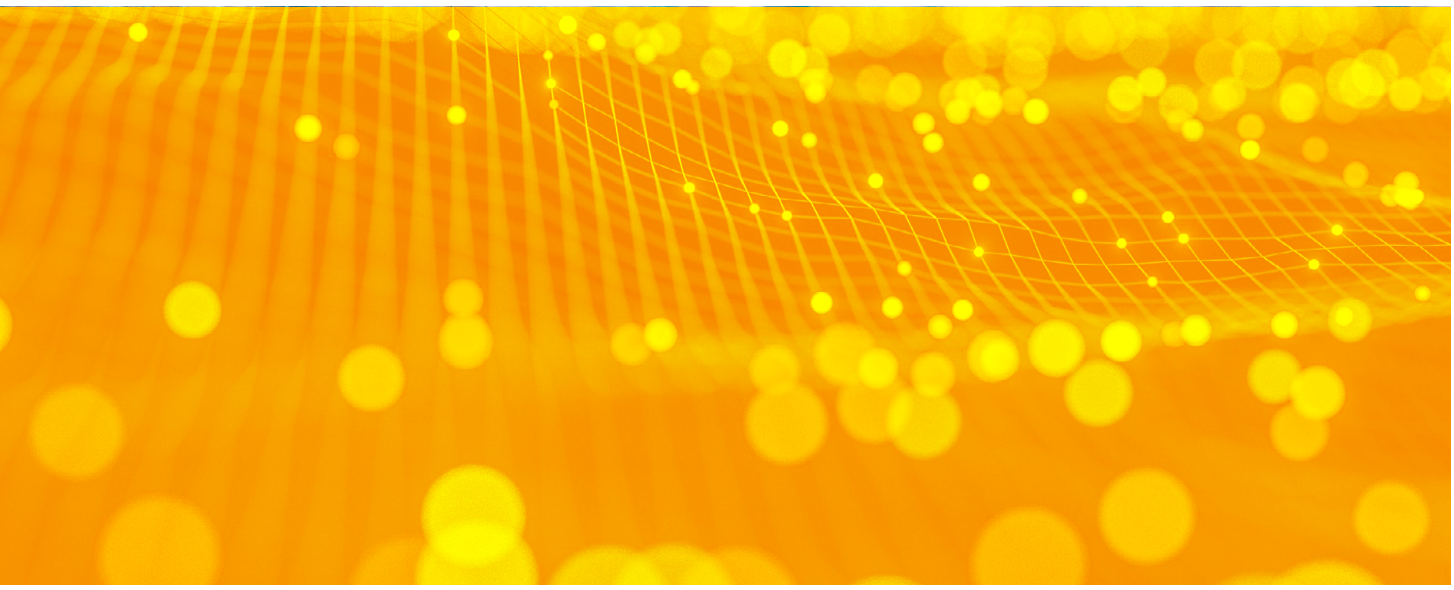
- **Grid modelling and observability (GE01–GE03):** Integration of multi-voltage network models and operational data into a shared DT environment
- **Planning and hosting capacity (GE04–GE06):** Creation of a dynamic hosting capacity map and anticipatory planning tools for new renewable and EV connections
- **Operational and customer applications (GE07–GE08):** Predictive voltage control and self-service grid connection assessment for customers and developers

Hungarian Pilot Site

The Hungarian pilot site includes **three UCs (HU01–HU03)** that integrate **MAVIR (TSO)**, **HUPX (market operator)**, and **E.ON EED (DSO)**. It explores how physical grid and market DTs can operate together to achieve **real-time co-optimisation** of capacity and balancing markets.

Each individual UC has the following focus:

- **Flow-based capacity calculation (HU01):** Integration of grid topology and market models to optimise cross-border capacity allocation
- **Dynamic line rating (HU02):** Use of environmental and operational data to adjust network limits in real time
- **Market co-optimisation (HU03):** Synchronisation of balancing and energy markets with grid operational constraints



Iberian Pilot Site

The Iberian pilot site, involving **REE**, **REN**, **OMIE**, **ANELL**, and **Cuerva**, includes **14 UCs (IB01–IB14)** and represents the most comprehensive implementation of the TwinEU concept. It integrates the entire electricity value chain of Spain and Portugal, linking TSO, DSO, and market DTs in a unified ecosystem.

The 14 UCs can be thematically grouped as follows:

- **Forecasting (IB01–IB04):** High-accuracy prediction of renewable generation and demand across Iberia
- **Market and congestion management (IB05–IB08):** Market-based flexibility activation and cross-border congestion mitigation
- **Flexibility services and local optimisation (IB09–IB11):** Coordination of distributed energy resources between DSOs and TSOs
- **System interoperability and interfaces (IB12–IB14):** Development of secure data exchange standards and shared visualisation tools

Italian Pilot Site

The Italian pilot site includes five UCs coordinated by ENEL and TERNA. It focuses on building information modelling (BIM)-based approaches for power plant design validation – for both distribution and transmission networks – as well as stability analysis and defence system design using DTs that represent both network types.

The UCs include:

- **Design Validation (EACL-IT-01, EACL-IT-02, and EACL-IT-03):** A unified review and validation process in which the TSO – currently relying on manual checks and technical response times – and the DSO – now limited to asynchronous designer–validator interactions – will evolve towards automatic BIM-based controls and synchronous access to project elements. The two operators will also work to harmonise data models and formats, enabling a common framework that simplifies designers' activities and reduces duplication.
- **Defence System UC (IT01 and IT02):** Simulation of defence strategies to evaluate their impact on both the DSO and TSO networks. New defence system strategies will also be developed. Additionally, the impact of DER interventions on distribution system operation will be assessed.

Slovenian Pilot Site

The Slovenian pilot site, involving **ELES (TSO)**, **EG (DSO)**, and **HSE (market actor)**, includes **two UCs (SLO-TSO-UC01, SLO-DSO-UC02)** that focus on **real-time system analysis and federation readiness**. It validates how existing national DTs can interoperate and exchange data securely.

Its UCs demonstrate:

- **Wide-area monitoring and dynamic analysis (SLO-TSO-UC01):** Assessment of transmission and distribution system stability in real time
- **Interoperable data exchange and coordination (SLO-DSO-UC02):** Testing semantic alignment and communication standards for cross-domain coordination

This pilot strengthens the System Security and Stability scenario, confirming the technical readiness of Central European operators for digital federation.

Gap Analysis

While landmark initiatives like INSIEME and TwinEU are establishing the critical federated architecture for a Europe-wide digital grid, gaps remain when measured against the comprehensive, high-level goals defined for this transformation. These projects are successfully tackling the foundational challenge of data sharing. However, a true DT must transcend being just a “data space”.

A data space is a fundamental **prerequisite**, enabling secure and sovereign data exchange, but the DT itself must add a layer of processing, simulation, and predictive intelligence on top of that data to become a federated DT. Furthermore, TwinEU’s valuable approach is built on real-world, specific pilots, each addressing immediate operational challenges. The approach of this report, starting from strategic high-level goals, may reveal different priorities and require new UCs to bridge the gap between current pilot-driven capabilities and the overall strategic vision.

UC1

TwinEU’s **Iberian (IB01–IB14)** and **Bulgarian (BG01–BG08)** pilots have made significant progress towards consumer participation and data-driven flexibility. The Iberian pilot demonstrates market-based flexibility activation (IB05–IB08) and develops interoperability tools (IB12–IB14) that align well with data space principles. The Bulgarian pilot applies AI-based forecasting and predictive analytics (BG03–BG05), contributing to better observability across the grid.

However, flexibility is still treated as a series of disconnected processes rather than a single, continuous flow linking TSOs, DSOs, and aggregators.

Aggregators are acknowledged but not fully empowered with standard interfaces or business logic for portfolio management. Observability improvements concentrate on the HV and MV levels, leaving LV networks largely unexplored. Even in the Iberian pilot, cross-border flexibility activation remains conceptual rather than operational.

INSIEME and other data space initiatives provide the necessary foundation for data exchange, yet lack the simulation and validation layers required for flexibility trading. The next step must connect these elements to create an end-to-end flexibility chain covering need identification, activation, verification, and settlement through interoperable, sovereign data exchange.

UC2.1

The **German pilot (GE01–GE08)** provides some of the most relevant work for anticipatory grid planning, particularly through dynamic hosting capacity analysis (GE04–GE06) and integrated TSO–DSO planning tools. Other examples include **IT01–IT02** in Italy, which focus on DER pre-qualification for grid services, and **HU01** in Hungary, which links network and market capacity through flow-based methods.

These UCs demonstrate strong analytical capabilities but remain confined within national or operator boundaries. TwinEU’s approach is technically advanced but fragmented when measured against the high-level goal of fully coordinated planning. Scenario assumptions and methodologies differ between pilots, preventing comparability or joint planning.

Models are exchanged, but analytical tools are not yet interoperable. Sector coupling, a major factor for future investment decisions, has not been integrated, and transmission and distribution development plans still lack automated alignment or validation.

TwinEU successfully demonstrates the technical layers of anticipatory planning, but not the procedural and cross-sector coordination needed for coherent investment strategies. Still missing is a federated planning environment, where shared scenarios and data models allow operators to plan jointly and transparently across voltage levels and borders.

UC2.2

Resilience is addressed in the **Italian** pilots, which test defence and restoration schemes. These pilots prove that DTs can support grid restoration and local operational resilience. However, this case does not meet the broader objective of using advanced DER capabilities to support system resilience, nor does it demonstrate the level of DSO–TSO cooperation required to achieve it.

On the other hand, GE-07 and GE-08 in the German pilot address cooperation and data exchange for sharing DER flexibility capabilities, but they do not address the potential for resilience.

This gap is critical. With the increasing importance of DER in the European energy system, system resilience requires the intelligent use of distributed energy storage and power electronics, not just for energy supply, frequency regulation, and congestion relief, but also for islanding, black-start capability, and voltage stability.

UC3

TwinEU pilots make considerable progress towards coordinated TSO–DSO security assessment, but the pilots do not yet achieve the full scope of the high-level goal. The **Dutch–French (NL01–NL02, FR01)**, **Slovenian (SLO-TSO-UC01, SLO-DSO-UC02)**, and **Italian** pilots each address important aspects of system security, yet their efforts remain fragmented and limited in operational integration.

The Dutch–French pilot demonstrates cross-border data federation and dynamic stability analysis but remains confined to specific interconnection studies. The Slovenian pilot focuses on model alignment and local dynamic analysis, which is valuable for interoperability but not continuous coordination. The Italian pilot explores operational visibility and restoration validation, yet it largely reflects transmission-level security rather than true joint assessment with DSOs.

Together, these initiatives test parts of coordinated security assessment, but a holistic view is needed to deliver a unified framework that connects forecasting, real-time data exchange, and joint decision-making.

This comparison of ongoing initiatives shows that, although significant progress has been made in data sharing and specific applications, significant gaps persist because most efforts remain fragmented and rely on bottom-up approaches. The next chapter aims to address these gaps by presenting UCs from the previous cluster. It applies a top-down approach based on high-level objectives and expert input to outline an integrated path towards achieving the overall goals. In combination with learning from other leading initiatives, they should provide more complete guidance for TSOs and DSOs.

CHAPTER 5

Detailed Use Cases

For each of the clusters introduced in Chapter 2, a dedicated UC was developed to address one or more of the identified high-level goals. The only exception is Cluster 2, where resilience enhancement was separated into its own UC in recognition of the advanced nature of the requirement functionalities and high priority of resilience functionalities.

Every UC is presented through three progressive levels of implementation maturity, reflecting a modular pathway from early deployment to fully integrated operation:

- National MVS: focused on establishing essential data infrastructure, basic interfaces, and initial collaboration mechanisms
- ANS: includes increased automation, analytical capability, and operational integration
- European Solution: enabling interoperability and cross-border cooperation at the continental scale

This structure provides a consistent lens to compare readiness, ambition, and expected impact, while introducing a harmonised view of how DT solutions can grow from local pilots into a federated European ecosystem. The MVS for each UC is further detailed in the Annex following the IEC 62559 template, ensuring traceability and a practical starting point for implementation.

UC Cluster 1: Consumer-centric Flexibility for Scalable Grid Solutions

The UC of consumer-centric flexibility enabled by DT technology represents a transformative approach in the energy sector, focusing on enhancing grid observability and integrating flexibility services into the market. Consumers are no longer limited to pure consumption – these units increasingly also have storage, production, and intelligent devices, all capable of offering flexibility. The goal is to enable the integration of all flexibility potential, regardless of size, technology, or voltage level, to maximise efficient and safe system operation. As LV and MV customers increasingly integrate generation, storage, and intelligent devices, traditional consumers evolve into a grid resource. While flexibility from larger units is currently a mature solution, the growing potential of smaller users is currently underexplored.

This UC addresses the untapped potential of distributed flexibility by empowering aggregators to engage consumers effectively using a DT as the technical tool.

It is important to note that while DTs are critical technical tools, their success depends on country-specific market rules and a supportive design framework. This framework must also provide clear solutions for coordinating local grid and system needs when accessing distributed flexibility.

This section provides a detailed description of how this UC can be implemented, including foundational elements, relevant areas, and potential solutions.

Description

The consumer flexibility UC aims to leverage DT technology to help aggregators enable end-user participation in distributed flexibility. As direct activation of consumers is not feasible, aggregators play a central role in interfacing with end users and coordinating their flexible resources. This DT solution aims to provide aggregators with standardised interfaces and advanced analytics to create a dynamic environment where they can identify, manage, and monetise consumer flexibility. By highlighting potential business opportunities and streamlining operations, the UC fosters aggregator engagement, ultimately contributing to grid stability and optimisation. Aggregators serve as the essential link between end users and the energy system, proposing flexible resources on their behalf.

The DT solution empowers consumers indirectly by equipping aggregators with standardised interfaces, real-time data, and advanced analytics. It focuses on making flexibility services accessible and manageable for end users through simple, replicable systems that require minimal customisation, ensuring scalability across different contexts.

For this UC to succeed, the DT system must clearly demonstrate potential business cases to aggregators. By identifying monetisable flexibility opportunities, streamlining operations, and reducing complexity, the DT helps aggregators build viable business models. These insights and tools serve as key incentives for aggregator engagement, enabling them to unlock consumer flexibility and contribute to grid stability and optimisation.

System operators can leverage this flexibility to enhance grid management. DSOs can use consumer flexibility to manage local grid constraints and maintain reliability while grid extensions are under construction. TSOs, meanwhile, should actively integrate prosumer flexibility into congestion management and balancing markets, treating it on par with large generators. This will support a more distributed and resilient approach to system balancing. The UC can be developed independently for DSOs and TSOs or jointly across both levels. When TSOs are involved, it is essential to address grid limitations at the transmission level without creating adverse impacts at the distribution level, requiring coordinated planning and data exchange between operators.

To implement this UC, several areas must be considered, each of which can be developed to varying levels of depth and maturity. A full implementation across all areas would result in a highly mature DT, while a partial integration would yield an MVS. The areas introduced first represent the fundamental components of a minimal solution, while the subsequent areas describe more sophisticated levels of implementation. The different areas to be considered for this UC are:

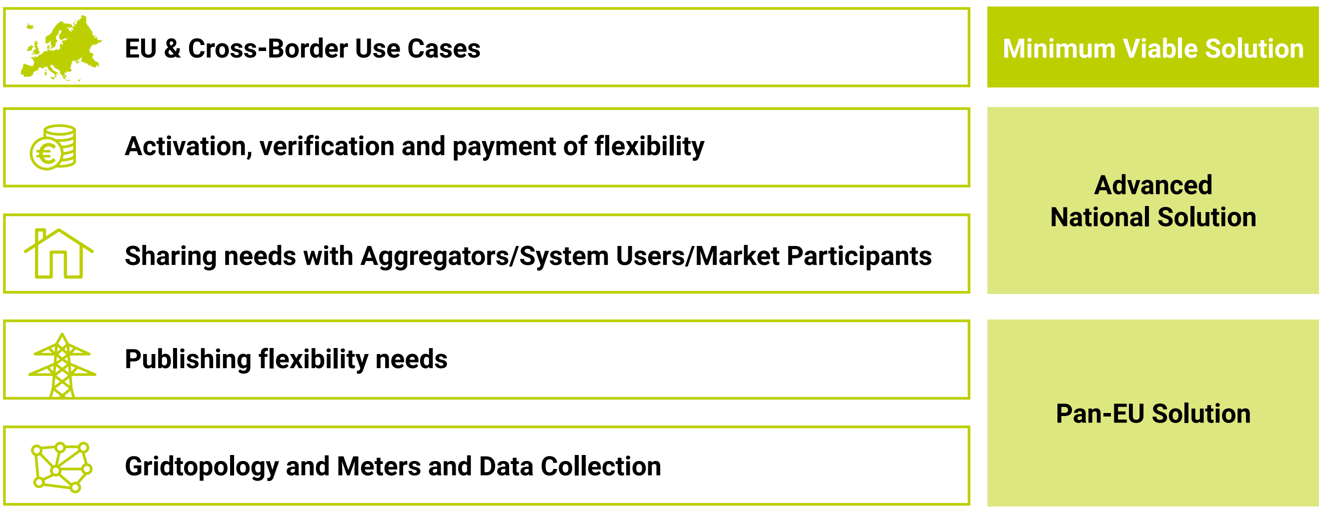


Figure 7: UC1 Framework

1. DATA COLLECTION AND INFRASTRUCTURE

Purpose:

To establish the digital and physical infrastructure necessary for data acquisition, transmission, and processing, forming the backbone of the DT.

Key components:

- **Grid topology information:**
  - Geographic information systems (GIS)
  - Digital models of grid nodes, lines, and substations
  - Additional geospatial data
- **Smart meter systems:**
  - Device configurations and capabilities
  - Data granularity and frequency
  - Integration with grid management layers
- **Communication infrastructure:**
  - Mediums (wireless / wired)
  - Concentrators (proprietary network)
  - Protocols and standards
  - Cybersecurity and data privacy measures

Implementation notes:

This area is foundational. Without a robust data infrastructure, higher-level functionalities like market integration cannot be reliably achieved. A key consideration in this area is the potential to leverage existing data structures, particularly the CEEDS. To reduce additional costs and improve efficiency, it is essential to prioritise the reuse of established infrastructure and actively participate in these emerging data ecosystems. This enables the collected data to be utilised across multiple applications, ranging from grid operations to market integration, while fostering interoperability, transparency, and innovation within the broader energy system. When designing system operator or country-specific solutions, later integration into broader initiatives like the data space envisioned by INSIEME should be considered, and interoperability prioritised. Compliance with and support for the Network Code on Demand Response (NC DR) currently under review by the European Commission is also a central aspect to be considered, especially with its enforcement expected by 2027.

2. DEFINING FLEXIBILITY NEEDS

Purpose:

To identify, quantify, and understand grid flexibility requirements based on the data from the DT, taking into consideration what can be solved based on connection agreements.

Key elements for defining flexibility needs:

- **Location:** Which grid node or area?
  Transformer station or radial?
- **Voltage level:** What voltage level?
- **Time:** When is flexibility needed?
- **Duration:** How long should it last?
- **Volume:** How much capacity?
- **Speed:** How fast should it be activated?
  How far in advance do we know flexibility needs?

Implementation notes:

This step requires close collaboration between TSOs and DSOs to identify where flexibility is most needed and to coordinate activation strategies. Though related, it is important to emphasise this step has both a different geographic as well as time scope in relation to the Flexibility Needs Assessment methodology.

3. PUBLISHING FLEXIBILITY NEEDS AND MARKET INTEGRATION

Purpose:

To communicate flexibility needs to market participants and integrate these needs into existing or new market mechanisms.

Key elements:

- **Stakeholder engagement:**
  - Aggregators, suppliers, and end users
- **Transparency and accessibility:**
  - Public availability of signals and data
  - Interfaces for accessing flexibility opportunities
  - Low entry barrier: information should be accessible at low technical cost and effort
- **Information:**
  - Risk profile and technical constraints of flexibility suppliers
  - DSO and TSO requirements (based on the previous step)
  - Estimation of market potential (based on the previous step)

Implementation notes:

This section outlines the publication of flexibility needs, which can range from basic daily communications by DSOs and TSOs via standardised interfaces to near-real-time transparency through APIs, open data portals, and integrated market platforms.

Flexibility needs must be published to address system or network needs and support market mechanisms. Coordination between system operators is essential, and actions taken at the transmission level (e.g. activating flexibility) must not inadvertently cause operational challenges or constraints at the distribution level.

4. ACTIVATION AND PAYMENT OF FLEXIBILITY

Purpose:

To operationalise flexibility services through activation protocols and ensure fair compensation for participants.

Key elements:

- **Activation mechanisms:**
  - Request-based triggers (manual or automated)
  - Verification of service delivery
- **Settlement and payment:**
  - Contractual frameworks (e.g. market-based, rules-based, tariff-based)
  - Pricing models (e.g. time-based, performance-based)
- **Market design considerations:**
  - Single vs coordinated market structures
  - Incentive alignment across the value chain

Implementation notes:

This stage covers the operational and contractual aspects of flexibility services, from activation to settlement. The NC DR provides the foundation for contractual arrangements and ensures consistency across actors.

Flexibility is triggered through request-based activation– either market-driven or contract-based – followed by verification, settlement, and payment and/or penalties. Market design should promote efficiency across the value chain. Solutions could range from relying on standardised but separate market processes and basic verification (e.g. meter data comparison) to the use of fully digital, integrated systems with automated activation, verification, and settlement.

Choosing the right level of integration and coordination ensures incentives are aligned, and flexibility remains both technically effective and economically sustainable.

Solution Implementation

Implementation maturity varies across several key dimensions. By integrating different areas to varying degrees, solutions can range from basic data platforms to sophisticated DT systems that enable flexibility trading across TSOs and DSOs.

A **national MVS** focuses on establishing foundational capabilities. For this UC, the focus at this stage is integrating relevant areas at a basic level, focusing on data infrastructure, and publishing flexibility use for integration into external platforms.

This progresses to an **ANS**, which incorporates full integration, advanced functionalities, and advanced capabilities. The final stage is a **European solution**, which explores cross-border flexibility and harmonised digital infrastructure.

MINIMAL VIABLE SOLUTION

This solution establishes the essential components needed to begin managing grid flexibility. It is particularly suited for system operators who are in the early stages of DT development and may lack the resources for advanced implementations.

The initial phase emphasises straightforward data architectures and the external communication of flexibility needs. At this stage, the DT should deliver only the essential data and resolution necessary for external stakeholders to respond to identified flexibility requirements. UCs may rely on existing metering and grid topology data, acknowledging limitations such as incomplete smart meter coverage and variable data quality. Aggregated and estimated data may be used when precise information is unavailable.

Where feasible, existing data infrastructures, such as data spaces, should serve as the foundation for the data architecture. Based on the available data, generic flexibility signals can be generated. These may include price signals or simple indicators specifying the timing and magnitude of flexibility needs according to the European framework and specific national regulations.

These signals should be made accessible to relevant actors, including other system operators and aggregators, via data spaces, the DT platforms of other system operators, or external platforms. An initial estimation of the specific data-sharing and resolution requirements for participating in flexibility markets can be made by reviewing the minimum technical specifications of current platforms.

ADVANCED NATIONAL SOLUTION

The concept of a "maximum viable solution" refers to a future-oriented, highly integrated setup across all described areas, characterised by advanced technologies and mature market mechanisms.

This vision should be seen as a directional guide – a space where front-runners can explore and where best practices may emerge. It is not a fixed endpoint, but rather a framework for identifying what is possible and valuable. As organisations advance, it becomes increasingly important to evaluate whether further integration or added features continue to deliver meaningful benefits or simply introduce unnecessary complexity and cost.

Given the evolving nature of technologies and market dynamics, it is difficult to define a single maximum viable solution today. Instead, the focus should be on understanding the gap between current capabilities and this advanced vision, and on recognising the point at which further advancement may become inefficient or overly complex.

This approach encourages experimentation and learning while also promoting critical reflection on what truly adds value. It supports the development of a catalogue of best practices that can guide others in their journey towards more integrated and effective solutions.

In the area of **data collection and infrastructure**, maximum viable solutions would typically rely on comprehensive and high-quality datasets, including detailed grid topology models and full smart meter coverage supported by advanced communication systems. Such setups enable real-time data exchange and support a wide range of applications, from operational monitoring to market facilitation. Importantly, these solutions would be designed with interoperability in mind, allowing integration into broader European data ecosystems and initiatives. An important consideration is whether these solutions can be directly integrated into European data spaces.

When it comes to **defining flexibility needs**, an advanced approach would involve objective, data-driven methods for identifying where and when flexibility is required. This could include system-level forecasting and localised analysis at the grid node level. The goal is to move beyond reactive measures and towards predictive, proactive planning that supports both operational efficiency and long-term grid development.

For **sharing flexibility needs and market integration**, maximum viable solutions would emphasise transparency, accessibility, and automation. Flexibility signals and data would be made available at any time horizon, including in near real time through standardised interfaces and digital platforms, enabling aggregators, suppliers, and end users to respond effectively. Coordination between system operators would be embedded in the design, ensuring that local and national needs are balanced and that market mechanisms reflect actual grid conditions.

Finally, in the area of **activation, verification, and payment of flexibility**, a maximum solution would feature fully digital processes from activation to settlement. Verification and compensation would be automated, supported by consistent contractual frameworks and aligned incentives across the value chain. These systems would not only ensure technical reliability but also promote efficiency, economic sustainability, and stakeholder trust.

Overall, maximum viable solutions are not static endpoints but evolving targets. They provide a reference for what can be achieved when systems are designed for integration, scalability, and value creation. As technologies and market structures continue to develop, these solutions will help guide the energy sector towards more resilient, efficient, and participatory models.

EUROPEAN AND CROSS-BORDER CONSIDERATIONS

An even more advanced application of DTs involves integrating European and cross-border dimensions, unlocking the potential for cross-border flexibility and a harmonised European infrastructure. This integration could begin with national DTs that are interoperable with European datasets, market signals, and cross-border pilot projects. These pilots could leverage federated national data spaces to facilitate the exchange of flexibility-related information.

At more mature stages, this could evolve into a federated network of DTs, enabling seamless interaction between national and European systems. Such a network would support real-time cross-border flexibility trading, standardised data protocols (e.g. using NC DR), and enhanced transparency regarding flexibility needs and offerings. Additionally, the underlying data spaces could be extended to integrate with other industry sectors, fostering broader interoperability and innovation.

UC Cluster 2.1: Enhanced Network Planning & Hosting Capacities

This UC focuses on improving the ability of TSOs and DSOs to anticipate and plan for future grid connection needs arising from the integration of RES and sector-coupling technologies. The coordinated planning approach aims to strengthen common planning steps and strategies of shared interest, ensuring that future grid investments and reinforcements are developed consistently across voltage levels. Ideally, coordinated planning should be aligned both horizontally and vertically across system operators and voltage levels, to the greatest feasible extent.

Description

Effective TSO–DSO coordination for long-term grid planning requires aligned time frames, consistent scenario assumptions, defined planning boundaries, and harmonised planning cycles. Such coordination ensures that network investments, flexibility resources, and new technologies are assessed coherently across voltage levels. It helps anticipate where and when reinforcements are needed, optimises the use of existing assets, and supports a resilient, cost-efficient, and decarbonised electricity system.

This UC promotes a structured framework for TSO–DSO cooperation, progressing from national-level coordination to regional or pan-European planning environments, where benefits and implementation feasibility justify this evolution. It covers long-term (years ahead or more) and, where relevant, midterm (months ahead) planning activities, rather than operational (near-real-time) processes, focusing on analytical consistency, shared data, and coordinated methodologies.

TSOs and DSOs have jointly identified several **key assessment areas** that form the backbone of coordinated planning. Each assessment type represents a distinct analytical capability required for anticipatory and harmonised grid development:

- **Grid Reinforcement and Interface Planning Assessment:**
  Analyse long-term needs for grid reinforcements and expansions across both transmission and distribution levels, with particular attention to TSO–DSO interface substations and boundary points. This assessment identifies areas likely to experience congestion, reverse power flows, or reliability challenges due to evolving generation and demand patterns. It supports the evaluation of reinforcement options, substation upgrades, and interface capacity enhancements, balancing cost-effectiveness, implementation timing, and overall system efficiency.

  Coordinated assessment of reinforcements ensures that planning actions are mutually consistent, avoiding duplication and promoting a seamless flow of electricity across network boundaries.

- **Sector Coupling and Emerging Technologies Assessment:**
  Examine the spatial and temporal effects of integrating new energy systems and technologies, such as hydrogen production, large-scale heat electrification, EV infrastructure, data centres, and industrial demand electrification, as well as the possible phasing out of gas distribution at the medium or low pressure level.

  Assess the impacts of these developments on grid capacity, flexibility availability, and inter-sectoral synergies. This analysis supports integrated planning approaches that consider multiple energy carriers, helping anticipate cross-sector dependencies and optimise infrastructure utilisation.

- **Grid Hosting Capacity Assessment:**
  Assess the ability of existing and future electricity networks to accommodate additional renewable generation, new demand centres, or sector-coupled connections (e. g. EV hubs, heat pumps, hydrogen electrolysers). Identify technical and spatial constraints, bottlenecks, and potential for flexibility-based mitigation. Hosting capacity assessments provide early visibility on where connection requests can be accepted, where reinforcements are justified, and how local flexibility can defer or optimise investments. The main objective is to deliver a transparent, data-driven view for future connections, improving predictability for stakeholders and aligning capacity planning with broader decarbonisation and electrification objectives.

- **Scenario Building:**
  Develop consistent long-term scenarios capturing key energy system transitions, including electrification trends, climate impacts, distributed generation growth, and evolving consumer behaviour. Align scenario assumptions across system operators, ensuring that demand projections, renewable potential, and flexibility needs are represented coherently. These scenarios serve as the foundation for coordinated network studies, investment prioritisation, and system resilience evaluations.

- **Investment Plan Alignment:**
  Harmonise methodologies, assumptions, and datasets used for transmission and distribution network development plans. This assessment ensures that investment priorities are consistent across system levels, regulatory frameworks, and European targets. It promotes transparency in cost allocation, facilitates joint progress monitoring, and strengthens alignment between national infrastructure strategies and EU policy objectives.

- **Europe-wide scenario analysis:**
  Conduct pan-European scenario-based assessments capturing cross-border energy flows, interconnected system behaviour, and multi-country interactions across electricity and other energy vectors. This includes evaluating resource adequacy, climate-driven extremes, flexibility interactions, and structural bottlenecks from a continental perspective. Europe-wide scenario analysis ensures coherence between national planning strategies and EU-level objectives, providing insight into where coordinated reinforcements, cross-border capacity expansions, or harmonised flexibility measures may deliver system-wide benefits. It forms an essential analytical layer for integrated European planning under future energy system architectures.

Together, these coordinated assessments define the **analytical backbone** for advanced network planning. A **DT solution** capable of performing these assessments would progressively evolve from an **MVS** focused on common data requirements and early coordination mechanisms to an **ANS** integrating analytical automation and scenario-based evaluations, and ultimately to a pan-**European environment** enabling cross-border consistency, harmonised methodologies, and integrated multi-energy planning. At each maturity stage, the viability of these assessments depends on achieving an appropriate **balance between data processing capacity, model granularity, and computational performance**. Only when the data infrastructure, interoperability frameworks, and analytical capabilities reach sufficient maturity can the DT solution be fully realised, unlocking its full benefits, such as faster scenario evaluation, real-time investment validation, and transparent pan-European planning.

Building on this analytical framework, the following section outlines how these capabilities can be progressively implemented, from a national MVS to an ANS with coordination mechanisms and, ultimately, a European-level DT environment that supports joint TSO–DSO planning and long-term system development.

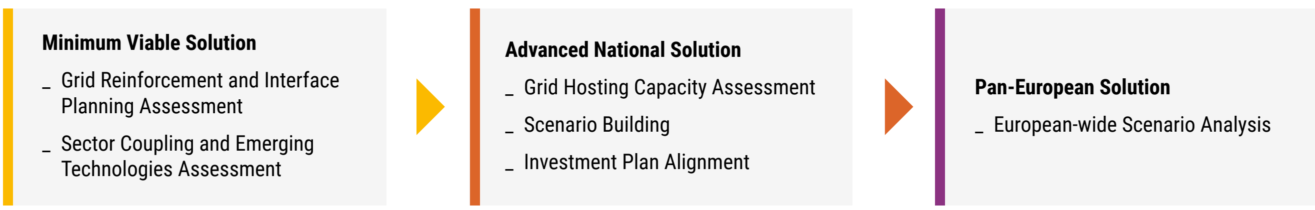


Figure 7: Maturity stages of DT solution implementation

Solution Implementation

MINIMUM VIABLE SOLUTION

The MVS represents the first implementation phase of coordinated long-term grid planning between TSOs and DSOs. The focus is on establishing practical collaboration mechanisms and early data-sharing capabilities to support grid reinforcement and interface planning, sector-coupling, and emerging technologies assessments.

At this stage, the objective is to validate coordination concepts, test dataset interoperability, and demonstrate the analytical feasibility of early joint studies.

Functional Requirements:

- Establish data exchange requirements for sharing non-confidential data and defining grid-simplification processes. Any new or specific data requirements should be clearly assessed, defined, and transparently communicated to the relevant stakeholders.
- When feasible, establish secure interfaces between the TSO and DSO planning environments.
- Enable integration of network topology for interface substations and boundary nodes.
- Define clear observability rules and evaluation criteria.
- Support power flow and contingency simulations to identify congestion, reverse power flows, and reinforcement needs.
- Incorporate mapping of emerging sector-coupled loads (e.g. data centres, EV hubs, hydrogen pilot projects, and others).
- Facilitate joint reporting and visualisation tools for planning coordination and investment discussion.

Non-Functional Requirements:

- Data quality and validation: Ensure consistency of input datasets across operators.
- Define clear data aggregation rules when needed.
- Interoperability: Adopt strategies for data models to support cross-operator integration, taking into account alignment of standards and translation among already implemented standards.
- Security and access control: Protect shared planning data through secure data exchange protocols and accessibility rights.
- User accessibility: Provide intuitive interfaces that enable planners from both operators to work with the data and results relevant to their competencies. The design should clarify each system operator's access rights and intended use.
- Scalability: Design a modular architecture that enables the integration of additional datasets or functionalities later.

ADVANCED NATIONAL SOLUTION

The ANS builds on the early coordination framework, extending its analytical scope and technical depth and shifting focus towards scenario building, aligning assumptions, planning methodologies and horizons, and data models to create consistent national planning frameworks. Key focus areas include advanced grid-hosting capacity and investment plan alignment between transmission and distribution network development plans.

Functional Requirements:

- Perform hosting capacity evaluations and congestion studies, incorporating renewable generation, sector coupling, and flexibility exchange.
- Develop shared scenario-building strategies integrating demand growth, electrification, DER expansion, national climate objectives, and flexibility potential.
- Implement automated data ingestion of available TSO and DSO datasets.
- Enable scenario-based investment evaluation comparing reinforcement and flexibility alternatives.
- Introduce probabilistic analysis to evaluate uncertainties in demand, generation, and technology uptake and connection applications.
- Establish national coordination dashboards for scenario comparison, validation, and transparent reporting to regulatory bodies.
- Support investment plan alignment through automated comparison of transmission and distribution network development plans.
- Introduce analytical automation, enabling automated execution of recurring analyses, systematic key performance indicator (KPI) generation, and streamlined iteration of planning runs.

Non-Functional Requirements

- Model accuracy and granularity: Ensure alignment of planning horizons, spatial resolution, and assumptions.
- Addressing gaps in data availability and quality: Define clear strategies to complement missing datasets and resolve misalignments in underlying assumptions.
- Performance and computational efficiency: Enable iterative scenario simulations within reasonable time frames. Provide clear aggregation data rules to improve computational performance.
- Governance and accountability: Formalise joint validation of assumptions and results between TSO and DSO entities. Clearly define which TSOs and DSOs have access to which data, and for what purpose.
- Interoperability: Ensure compatibility with national and European data standards to support future integration.
- User-centric design: Promote usability, traceability, and clear visualisation for planners and decision-makers.

EUROPEAN-LEVEL SOLUTION

At the pan-European level, the coordinated planning framework evolves into a federated digital environment supporting harmonised methodologies, multi-energy integration, and cross-border investment coordination. Key focus area includes Europe-wide scenario analysis, ensuring consistency at the pan-European level, and promoting better transparency across system operators.

Functional Requirements:

- Integrate national and regional (cross-border) datasets into a federated European planning platform.
- Enable Europe-wide scenario analysis, including resource adequacy and system interdependencies across interconnected infrastructures, countries, and energy vectors.
- Provide visualisation and reporting functionalities for EU institutions and regulatory frameworks.

Non-Functional Requirements:

- Interoperability and standardisation: Ensure full compatibility of national models and data exchange formats.
- Scalability and computational performance: Support large-scale, multi-country evaluations with high data volume.
- Data governance and confidentiality: Define clear rules for cross-border data access, validation, and usage.
- Transparency and auditability: Ensure traceable processes for scenario building, modelling, and investment validation.

The implementation of this UC follows a progressive, modular approach, where early coordination mechanisms and data-sharing capabilities form the foundation for advanced analytical and digital solutions. Each maturity stage increases both the analytical depth and geographical scope of coordinated planning, ultimately converging into a pan-European ecosystem in which TSOs and DSOs jointly anticipate and plan grid developments with full data interoperability, analytical consistency, and strategic alignment.

UC Cluster 2.2: Enhanced Network Planning for High Resilience to HILF Events Through DER

This UC defines how TSOs and DSOs can jointly prepare, model, and recover from rare but high-impact disruptions (HILF events) using shared digital models and data-driven coordination, ensuring the electricity grid can withstand and recover from both physical and cyber shocks. Ensuring electricity system resilience against HILF events such as extreme weather, climate-related incidents, large-scale technical faults, or coordinated cyber threats requires a harmonised and data-driven approach between TSOs and DSOs. This UC aims to establish a common analytical and methodological framework for anticipating, assessing, and mitigating the grid impacts of such events through coordinated modelling, simulation, and restoration planning.

Description

This UC focuses on assessing system impacts rather than external causes, providing a consistent method of translating disruptive events into measurable changes in generation, demand, and asset availability. Through shared modelling and simulation environments, operators can jointly evaluate vulnerabilities, optimise restoration strategies, and strengthen preparedness and recovery capabilities at the national and European levels. When considering cyber threats or other malicious attacks, DT conceptualisation and implementation shall ensure that they do not facilitate the planning and execution of such attacks.

Effective TSO–DSO coordination for resilience planning requires:

- Aligned methodologies for translating HILF events into network stress scenarios (e.g. load shedding, DER curtailment, or asset disconnection)
- Consistent datasets defining generation mix, flexibility potential, and restoration resources
- Integrated simulation approaches allowing both static and dynamic analyses to capture steady-state and transient impacts
- Clear aggregation rules to ensure computational feasibility while maintaining analytical accuracy

This UC establishes the methodological foundation for resilience-oriented planning, testing flexibility behaviour, improving restoration strategies, and enabling joint post-incident assessments between TSOs and DSOs.

It builds on common principles of interoperability, proportional data exchange, and cybersecurity compliance as defined in national and European frameworks. Identifying key assessment areas represents a distinct analytical capability required to enhance grid resilience and coordinated recovery under HILF conditions:

Event-to-impact translation and system stress modelling: Develop standardised methodologies for converting different categories of HILF events (e.g. solar eclipse, storm, flood, heatwave, human-caused physical damage, cyber intrusion) into quantifiable system impacts, such as demand surges, generation loss, or asset disconnections. Define uniform input parameters (e.g. weather severity indices, spatial impact zones, asset vulnerability profiles) and adopt modular approaches to facilitate scenario scalability. This involves a deep understanding of local grid impacts and system-wide impacts that can scale up into greater simulation scopes.

- **Grid security assessment:**
  Perform both steady-state (power flow) and dynamic (transient stability) simulations to evaluate system robustness under stressed conditions. Static assessments identify overloads and voltage violations, while dynamic assessments test frequency and voltage stability, protection coordination, and control resilience. Where computational limitations exist, data aggregation and network simplification rules should be defined to balance precision and performance.

- **DER flexibility and response modelling:**
  Quantify the contribution of DERs – including storage, demand response, and inverter-based generation – to resilience enhancement. Evaluate flexibility activation potential, responsiveness under disturbed conditions, and the effectiveness of DERs in supporting black-start or islanded operations. Establish standard response templates for different asset categories (e.g. EV charging stations, grid-forming vs grid-following inverters, and others) to ensure consistent system behaviour representation.

- **Restoration strategy and black-start coordination:**
  Design coordinated restoration strategies integrating TSO–DSO operational hierarchies and conditions, resource availability, and geographical dependencies. Assess alternative restoration paths, prioritisation of critical loads, and the role of DERs and load shedding in accelerating service recovery. Include probabilistic assessments to capture uncertainty in resource availability and environmental conditions during recovery.

- **Cybersecurity and operational risk categorisation:**
  Incorporate cybersecurity risk classes into resilience planning, following current and forthcoming EU legislation (e.g. NIS2, CER Directive). Evaluate potential grid impacts from cyber events in parallel with physical contingencies, ensuring that system defence and restoration strategies remain aligned across operator levels.

- **Joint post-incident assessment and continuous learning:**
  Define a joint structured framework for post-event evaluation and data sharing between TSOs and DSOs. Analyse the performance of protection systems, restoration timelines, and DER responses. Use these insights to refine models, improve contingency assumptions, and strengthen preparedness for future events.

At each maturity stage, the effectiveness of resilience-focused assessments depends on achieving the right balance between model accuracy, computational performance, and the quality of the underlying datasets describing assets, flexibility resources, and event impact parameters. Building on this resilience-oriented analytical framework, the following section outlines how the required capabilities can be progressively implemented – starting from an MVS that establishes common methodologies and foundational modelling practices; advancing towards an ANS that integrates dynamic simulations, cybersecurity considerations, and DER response modelling; and ultimately reaching a pan-European DT environment that supports harmonised cross-border resilience assessments, coordinated restoration planning, and integrated HILF preparedness at the continental scale.

Minimum Viable Solution

- HILF Event Translation Methodology
- Steady-state Grid Security Assessment
- Initial Coordinated Restoration Schemes

Advanced National Solution

- Advanced HILF Event Translation Methodology
- Dynamic Grid Security Assessment
- DER Flexibility and Response Modelling
- Cybersecurity and Operational Risk Categorisation

Pan-European Solution

- Joint Post-Incident Assessment
- Regional Restoration Strategy and Black-Start Coordination

Figure 8: Enhanced TSO–DSO network planning – DT implementation steps

Solution Implementation

A DT solution integrating these analytical capabilities can progressively evolve through three maturity levels, ensuring scalability, interoperability, and computational efficiency.

MINIMUM VIABLE SOLUTION

The initial phase focuses on foundational coordination mechanisms and essential analytical capabilities for static security and basic restoration planning.

Functional Requirements:

- Establish a shared HILF event translation methodology (e.g. mapping a solar eclipse, storm severity, or other events into generation / demand changes or asset unavailability).
- Define critical network elements that significantly impact the overall system for which modelling strategies should be defined, and N-X criteria should be applied.
- Conduct steady-state grid security assessment (N-X or N-1-X) and restoration simulations for representative event types.
- Define and test aggregation and simplification rules for grid models to optimise performance.
- Implement proportional data sharing and secure exchange mechanisms between TSO and DSO environments.
- Develop initial coordinated restoration schemes linking roles, priorities, and key recovery assets across voltage levels.

Non-Functional Requirements

- Ensure data confidentiality through secure exchange protocols.
- Define standardised modelling templates for generators and DERs to overcome encryptions and ensure appropriate asset behaviour.
- Maintain traceable model assumptions and event-to-impact mappings.
- Support limited dynamic analysis for pilot networks where computationally feasible.

ADVANCED NATIONAL SOLUTION

This phase extends resilience planning capabilities, integrating advanced analytical automation and simulation-based decision support.

Functional Requirements:

- Implement advanced HILF event translation methodology, expanding event libraries to include meteorological, climatic, and technical disturbances relevant on the national scale.
- Perform dynamic grid security assessments to gauge stability margins and support the design of special protection schemes under complex scenarios.
- Where computationally feasible, incorporate protection settings and schemes to better anticipate system protection behaviour and grid responsiveness.
- Integrate DER flexibility and demand response models to assess resilience capabilities.
- Support the enhancement of national coordination dashboards, if any, for multi-scenario visualisation and reporting.
- Include cybersecurity categorisation and simulate impact mitigation pathways.

Non-Functional Requirements

- Implement automated data ingestion of TSO–DSO datasets.
- Optimise computational efficiency through hierarchical aggregation rules.
- Ensure model interoperability with national planning and operational tools.
- Maintain auditability, allowing ex post validation of assumptions and results.

EUROPEAN-LEVEL SOLUTION

At the European level, the DT environment evolves into a federated resilience platform enabling cross-border coordination and harmonised methodologies.

Functional Requirements:

- Support joint post-incident assessments and coordinated restoration strategies across borders.
- Conduct static (N-1) contingency and restoration simulations for representative event types.
- Establish a shared European framework for HILF event impact assessment and resilience indicators.
- Conduct regional and cross-border contingency and restoration evaluations.
- Evaluate national resilience metrics for a pan-European risk preparedness process.

Non-Functional Requirements:

- Ensure interoperability with European data exchange standards and federated architectures.
- Support large-scale dynamic simulations with parallel computation capabilities.
- Guarantee cybersecurity compliance and confidentiality across jurisdictions.
- Enable transparent performance benchmarking and EU-level reporting.

At each implementation stage, success depends on achieving a balanced integration of data quality, computational capacity, and analytical granularity. As data infrastructures, interoperability frameworks, and analytical tools mature, DTs will deliver increasing benefits, from faster event analysis and coordinated restoration planning to fully transparent, pan-European resilience management.

UC Cluster 3:
UC3 Coordinated TSO–DSO Security Assessment

UC3 focuses on the coordinated security assessment between TSOs and DSOs. The other high-level goals of Cluster 3 Advanced Forecasting and Decision Support are seen as enablers for an advanced security assessment.

The coordinated TSO–DSO security assessment addresses four key operational domains – congestion management, voltage control, contingency and short-circuit analysis, and dynamic security assessment – to ensure that both transmission and distribution operations are mutually supportive rather than conflicting.

The DT relies on continuous data exchange, synchronised grid modelling, and flexible analysis capabilities that serve both as a shared platform and as a tool for individual operator assessments. This is essential given the growing interdependence created by DER, active customers, electrification, and RES volatility. The goal is to enable accurate and joint assessments through regular exchange of structural and real-time grid data.

Description

The coordinated TSO–DSO security assessment aligns with security needs such as **congestion management**, **contingency and short-circuit analysis**, **dynamic security assessment**, and **voltage control**. It involves continuous data upload and storage of all relevant grid data, with flexible use for both a common platform and individual analysis.

The DT provides a shared, detailed view of the system state, enabling accurate and joint assessments. The DT aggregates structural (grid topology, capacities, templates) and real-time (SCADA / PMU, forecasts) data from TSO and DSO systems. It dynamically adapts model granularity depending on the planning horizon, from week-ahead aggregated forecasts to real-time state estimation and dynamic stability analysis.

Congestion and Voltage Issue Management

Cooperation between TSOs and DSOs is vital to prevent operational conflicts and ensure the efficient use of flexibility across the system. The DT supports coordinated network congestion management by providing both operators with a consistent and up-to-date picture of network loading and available flexibility.

- TSO frequency control can access DER-based flexibility connected at the DSO level without creating new local congestion, as the DT identifies and flags potential overload risks before activation.
- DSO congestion management actions are executed while system balance is managed through the mechanisms defined in the national framework, or by reducing the TSO's contracted frequency reserve capacity.
- TSOs and DSOs must ensure that flexibility activation – whether for delivering balancing, local, or ancillary services for TSOs or DSOs, energy sharing within the citizen energy community, or any other purpose – does not create or aggravate voltage issues.
- System operators set or update grid pre-qualification for products (likely with planning assumptions) and temporary limits on bids or products (with operations tools) to ensure that delivering balancing, local, or ancillary services does not create or aggravate congestion or voltage issues.

This mutual visibility and coordination prevent counteracting actions, help avoid unnecessary redispatch costs, and enable the safe, efficient participation of distributed resources in system balancing and network congestion management services. Ensuring harmonised congestion management processes among DSOs and TSOs using the flexibility described in UC Cluster 3 is closely related to UC1.

Voltage Control

Coordinated voltage control between the TSO and DSO levels is becoming increasingly critical as reactive power flows and distributed generation affect local and regional voltage profiles. DTs allow real-time analysis of voltage sensitivity and reactive power exchanges between grids, supporting co-optimised voltage control strategies. Operators can simulate the effect of DER reactive power support or tap-changer adjustments and determine the best joint actions to maintain voltage within limits while minimising losses and avoiding overcompensation.

Contingency and Short-Circuit Analysis

The increasing interdependence of transmission and distribution systems, driven by renewable integration, electrification, and distributed generation, necessitates improvements in standard TSOs and DSOs contingency analysis, taking into account their mutual electrical influence. The DT provides a platform for performing contingency analysis and identifying possible congestion in the transmission and distribution grids. This joint analysis enables both operators to coordinate the remedial actions needed to alleviate grid congestion.

Modern power systems with a high penetration of converter-based resources and HVDC links exhibit changing short-circuit characteristics. Cooperation between TSOs and DSOs ensures that fault-level assessments are consistent across boundaries. The DT provides a platform to dynamically calculate short-circuit currents, taking into account network topology, operational configuration, and converter behaviour.

This joint analysis helps both operators coordinate protection settings, maintain compliance with fault-level requirements, and identify necessary network reinforcements.

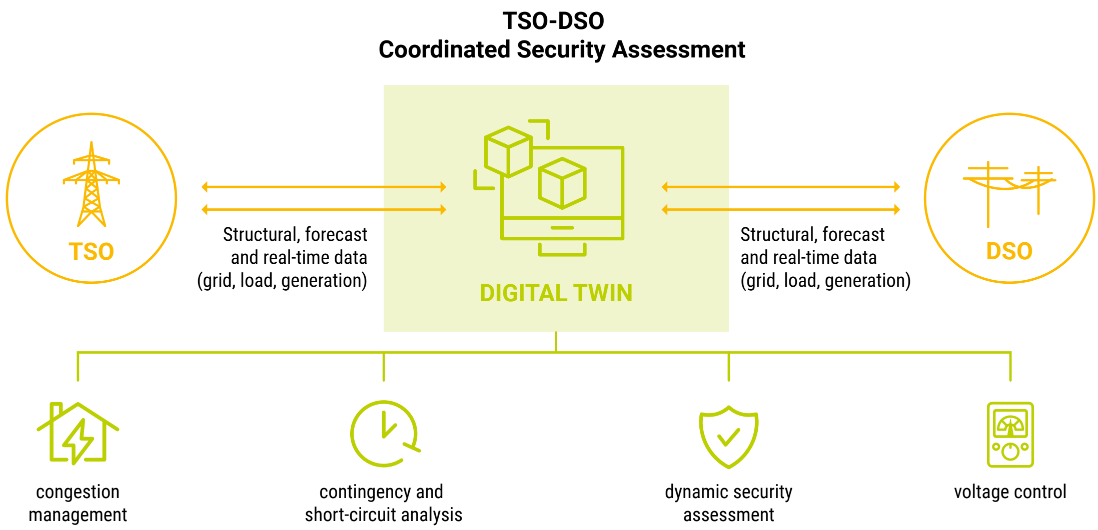


Figure 10: TSO–DSO coordinated security assessment

Dynamic Security Assessment

The DT enhances dynamic security assessments by considering both transmission system inertia and contributions (or lack thereof) of distributed generation at the DSO level. Using measured and forecasted data, the DT performs dynamic security analyses that evaluate the system's resilience to disturbances.

When the assessment identifies insufficient inertia or reduced fault tolerance, the TSO can adapt operational plans by, for example, increasing frequency control capacity, adjusting the dimensioning event, or temporarily curtailing renewables in favour of synchronous generation. This coordinated, data-driven decision-making preserves frequency stability and overall system robustness.

Solution Implementation

MINIMUM VIABLE SOLUTION

The first stage focuses on creating the foundation for coordinated TSO–DSO security assessment at the national level. At this stage, the DT serves primarily as a secure, shared environment for data exchange and visualisation. The objective is to develop a **minimum viable product** that integrates essential static and near-real-time grid data from both TSO and DSO networks to establish a unified view of the national power system. The DT in this phase operates mainly as a **data repository and offline simulation tool**, supporting tasks such as coordinated outage planning, day-ahead congestion analysis, and preliminary dynamic stability assessments. Implementation begins with defining and harmonising the **minimum dataset** for information exchange in line with existing European legislation (SOGL, KORRR) and the results from Cluster 2. Governance arrangements, data-access protocols, and cybersecurity frameworks are also tested and refined. The outcome of this stage is a viable product that demonstrates technical feasibility, data interoperability, and secure collaboration between operators, providing the foundation for more advanced functionality in later phases.

ADVANCED NATIONAL SOLUTION

In the second stage, the DT evolves from a static planning tool into an **operational decision-support system**. Real-time and high-frequency data, such as PMU and SCADA measurements, are progressively integrated, enabling continuous synchronisation with the live grid state. This allows the platform to support **dynamic and near-real-time security assessments**, including coordinated congestion management and frequency stability studies that consider distributed energy resources and local flexibility activation. At this level of maturity, the national DT supports **joint operational planning** and **coordinated response scenarios**, where both TSOs and DSOs can simulate corrective measures and assess their mutual impacts before implementation. The system also provides feedback loops for adaptive operational strategies, for example, when low system inertia requires adjustments in reserve capacities. By the end of this stage, the national DT becomes an integral tool in operational coordination, bridging the gap between research pilots and daily operations.

EUROPEAN-LEVEL SOLUTION

The final stage extends the national DT concept into a **federated European framework**, connecting multiple national or regional DTs under a common interoperability layer. This European-level product enables **cross-border coordination** of system security assessments, enhancing the collective situational awareness of the continental grid. In this stage, TSOs and DSOs from different Member States can perform **joint static and dynamic security analyses** that consider interdependencies across national boundaries. The European-level DT also supports large-scale simulations for grid resilience, regional balancing, and integration of renewable energy at the continental scale. To achieve this, governance structures and data exchange standards are harmonised, and a federated architecture ensures that data ownership remains at the national level while key insights are shared across the network. The result is an interoperable and cooperative DT ecosystem capable of supporting both national operations and pan-European coordination. It enhances grid security, reduces system-wide risks, and underpins the long-term transition towards a resilient, digitalised, and decarbonised, but also secure and reliable European electricity system.

CHAPTER 6

Integration Requirements for Digital Twin Deployment

The UCs described in Chapter 6 outline how DT capabilities can be applied to achieve both operational and strategic goals. However, successful deployment depends on each operator's ability to translate those UCs into specific, actionable integration requirements. These requirements ensure that DT solutions are not isolated experiments but form a cohesive, interoperable layer within a wider European digital ecosystem.

Each TSO and DSO must therefore assess its existing systems, data flows, and operational practices to identify functional and non-functional specifications. These specifications define what the DT must deliver locally while remaining consistent with European interoperability and governance principles. The resulting configurations will differ by operator but must all connect within a shared European framework, ensuring compatibility, transparency, and scalability.

Functional and Non-Functional Requirements Overview

DT requirements can be divided into functional and non-functional categories:

- Functional requirements define the expected roles and analytical capabilities of the DT within an operator's environment – how it collects, processes, and exchanges information to support planning, operation, and coordination.
- Non-functional requirements define performance, scalability, security, and resilience conditions under which these functions must operate.

The two dimensions must evolve together. A technically advanced DT that lacks secure governance or performance scalability will not be sustainable, and conversely, a highly resilient system without harmonised data models will fail to interoperate effectively.

Integration Layers and Key Requirements

Data & Information Layer – Governance, Quality, and Semantics

Data is the foundation of every DT. A robust data governance framework ensures that information exchanged between systems is accurate, consistent, and traceable across organisational boundaries.

Operators are encouraged to establish governance processes aligned with **ISO/IEC 38505-1** and to apply the **EU Data Act**, clearly defining data ownership, stewardship, and access rights. The framework must also ensure compliance with **GDPR** regulation and the **NIS2** directives, embedding transparency, accountability, and trustworthiness throughout the data life cycle. Data spaces initiatives like INSIEME and publications like KORR Data Exchange Standards can serve as useful guidelines. DTs rely on harmonised semantics and models to make data reusable across planning, operation, and flexibility management.

The **Common Information Model (IEC 61970/61968)**, **Common Grid Model Exchange Standard (CGMES)**, and **SAREF ontology** can serve as reference points. Operators should also consider alignment with European energy data spaces such as **INSIEME**, ensuring that local data governance supports federation into cross-border environments.

Key objectives:

- Ensure data traceability, accuracy, and contextual meaning
- Define ownership and access processes compatible with the EU data space principle
- Enable reusability of data across multiple DT applications

Communication & Interface Layer – Standards and Interoperability

Interoperability is essential to enable DTs from different vendors or operators to work seamlessly together, requiring the consistent use of open standards, protocols, and interfaces.

At this layer, operators should prioritise adopting:

- IEC 61850 for substation communication and protection data
- IEC 62325 for market data exchanges
- OPC UA and MQTT for Internet of Things (IoT) and edge-device integration
- Open, standards-based APIs for enterprise systems (e.g. ERP, EAM, GIS, DERMS)

Interfaces must be technology-neutral and vendor-independent, avoiding proprietary dependencies that hinder interoperability. Open APIs should be treated as a baseline requirement in procurement and system upgrades.

Semantic consistency between data models and APIs is equally critical. Harmonised interface definitions ensure that data generated by legacy or enterprise systems can be reused in broader national or European contexts without costly translation.

Key objectives:

- Adopt common standards and semantic models to ensure interoperability
- Use open APIs for all DT interfaces and enterprise integrations
- Design interfaces for future scalability and cross-border federation

Application & Processing Layer – Performance, Scalability, and Architecture

- The performance and scalability of a DT determine its long-term viability. Operators must design architectures that can accommodate growing data volumes, additional functionalities, and increased analytical complexity without significant redesign.
- A cloud-native, modular design – even when deployed on-premises – supports scalability, portability, and resource efficiency. Containerised services, micro-architectures, and event-driven data pipelines enable distributed computing while maintaining flexibility.
- To support continuous innovation, DT architectures should separate data, services, and interfaces so that specific components can be upgraded or replaced independently. This modular approach also ensures compatibility with legacy IT and OT systems.

Key objectives:

- Design modular, cloud-ready, and horizontally scalable architectures
- Ensure consistent performance under varying data loads
- Support integration with legacy systems without redesign
- Enable elastic resource allocation and continuous improvement

Governance & Security Layer – Cybersecurity and Resilience

- Security and reliability must be integrated by design, not added as afterthoughts. This means embedding protection, monitoring, and compliance mechanisms across every life cycle stage of the DT, from concept to operation.
- Compliance with ISO 27001, IEC 62443, NC CS (Network Code on Cybersecurity), and the Cyber Resilience Act provides a strong foundation for risk management, incident response, and auditability. Operators should encrypt data in transit and at rest, apply multi-factor authentication, and maintain strict separation between information technology (IT) and operational technology (OT) domains.
- Beyond cybersecurity, digital resilience must be considered. A resilient DT should maintain critical functions during disruptions, such as communication failures or HILF events, and recover gracefully through redundancy and automated restoration. This directly aligns with the resilience objectives defined in UC Cluster 2.2.

Key objectives:

- Implement security-by-design and compliance-by-design principles
- Ensure continuity of operations during cyber or physical disturbances
- Adopt unified risk management across all system layers
- Promote operator trust through transparent governance and certification

Common vs Local Integration Requirements

While implementation strategies vary, TSOs and DSOs share a core set of integration requirements that form the backbone of interoperability. The table below summarises common versus operator-specific elements.

Layer	Common (Pan-European) Requirements	Operator-Specific (Local) Requirements
Data & Information	Consider use of CIM / CGMES; develop translator / adapter among standards Semantic alignment with EU Data Spaces; legal and regulatory compliance (especially GDPR and the Data Act)	Legacy data migration; local data ownership rules
Communication & Interface	IEC 61850 / 61970 / 62325; open APIs; standardised protocols	Custom adapters for legacy SCADA or metering
Application & Processing	Modular, container-based architecture; scalability benchmarks	Performance tuning for specific grid sizes or IT constraints
Governance & Security	ISO 27001, IEC 62443, NIS2, CRA compliance	National cybersecurity certification; regional redundancy policies

Table 1: Common vs Local Integration Requirements

This structure ensures that all DT implementations maintain a shared baseline of interoperability while allowing flexibility for local optimisation.

Integration Readiness Assessment

Before deployment, each operator should perform an integration readiness assessment covering the four layers described above. The assessment should evaluate:

1. Existing data and system integration maturity
2. Compliance with key standards and EU legislation
3. Scalability and performance readiness
4. Security, resilience, and governance procedures

The results of this assessment guide investment prioritisation and help align national initiatives with the European federation goals of TwinEU and INSIEME. They also support regulators and policymakers in monitoring progress towards a harmonised, digitalised grid.

Alignment with European Frameworks and Projects

Integration efforts must be coherent with wider European programmes shaping the digital energy landscape.

- TwinEU defines the federated DT architecture for the European electricity system, offering the structural foundation for cross-border interoperability.
- INSIEME develops the CEEDS, ensuring data sovereignty and secure federation across platforms.
- The EU Data Act, GDPR, NIS2, and Cyber Resilience Act together form the regulatory framework underpinning trust, security, and lawful data exchange.

Aligning local DT deployments with these frameworks ensures that national solutions remain interoperable and future-proof, ready to evolve into the broader European digital ecosystem.

DT integration is not a one-time project but a continuous process of harmonisation, standardisation, and adaptation. The four integration layers (Data & Information, Communication & Interface, Application & Processing, and Governance & Security) form the foundation for this evolution. By embedding interoperability and security by design, operators can ensure that their DTs remain reliable, scalable, and aligned with European objectives. When combined with the functional maturity pathway defined in Chapter 5, these integration requirements pave the way for a federated, resilient, and future-ready DT ecosystem supporting Europe's digital and decarbonised electricity system.

CHAPTER 7

Conclusion

The European electricity system is on the brink of a fundamental transformation, with digitalisation emerging as a critical enabler for a low-carbon, integrated energy future. The previous DESAP report on TSO-DSO Challenges & Opportunities for the Digital EU Electricity System outlined the urgent challenges faced by TSOs and DSOs, including fragmented data systems, missing data, insufficient observability across voltage levels, and limited forecasting accuracy for regulatory and resource constraints. It called for a strategic, collaborative approach to DT implementation, underpinned by clear governance, high data quality, and interoperability across all system levels.

But recognising challenges is only the beginning. To accelerate digitalisation, it is now critical to move from analysis to action, defining a clear path forward, setting priorities, and identifying where digital technologies can deliver the most impact. This report takes that next step by defining high-level goals for the three identified clusters and translating them into concrete UCs. These UCs are structured around the thematic clusters from the first report and were developed to fulfil their strategic objectives. In doing so, they also considered insights from a landscape and gap analysis, ensuring that the proposed solutions address current shortcomings in DT development and help advance the digital maturity of Europe's electricity system.

Each UC is structured to highlight the key dimensions necessary for successful implementation. It outlines the critical areas to consider and presents a spectrum of solutions, from minimal and advanced national implementations to a European-level solution, including a detailed description of the minimal viable UC based on the IEC 62559 standard. This approach ensures that system operators across varying levels of digital maturity are supported and guided in advancing their digitalisation and DT adoption journeys.

The high-level goal of **Cluster 1** is to empower consumers to actively participate in flexibility markets by providing intuitive, standardised digital interfaces that enable seamless interaction with the grid and support scalable, consumer-centric flexibility services. **UC1** supports this by equipping aggregators with standardised DT interfaces, real-time data, and advanced analytics to identify, manage, and monetise consumer flexibility, ultimately enabling scalable end-user participation in flexibility markets and enhancing grid observability and optimisation. Relevant areas for the UC are data collection and infrastructure, defining flexibility needs, flexibility sharing and market integration and activation, and monetising of flexibility. Implementation ranges from foundational national solutions focused on basic data infrastructure and the external communication of flexibility needs to advanced national and European-level systems that enable real-time, automated flexibility trading across borders through fully integrated, interoperable DT platforms.

Cluster 2 aims to equip system operators with predictive, data-driven tools that enable proactive grid planning, optimise hosting capacity, and enhance resilience, ensuring infrastructure is ready for future energy demands and operational challenges. **UC2.1** supports Cluster 2's high-level goals by enabling TSOs and DSOs to jointly plan future grid developments in a consistent, data-driven way. It strengthens anticipatory investment, optimises hosting capacity, and enhances resilience by aligning planning assumptions, scenarios, and methodologies across voltage levels. Through coordinated assessments, it ensures infrastructure is developed efficiently and in line with long-term system needs. Implementation follows a progressive approach, from an MVS focused on early coordination and data exchange to an ANS with scenario-based planning, and ultimately a pan-European environment enabling harmonised, cross-border infrastructure development. Additionally, **UC2.2** was developed separately due to the high complexity of ensuring grid resilience in the face of HILF events, especially with the use of DER capabilities, including storage, demand response, and inverter-based generation. It supports the goals of Cluster 2 by establishing a shared TSO–DSO framework for modelling, simulating, and planning responses to extreme disruptions, such as severe weather, using DER-based flexibility and coordinated restoration strategies. By focusing on system impact rather than event cause, it enables consistent stress modelling, improved preparedness, and faster recovery across all system levels. Implementation again follows a staged approach, starting with basic coordination and static simulations and evolving into a pan-European DT environment for harmonised, cross-border resilience planning and recovery.

UC3.1 supports the goal of Cluster 3 by enabling coordinated TSO–DSO security assessments that ensure stable, efficient, and resilient grid operations in a system increasingly shaped by decentralised resources and real-time dynamics. It addresses key operational areas – like congestion management, voltage control, contingency and short-circuit analysis, and dynamic security assessment – through shared data, synchronised modelling, and joint simulations. Implementation progresses from an MVS focused on secure data exchange and offline simulations to an advanced national decision-support system, and ultimately to a federated European platform for cross-border security coordination.

To complement these UCs, Chapter 6 outlines the integration requirements that make DT deployment practical and interoperable. It highlights four essential layers: Data & Information, Communication & Infrastructure, Application & Processing, and Governance & Security. Furthermore, it highlights common versus individual integration requirements. Operators should assess readiness across these dimensions and align with European frameworks such as TwinEU, INSIEME, and key legislation to ensure interoperability and future-proof solutions. Integration is a continuous process, forming the backbone of a federated and resilient DT ecosystem.

By combining actionable UCs with clear integration guidelines, this report equips system operators to accelerate digitalisation, strengthen resilience, and prepare the grid for the challenges of the future. It supports a harmonised, interoperable approach that enables smarter planning, real-time operations, and consumer engagement, therefore contributing to the goal of accelerating Europe's energy transition.

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APPENDIX 1

Cluster 1 UC1

Description of the Use Case

Name of the Use Case

ID	Area/Domain(s)/Zone(s)	Name of Use Case
	Customers, Business, Market, Data and Information Exchange	Consumer-centric prosumer flexibility for scalable grid-solutions

Version Management

Version No.	Date	Name, Author(s)	Changes	Approval Status (draft, for comments, for voting, final)
1.00	2025-05-16		Draft	Final

Scope and Objectives

Scope	Enable demand-side flexibility through DT technology by empowering aggregators to manage consumer flexibility and integrate it into grid and market operations. Focus on the foundational capabilities required to start managing grid flexibility using DT technology: – Establish basic data infrastructure using existing metering and grid topology data – Publish generic flexibility signals (e.g. timing, magnitude, price) to aggregators and system operators via data spaces or external platforms – Ensure interoperability by leveraging existing data ecosystems and standards – Provide only essential data resolution for external stakeholders to respond to flexibility needs – Support initial market participation through simple communication of flexibility requirements, without advanced analytics or automated activation
Objective	1. Enhance grid observability and stability. 2. Provide aggregators with standardised interfaces and analytics to monetise flexibility. 3. Support DSOs and TSOs in leveraging consumer flexibility for congestion management and balancing markets. 4. Democratise the energy sector by integrating small units and DSOs and low participation borders.
Related Business Case(s)	Grid optimisation, market integration, aggregator business models

Narrative of Use Case

Short Description

A DT-based solution enabling aggregators to unlock consumer flexibility for grid and market optimisation, starting with minimal viable capabilities for data sharing and flexibility signalling.

Complete Description

The UC leverages DT technology to empower aggregators / flexibility service providers (FSP) with tools to identify, manage, and monetise consumer flexibility. It supports DSOs in managing local grid constraints and TSOs in integrating flexibility into balancing markets.

At its minimum viable stage, the solution focuses on basic data architectures, reuse of existing infrastructures, and publication of generic flexibility signals to relevant actors. This enables DSOs and TSOs to begin managing flexibility effectively while laying the groundwork for advanced functionalities such as automated activation, verification, and settlement.

Future stages progress towards full integration at the national and European levels, incorporating advanced analytics, real-time coordination, and harmonised digital infrastructures for cross-border flexibility trading.

Key Performance Indicators

ID	Name	Description	Reference to mentioned use case objectives
KPI1	Grid Stability	Reduced congestion	Objective 1
KPI2	Market Participation – Aggregators	Number of aggregators engaged	Objective 2
KPI3	Flexibility Offer	MW of flexibility offered through aggregators	Objective 2
KPI4	Flexibility Volume	MW of flexibility activated	Objectives 1 and 3
KPI5	Reliability of Microflex	Performance score of delivered vs procured flexibility	Objectives 1, 3, and 4

Use Case Conditions

Assumption	– Small flexibilities that are aggregated via a market aggregator have the potential within a redispatch or ancillary power scheme to strengthen and stabilise the grid. – Asset owners / users have an incentive (lower tariffs, revenue from local markets, agreements, dynamic price signals) to act in a grid-friendly manner when provided with information on how to do so. – There is a political and economical need to use flexibility at the LV level for the TSO. If flexible power at the LV level is only to be used for challenges and business cases in the distribution grid, the described UC is still valid, but only on the DSO level. – Aggregators act as intermediaries; consumers cannot be directly activated.
Prerequisites	There must be a regulatory framework enabling efficient flexibility at the customer level and enforcing the delivery of agreed-upon flexibility, for example, Implementing Acts on Access to Meter Data and Demand Response, which are currently being drafted.

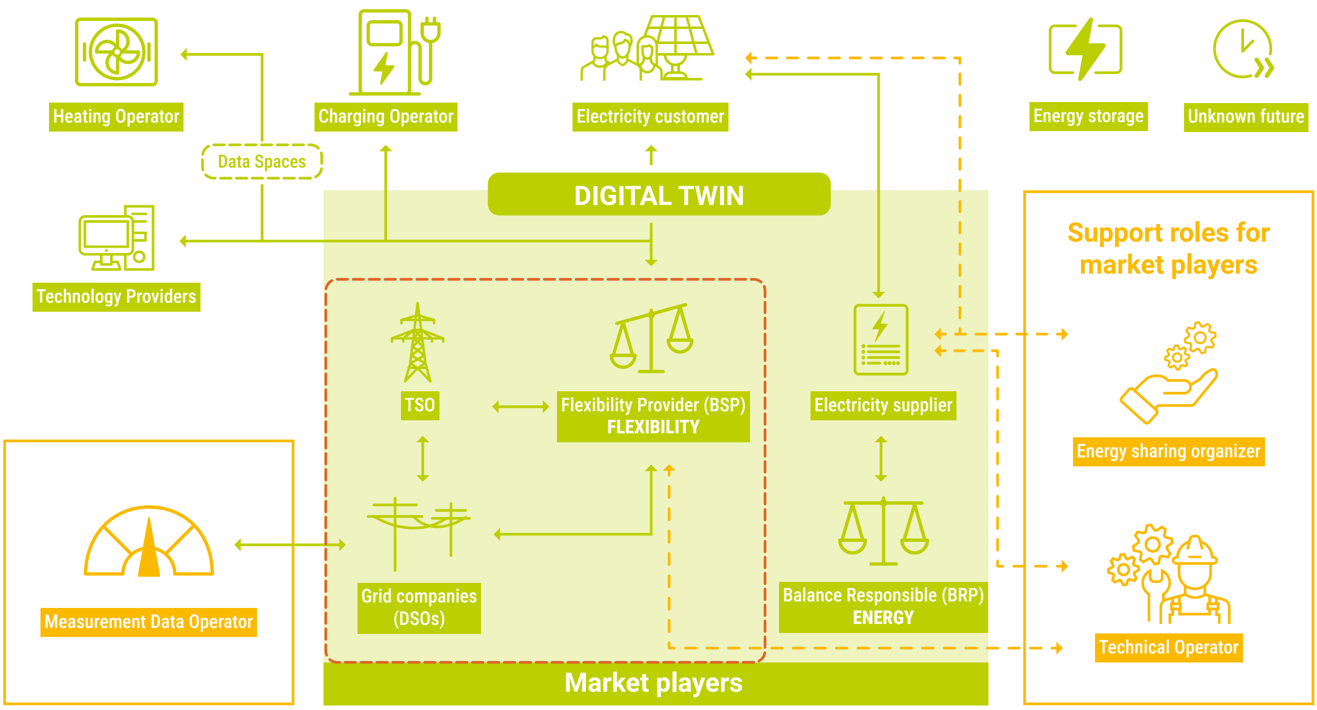
Further Information on the Use Case for Classification/Mapping

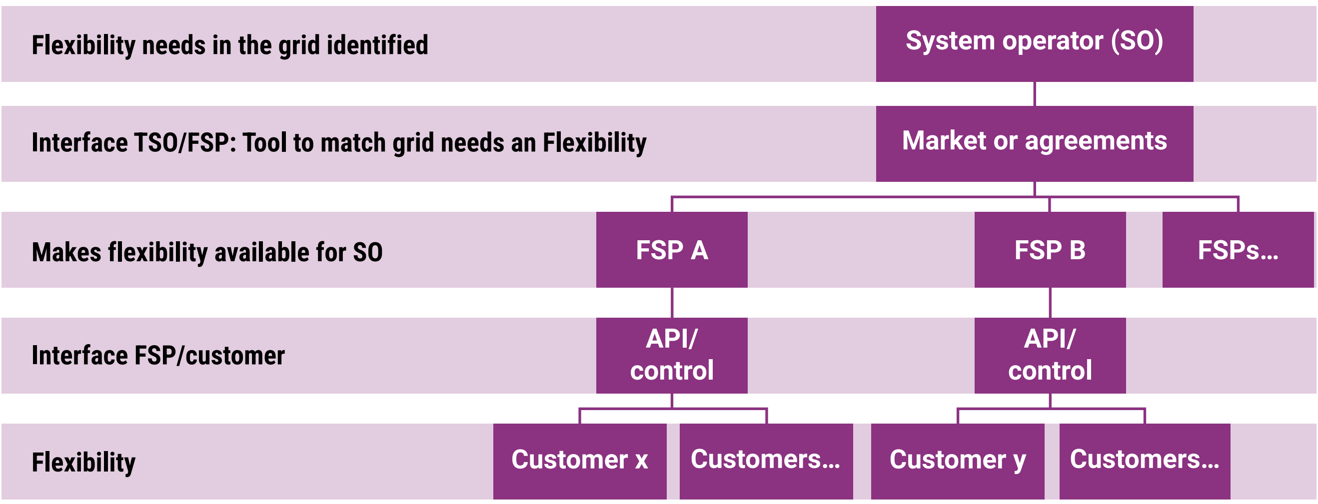
Relation to other use cases	
Level of Depth	Distribution – transmission level
Prioritisation	High
Generic, Regional, or National Relation	Regional or national
Nature of the use case	Technical and market-oriented.
Further Keywords for Classification	DT, (micro-)flexibility, aggregator, grid optimisation

Diagrams of the Use Case

Diagram(s) of Use Case

THE FUTURE ACTOR LANDSCAPE (2030)





Technical Details

Actors

Grouping		Group Description	
Actor Name	Actor Type	Actor Description	Further Information Specific to this Use Case
Aggregator / FSP	**Business**	Defined as any legal entity that offers flexibility services in the market, based on acquired (aggregated) capabilities, usually from third parties	Interfaces with consumers, manages flexibility
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	Uses flexibility for local grid management
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	The benefit of this UC for TSOs is that the aggregated flexibility is also available for TSO needs – such as frequency regulation and other ancillary services – after considering the constraints within the DSO grid.
Consumer / Asset Owner / User	**End User**	The owner / user of a micro-flexibility. Example EV User: A household that charges an EV and can adjust charging times based on electricity prices or grid needs. Example HEMS User: A building equipped with a home energy management system (HEMS) that optimises energy consumption and production from solar panels and batteries based on real-time data.	Provides flexibility indirectly via aggregator. Not an active actor in this UC, but participating via aggregator.

Step-by-Step Analysis of the Use Case

Digital Twin Implementation Scenarios for Grid Flexibility

Scenario Conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Data Collection & Infrastructure	Establish DT backbone with grid and meter data	DSO / TSO	Initiation of DT implementation	Basic IT infrastructure and metering in place	DT operational with core data available
2	Define Flexibility Needs	Identify location, time, volume, and speed of flexibility requirements	DSO / TSO	Grid congestion or balancing need	DT provides grid observability	Flexibility needs documented and ready for sharing
For more mature implementations						
3	Publish Flexibility Needs	Publish flexibility signals to aggregators and market platforms	DSO / TSO	Flexibility need identified	Standardised interface and data exchange available	Aggregators receive flexibility signals
4	Activation, Verification & Payment	Trigger flexibility resources, verify delivery and settle payments	Aggregator	Market signal or activation request	Contractual framework and verification mechanism	Flexibility delivered and payment settled

Detailed Process Steps for Data Collection & Infrastructure

Scenario Name		**Data Collection & Infrastructure**						
Step No.	Event	Name of Process / Activity	Description of Process / Activity	Service	Information Producer (actor)	Information Receiver (actor)	Information Exchanged (IDs)	Requirements, R-IDs
1	Grid topology acquisition	Collect GIS and grid models	Gather digital models of nodes, lines, substations	Data	DSO / TSO	DT system	IE-01	R-01, R-02
2	Smart meter integration	Connect metering systems	Integrate smart meter data streams into DT	Data	Consumer / Aggregator	DT system	IE-02	R-03
3	Communication setup	Establish data channels	Configure protocols, concentrators, and cybersecurity measures	Service	DSO / TSO	DT system	IE-01, IE-02	R-01, R-02, R-03

Scenario Name		Defining Flexibility Needs						
Step No.	Event	Name of Process / Activity	Description of Process / Activity	Service	Information Producer (actor)	Information Receiver (actor)	Information Exchanged (IDs)	Requirements, R-IDs
1	Analyse grid data	Identify flexibility hotspots	Use DT data to locate nodes / areas with congestion or balancing needs	Analytics	DT system	DSO / TSO	IE-01, IE-02	R-04
2	Quantify flexibility need	Calculate parameters	Determine location, time, duration, volume, and speed requirements	Analytics	DT system	DSO / TSO	IE-03	R-04, R-09
3	Validate require-ments	Confirm feasibility	Ensure flexibility needs align with connection agreements and market rules	Service	DSO / TSO	Aggregator	IE-03	R-04, R-05

Information Exchanged

Information Exchanged ID	Name of Information	Description of Information Exchanged	Requirement, R-IDs
IE-01	Grid Topology Data	Digital representation of grid nodes, lines, substations (GIS models)	R-01, R-02
IE-02	Smart Meter Data	Consumption and generation data from end users, aggregated where needed	R-01, R-03
IE-03	Flexibility Needs	Location, time, duration, volume, and speed of required flexibility	R-04, R-09
IE-04	Market Signals	Price signals and availability indicators for flexibility services	R-05
Needed for more mature implementation			
IE-05	Flexibility Offers	Location, time, duration, volume, and speed of offered flexibility	R-08
IE-06	Activation Requests	Instructions to activate flexibility resources, manual or automated	R-06
IE-07	Verification Data	Meter data or performance reports confirming delivery of flexibility	R-07

Requirements

Category ID	Category name for requirements	Category description
CAT-01	Data Interoperability	Ensure compatibility with existing data spaces and standards
CAT-02	Cybersecurity & Privacy	Protect data integrity and confidentiality
CAT-03	Market Integration	Enable communication with flexibility platforms
CAT-04	Activation & Settlement	Support operational and contractual processes

Requirement, R-IDs	Requirement name	Requirement description
R-01	Standardised Data Format	Use common standards for grid and meter data exchange
R-02	GIS Integration	Include geographic grid models in DT
R-03	Smart Meter Connectivity	Ensure data granularity and frequency meet minimum specs
R-04	Flexibility Need Publication	Publish needs via APIs or data spaces
R-05	Price Signal Transparency	Provide clear pricing models for flexibility services
R-06	Activation Protocols	Define request-based activation mechanisms
R-07	Verification & Settlement	Implement processes for verifying delivery and payment
R-08	Flexibility Offer Publication	Publish needs via APIs or data spaces
R-09	Load / Production forecasts / Info	Forecasts / info of loads and production not participating in flexibility service are integrated into DT

APPENDIX 2

Cluster 2 UC1

Description of the Use Case

Name of the Use Case

ID	Area / Domain(s)/Zone(s)	Name of Use Case
	System Planning, Future Flexibility and Assets Life Cycle	Enhanced Network Planning and Hosting Capacity

Version Management

Version No.	Date	Name, Author(s)	Changes	Approval Status (draft, for comments, for voting, final)
3.0	2025-11-10		Draft	Final

Scope and Objectives

Scope	This UC outlines the business requirements designed for advanced electricity network planning across and between DSOs and TSOs. It focuses on a coordinated planning approach designed to strengthen common long-term planning steps and strategies of shared interest, ensuring that future grid investments and reinforcements are developed consistently across voltage levels.
Objectives	1. Optimise planning timing and asset utilisation while ensuring long-term grid security and resilience. 2. Establish a shared analytical framework between TSOs and DSOs to support anticipatory grid planning, combining historical data with scenario-based forecasts. 3. Enable joint identification of reinforcement needs, congestion risks, and flexibility opportunities through interoperable data exchange and coordinated power flow studies.
Related Business Case(s)	Reduced SAIDI / SAIFI through improved maintenance Deferred or optimised capital expenditure through better planning and utilisation of existing assets and DER Reduced DER connection waiting times through optimised hosting capacity Improved operational efficiency through automated planning and TSO–DSO coordination

Narrative of Use Case

Short Description

In its implementation phase, the UC represents the foundational stage of the coordinated long-term grid planning DT between TSOs and DSOs. It establishes a technical and procedural framework for early interoperability, focusing on data consistency, network model integration, and coordinated grid reinforcement assessments.

The MVS provides a shared environment for joint power flow, contingency, and interface analyses, where the first harmonised datasets and simplified network representations are tested and validated. It aims to demonstrate the feasibility of cross-operator planning, ensuring consistent visibility of critical substations, interface nodes, and areas with emerging sector-coupled loads (e. g. data centres, hydrogen pilot projects, EV hubs, and others).

Complete Description

In its MVS phase, the UC represents the foundational phase of coordinated long-term grid planning between TSOs and DSOs. It focuses on building the essential data, analytical, and coordination capabilities required for effective joint planning and hosting capacity assessments. At this stage, the emphasis is on developing a common understanding of network boundaries, harmonising data exchange practices, and validating analytical processes such as power flow studies and reinforcement evaluations.

The MVS acts as a proof-of-concept environment, where interoperability, data governance, and analytical transparency can be tested and refined before scaling towards advanced and more integrated solutions. It supports technical validation of coordinated planning methodologies, enabling both system operators to jointly identify reinforcement needs, congestion hot spots, and opportunities for sector integration.

The following subsections outline the functional and non-functional requirements that define the MVS implementation, describing the minimum technical, analytical, and procedural features necessary to achieve reliable TSO–DSO coordination and provide a baseline for future DT development.

1. FUNCTIONAL REQUIREMENTS:

Data Exchange and Integration

- Establish data exchange pipelines using secure interfaces (e. g. APIs, message brokers, or SFTP gateways) based on standardised profiles or simplified exchange formats (e. g. JSON / XML) to ensure compatibility with existing TSO / DSO planning tools.
- Define minimum observability boundaries, i. e. data requirements for TSO–DSO interface substations, including:
  - Node and branch parameters (R / X, rating limits)
  - DER injection points and aggregated flexibility potential
  - Connection capacities and pending connection requests
- Develop model simplification and aggregation processes, allowing system operators to share reduced network equivalents (e. g. via impedance aggregation, net load modelling, or zonal representations) to ensure computational efficiency while preserving accuracy at interface points. This also applies to data from generation and other facilities (EV charging, battery storage, data centres, and others) which can safely and harmonically be integrated in the planning process.
- Integrate GIS topology and asset metadata to enable spatial visualisation and correlation with sectoral developments.

Analytical Capabilities

- Implement deterministic steady-state power flow simulations (AC / DC) for both base and contingency (N–1 or N-X-1) conditions to assess:
  - Congestion and reverse power flows across transmission-distribution boundaries
  - Voltage profile deviations and voltage control needs
  - Transformer or cable overloading under projected demand and generation growth scenarios
- Conduct sensitivity analyses on assets interface loading as new demand centres or RES connections are introduced.
- Perform early screening of reinforcement alternatives, comparing traditional grid expansion with local flexibility utilisation (e.g. demand response, storage dispatch, dynamic line rating).
- Enable preliminary sector-coupling assessments, evaluating the grid impact of major new loads or technologies using simplified temporal profiles.

Coordination and Reporting

- Facilitate joint visualisation and reporting dashboards, allowing TSO and DSO planners to compare reinforcement needs, connection backlogs, and investment priorities.
- Generate standardised coordination reports summarising grid constraints, planned works, and interface adequacy indicators (e.g. available hosting capacity, congestion probability).
- Introduce data quality validation routines to check completeness, plausibility, and alignment of shared datasets.

2. NON-FUNCTIONAL REQUIREMENTS

Interoperability and Standards

- Adopt relevant standards (CIM CGMES or others) for data model subsets for core asset (critical network elements) and topology data, enabling future expansion to full interoperability.
- Define a metadata registry describing shared datasets (e.g. format, frequency, ownership, versioning) to ensure consistency and traceability.
- Develop translation adapters for legacy DSO / TSO planning tools for future compliance.

Data Quality, Aggregation, and Security

- Introduce data aggregation rules (e.g. feeder grouping, load / generation clustering) to ensure computational efficiency and data confidentiality.
- Apply role-based access control for shared datasets and limit visibility to necessary model boundaries.
- Secure all exchanges using encryption, data hashing, and audit trails for traceability and compliance with current and future cybersecurity frameworks.

Computational Performance

- Optimise computation through network partitioning techniques (e.g. zonal reduction, distributed computing).
- Establish benchmark KPIs (e.g. maximum network size, time-to-solve) for performance monitoring of joint simulations.

User Accessibility and Governance

- Implement intuitive interfaces with layered visualisation of TSO–DSO interfaces, allowing filtering by congestion level, reinforcement need, or flexibility potential.
- Ensure clear governance protocols specifying which party (TSO or DSO) maintains, validates, and updates shared data objects, and has access to it.
- Provide traceable version control for model revisions and simulation outputs, ensuring transparent auditability.

Scalability and Modularity

- Use a modular architecture, enabling incremental integration of additional DSOs or analytical modules (e.g. scenario analysis, dynamic studies).

Key Performance Indicators

ID	Name	Description	Reference to mentioned use case objectives
KPI-01	Data Interoperability Index	Measures the percentage of successfully exchanged and processed datasets between TSO and DSO systems without data loss, format errors, or semantic inconsistencies. Indicates readiness of data models and exchange mechanisms.	Objectives 1 and 2
KPI-02	Coordinated Planning Coverage	Percentage of substations, interface points, or regions included in joint TSO–DSO planning studies compared to total national grid areas. Reflects the operational extent of coordination achieved under MVS.	Objectives 1 and 2
KPI-03	Stakeholder Data Accessibility	Degree to which authorised users (TSOs, DSOs, regulators) can access shared data, results, and visualisations through common platforms or interfaces, measured via accessibility or satisfaction index.	Objective 2
KPI-04	Identified Flexibility Opportunities	Number or percentage of network zones where flexibility-based solutions are identified as viable alternatives to traditional reinforcements during planning studies.	Objective 3

Use Case Conditions

Assumption	_ Both TSOs and DSOs have existing grid models and planning tools capable of performing steady-state (power flow) and contingency analyses independently. _ Participating TSOs and DSOs are **willing to exchange non-confidential planning data** at the aggregated or interface level to enable joint analyses. _ Common or mappable data models are used, or conversion pipelines are established to ensure data compatibility. _ The level of **model simplification and temporal granularity is jointly agreed** to, ensuring computational feasibility and mutual understanding. _ Legal and regulatory frameworks permit data sharing for planning purposes while respecting confidentiality obligations.
Expected Outcomes	_ Verified **TSO–DSO data interoperability** for interface substations _ Demonstrated **joint analytical feasibility** for coordinated reinforcement _ Established **foundations for advanced DT development**
Prerequisites	_ **Data Interoperability Framework:** A minimum set of data exchange formats, mapping rules, and validation tools must be in place to ensure correct interpretation of exchanged datasets. _ **Secure Data Exchange Infrastructure:** Establishment of a secure digital environment that allows authorised planners to upload, access, and analyse shared planning data. _ **Grid Boundary Definition:** Clear identification and modelling of TSO–DSO interface substations and boundary nodes to allow cross-network studies. _ **Coordination Procedures:** Initial governance rules and communication protocols defined for coordination meetings, validation of study results, and change management. _ **Analytical Tools:** Common defined power flow and contingency analysis software (centralised or decentralised) capable of importing external network models and performing joint simulations.

Further Information on the Use Case for Classification/Mapping

Relation to other use cases	Resilience, customer flexibility – The MVS phase provides the foundational data and coordination mechanisms that other assessment areas will later build upon.
Level of Depth	Distribution – transmission level
Prioritisation	High – essential for establishing the data and procedural foundation for advanced national and European planning environments.
Generic, Regional, or National Relation	Regional case with interoperability validation and coordination of frameworks before upscaling.
Nature of the use case	Analytical / Planning – supports strategic grid development decisions through enhanced data sharing and methodological consistency, without direct operational control functions.
Further Keywords for Classification	Investment planning, coordinated grid development, data-driven network reinforcement

General Remarks

This MVS represents the foundational stage of coordinated grid planning and digitalisation between TSOs and DSOs. It focuses on establishing data exchange mechanisms, analytical interoperability, and trust frameworks necessary for long-term coordination. While no full hosting capacity or dynamic scenario modelling is implemented at this stage, the MVS provides critical building blocks, enabling future automation, scenario-based planning, and multi-energy integration.

The MVS outcomes will serve as proof of concept for coordinated national planning processes, informing the ANS design and helping identify regulatory or technical barriers to data exchange and joint investment planning.

APPENDIX 3

Cluster 2 UC2

Description of the Use Case

Name of the Use Case

ID	Area / Domain(s)/Zone(s)	Name of Use Case
	System Planning, Future Flexibility & Assets Lifecycle	Enhanced network planning for high resilience to HILF events through DER

Version Management

Version No.	Date	Name, Author(s)	Changes	Approval Status (draft, for comments, for voting, final)
1.00	2025-11-10		Draft	Final

Scope and Objectives

Scope	This UC defines the minimum viable capability for TSO–DSO coordinated resilience planning in the context of HILF events, such as extreme weather, large-scale technical failures, or future cyber contingencies. The MVS focuses on establishing the methodological and data foundations to model how these events affect the grid and to assess system response, recovery options, and the contribution of distributed resources. It aims to create a common analytical language and a shared event-to-impact translation process across operators.
Objectives	1. Establish a shared methodology to translate HILF events into quantifiable system impacts (e.g. loss of lines, assets, or generation). 2. Develop and test joint contingency and restoration assessments for representative events. 3. Identify critical network areas and boundary conditions relevant to resilience planning. 4. Define data exchange, interoperability, and confidentiality rules supporting secure coordination. 5. Prepare a foundation for future dynamic or cross-border resilience assessments by defining scalable analytical templates.
Related Business Case(s)	Reduced SAIDI / SAIFI through improved preparedness and faster restoration. Reduced economic and social losses through coordinated resilience measures. Optimised investment prioritisation for critical nodes and flexibility integration. Increased DER participation in resilience and restoration services.

Narrative of Use Case

Short Description

This UC establishes the first coordinated framework between TSOs and DSOs for assessing the resilience of the electricity grid against HILF events, such as extreme weather or large-scale equipment failures. The MVS focuses on developing common methodologies, data-sharing processes, and analytical templates to quantify system vulnerabilities and evaluate restoration strategies.

By enabling harmonised static contingency and restoration analyses, this phase lays the groundwork for future, more advanced dynamic and cross-sector resilience planning.

Complete Description

The UC represents the initial phase of implementing the enhanced network planning use case for HILF event resilience. It aims to establish a shared TSO–DSO methodological, data, and simulation framework that enables both operators to jointly model and evaluate the grid's response and recovery under extreme events such as storms, floods, heatwaves, cyberattacks, or multi-asset failures.

At this stage, the focus is on building analytical and procedural readiness, ensuring that resilience-oriented planning can be performed consistently across system boundaries. Rather than executing large-scale dynamic simulations or advanced DT automation, the MVS focuses on developing a proof of concept for joint analytical feasibility, methodological alignment, and secure data exchange.

The MVS enables the translation of disruptive events into quantifiable grid stresses, testing system behaviour under static contingency conditions, and defining early coordination mechanisms for restoration and recovery planning.

1. FUNCTIONAL REQUIREMENTS

Event-to-Impact Translation

- Establish shared documentation of representative HILF events, including meteorological, technical, and cyber-related disturbances.
- Define mapping functions between event parameters (e.g. wind speed, flood depth, temperature, solar eclipse coverage) and asset unavailability or performance degradation.
- Develop standardised impact templates describing expected system responses such as line outages, generator trips / reductions, voltage violations, or load shedding.

Common Scenario and Data Framework

- Align TSO–DSO datasets for grid topology, asset flows, and load-generation profiles.
- Ensure model simplification and aggregation rules to maintain data confidentiality while retaining analytical validity at interface nodes.
- Introduce harmonised parameter sets (e.g. critical load definitions, restoration time constants) to enable comparable analysis outcomes.

Static Security and Contingency Simulation

- Perform static (N–1 or N–X) contingency simulations using harmonised data inputs and solver settings.
- Identify overloads, voltage issues, and critical substations likely to trigger cascading effects during HILF events.
- Run preliminary sensitivity analyses on the effects of DER availability or flexibility activation under stress conditions. This defines the type of flexibility needed and the assumed response to the system conditions.

Restoration and Coordination Planning

- Develop simplified restoration templates, including coordination steps, critical load prioritisation, and asset recovery sequencing.
- Test data-driven coordination dashboards visualising stress propagation, restoration progress, and cross-boundary dependencies.
- Integrate simplified DER models to evaluate their potential role in supporting black-start or islanding strategies at this stage.

Governance, Data Exchange, and Reporting

- Define roles, responsibilities, and communication protocols for joint resilience studies.
- Enable secure data exchange using encrypted interfaces or controlled-access portals.
- Generate harmonised resilience reports, summarising vulnerabilities, restoration priorities, and coordination gaps.

2. NON-FUNCTIONAL REQUIREMENTS

Interoperability and Standards

- Adopt data models or compatible exchange formats for shared datasets.
- Maintain a metadata registry specifying dataset versions, ownership, and validation status.
- Develop translation or adapter modules to integrate legacy DSO and TSO simulation tools within a common framework.

Data Quality, Aggregation, and Security

- Apply aggregation and anonymisation rules to protect sensitive grid and asset data.
- Introduce data quality checks for completeness, temporal alignment, and semantic consistency.
- Ensure full compliance with cybersecurity frameworks through encrypted access control.

Computational Performance

- Optimise simulations via network partitioning and zonal model reduction to ensure computational feasibility.
- Define performance benchmarks (e. g. maximum model size, execution time) for iterative improvement.
- Support limited parallel computation where feasible to accelerate contingency evaluation.

User Accessibility and Collaboration

- Implement web-based or desktop visualisation dashboards displaying shared contingency results and restoration priorities.
- Ensure traceability and auditability of all simulation results through version control and model change tracking.
- Provide clear governance protocols defining roles and responsibilities, ownership, maintenance, and update frequency of shared analytical artefacts.

Scalability and Modularity

- Use a modular architecture that allows gradual integration of additional DSOs, regions, or analytical functions.
- Ensure that MVS results can be seamlessly upscaled towards advanced national or pan-European solutions, without structural redesign.

Key Performance Indicators

ID	Name	Description	Reference to mentioned use case objectives
KPI-01	Resilience Readiness Index	Measures the completeness and maturity of resilience methodologies jointly adopted by TSOs and DSOs	Objective 1
KPI-02	DER Flexibility Utilisation Rate	Percentage of DER capacity modelled and integrated into resilience assessments	Objective 2
KPI-03	Restoration Time Reduction	Estimated reduction in system or critical-load recovery time after simulated HILF events compared to baseline	Objectives 2 and 3
KPI-04	Post-Event Learning Integration	Frequency and quality of model updates or assumption revisions following real incidents	Objective 3

Use Case Conditions

Assumption	– Both TSOs and DSOs have access to compatible planning and simulation tools for static (N-1 / N-X) analysis. – National regulation allows or encourages data exchange for resilience assessment purposes under confidentiality agreements. – The focus is on system impact and restoration coordination, not root-cause (event origin) analysis. – DER participation is limited to mapping flexibility availability; dynamic response is not modelled yet.
Prerequisites	– Interoperable data exchange environment for network models and contingency results. – Event impact catalogue linking incident types (e. g. storm, flood, cyber) to representative asset failures. – Static contingency simulation environment (power flow and restoration path modelling). – Confidentiality and access control mechanisms for shared resilience data. – Joint validation procedure for resilience scenarios between TSO and DSO.

Further Information on the Use Case for Classification/Mapping

Relation to other use cases	
Level of Depth	DSO–TSO, covering cross-system coordination for resilience and restoration
Prioritisation	High – critical for national and (if feasible) European preparedness
Generic, Regional or National Relation	Regional, with potential cross-border extensions at the national and pan-European implementation phases
Nature of the use case	Analytical / simulation-based planning – not real-time operation
Further Keywords for Classification	Resilience planning, HILF events, DER flexibility, restoration, event-to-impact translation

General Remarks

At the MVS level, the UC validates the core analytical capability for resilience-oriented planning and provides proof of coordination feasibility between TSO and DSO for extreme-event analysis. The focus remains on static simulations, data harmonisation, and methodology development, not on advanced automation or dynamic studies.

Success at this stage is measured by technical readiness, process alignment, and analytical consistency across operators. It forms the essential foundation for scaling towards advanced national and pan-European resilience frameworks.

APPENDIX 4

Cluster 3 UC3

Description of the Use Case

Name of the Use Case

ID	Area / Domain(s)/Zone(s)	Name of Use Case
	System Operations, Dynamics, Control Rooms of the Future	Coordinated security analysis to optimise system operations

Version Management

Version No.	Date	Name Author(s)	Changes	Approval Status (draft, for comments, for voting, final)
1.00	2025-11-06		Draft	Draft

Scope and Objectives

Scope	The UC establishes a coordinated security assessment framework between TSOs and DSOs. It defines how a DT can enable simulations for joint system analysis by combining structural and measurement data with variable granularity to support multiple objectives, including congestion management, voltage control, contingency and short-circuit analysis, and dynamic stability assessment.
Objective	1. Create a **harmonised TSO–DSO operational view** supported by a shared DT platform that provides synchronised grid models and continuous data exchange. 2. **Ensure interoperability and data accuracy** by defining common exchange models, validation rules, and synchronisation processes for both structural and real-time information. 3. **Improve coordinated security assessments** (congestion management, voltage control, short-circuit / contingency analysis, and dynamic stability assessment) by providing consistent, simulation-ready grid representations for joint offline simulations that can be used to refine and adjust current operational models and later be integrated in the operation. 4. Maintain and prove **secure and efficient data exchange.**
Related Business Case(s)	Cross-level conflict avoidance, congestion cost reduction, enhanced frequency stability, improved voltage quality, and optimised use of distributed resources.

Narrative of Use Case

Short Description	Coordinated TSO–DSO security assessment using a DT that synchronises structural models and operational measurements across levels. The platform supports steady-state and dynamic studies across interfaces and turns operational data into actionable insights for congestion management, voltage control, short-circuit / contingency analysis, and dynamic stability assessment domains through offline simulations on the combined model.
Complete Description	The DT combines structural and real-time data from TSO and DSO systems in a common analytical framework. It ensures model consistency, time alignment, and data validation before each coordinated assessment. Depending on the operational horizon, the DT adapts the granularity of the data used for simulations. The platform contains the necessary data and can run offline simulations. For congestion, it identifies cross-level constraints and can identify possible conflicts on flexibility activations. For voltage, it evaluates reactive power exchanges and sensitivity at interfaces. For contingency and short-circuit analysis, it accounts for topology, protection limits, and converter-dominant behaviour. For dynamic security assessment, it includes inertia contributions, controls, and representative distribution effects, and can incorporate border-area dynamics when needed. While in the initial phase, the focus is on achieving secure and compatible data sharing for use on offline simulations, over time it can evolve into more continuous assessment and process integration.

Key Performance Indicators

ID	Name	Description	Reference to mentioned use case objectives
KPI-01	Structural Data Interoperability Rate	Share of required structural successfully exchanged through standardised, validated formats without manual conversion	Objectives 1 and 4
KPI-02	Real-Time Data Interoperability Rate	Share of required structural successfully exchanged through standardised, validated formats without manual conversion	Objectives 1 and 4
KPI-03	Model Consistency Success Rate / Share	Ratio of successfully validated data sets to total exchanged, reflecting data validity and correctness	Objectives 1 and 4
KPI-04	Model Synchronisation Latency	Average time between data availability (snapshot or telemetry) and generation of an analysis-ready DT model	Objectives 1 and 4
KPI-05	Congestion Management Accuracy Improvement	Relative improvement between coordinated offline simulations using shared TSO–DSO models and results obtained with simplified, non-coordinated models	Objectives 2 and 3
KPI-06	Voltage Limits Accuracy Improvement	Relative improvement between coordinated offline simulations using shared TSO–DSO models and results obtained with simplified, non-coordinated models	Objectives 2 and 3
KPI-07	Improvement in Short-Circuit and Contingency Accuracy	Relative improvement between coordinated offline simulations using shared TSO–DSO models and results obtained with simplified, non-coordinated models	Objectives 2 and 3
KPI-08	Incident Detection and Response Times	Mean time to detect (MTTD) and mean time to respond (MTTR), potentially using simulated attacks exercises	Objective 4
KPI-09	Operator Training Effectiveness	Number of hours-person operators trained in advanced combined TSO–DSO simulations	Objectives 1 and 3

Use Case Conditions

Assumption	– TSO and DSO each maintain structural and operational grid models in compatible formats that can be exchanged through a standardised interface. – Existing regulations and legislation allow, support, and potentially incentivise coordination – Cost and responsibility follow clear rules agreed upon and accepted by participants – Data required is available, sharing is allowed and agreed upon
Prerequisites	– Defined and agreed-upon dataset for structural and real-time data exchange, with validation and timestamping rules – Clear data and process ownership rules – OT / IT devices / infrastructure that provide the data to the required standards – Computational capacity is available in accordance with requirements

Further Information on the Use Case for Classification/Mapping

Relation to other use cases	UC1: Functionally related by cross-level flexibility topics UC2.1/UC2.2: This UC can be seen as the operational counterpart/complement of the planning UCs, focusing on shorter time frames (T-24/48h). Significant overlap on the data structural data requirements and possible synergy on the data and model validation.
Level of Depth	National level: Distribution – transmission
Prioritisation	High
Generic, Regional, or National Relation	National
Nature of the Use Case	Technical and system operation oriented
Further Keywords for Classification	Digital twin, control room of the future, dynamic security assessment, interoperability, cross-level simulation, grid congestion, contingency and short-circuit analysis, voltage control

Technical Details

Actors

Grouping		Group Description	
Actor Name	Actor Type	Actor Description	Further Information Specific to This Use Case
Transmission System Operator	**Grid Operator**	– Owns and provides transmission network data – Analyses simulation results on impacts of transmission network	
Distribution System Operator	**Grid Operator**	– Owns and provides distribution network data – Analyses simulation results on impacts of distribution network	
Data Platform	**Compute/Storage System**	Technology platform where data is stored and processed	

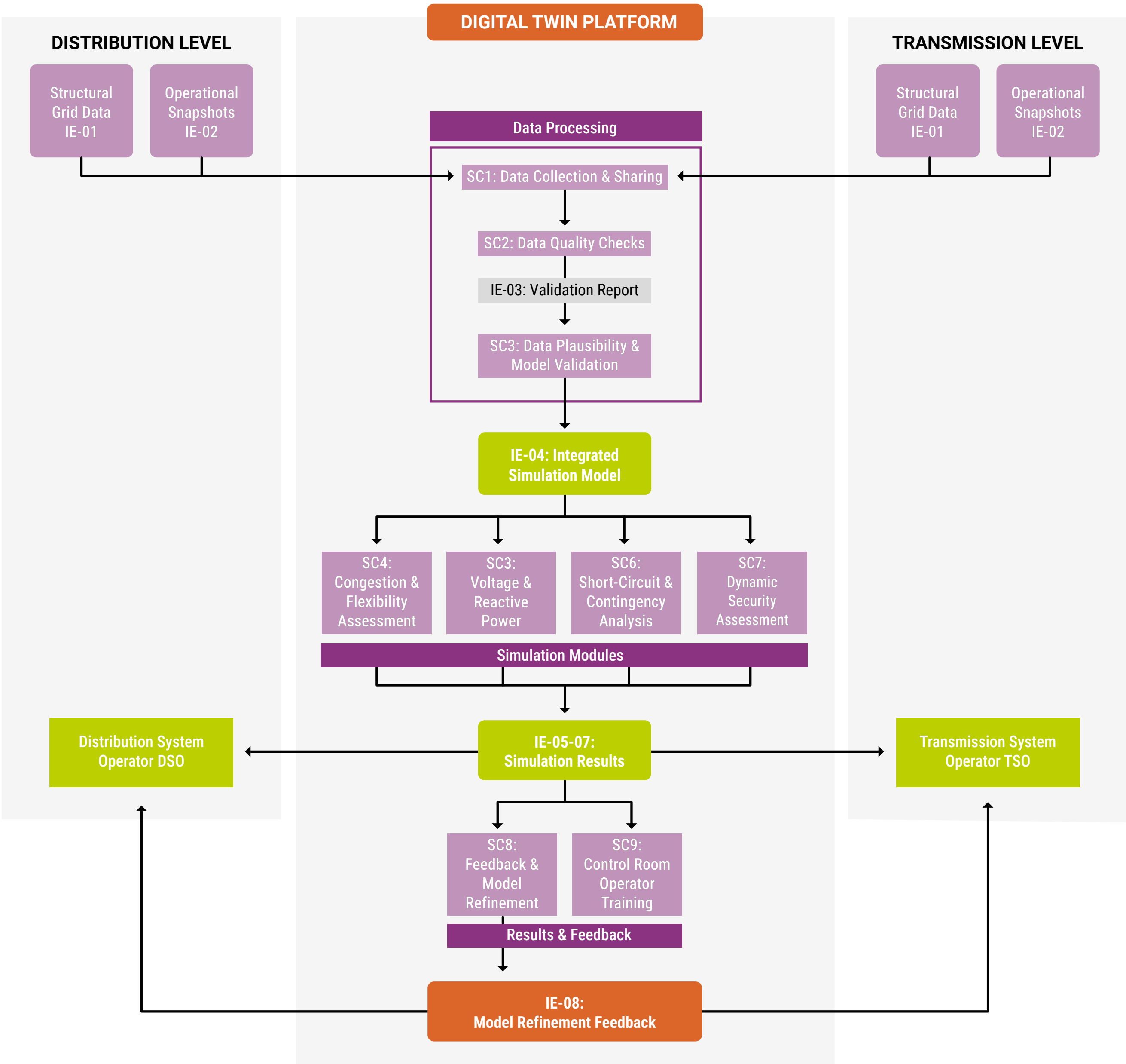
Step-by-Step Analysis of the Use Case

Overview of Scenarios

No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
SC1	Data Collection and Sharing	Exchange of structural and operational datasets between TSO and DSOs according to agreed-upon formats and schedules	TSO / DSO	Scheduled data exchange or model update request	Data available and communication interfaces active	Datasets successfully transferred and accessible to both parties
SC2	Data Quality Check	Verification of received data for format, completeness, timestamp consistency, and version control	DT Platform	Completion of data exchange (SC1)	Structural and operational data received	Data quality report produced; datasets validated or corrected
SC3	Data Plausibility and Model Validation	Check of physical and logical data correctness through convergence and plausibility tests	DT Platform	Completion of data validation (SC2)	Datasets validated for completeness and format	Plausibility confirmed; integrated model approved for simulation
SC4	Offline Congestion and Flexibility Assessment	Coordinated offline load-flow simulation to identify congestion and compare with simplified models	DT Platform	Model validated and approved (SC3)	Simulation-ready model available	Congestion results and improvement indicators document-ed
SC5	Offline Voltage and Reactive Power Assessment	Simulation of voltage profiles and reactive exchanges to assess coordination benefits	DT Platform	Model validated and approved (SC3)	Integrated model with verified parameters available	Voltage results and improvement metrics available
SC6	Offline Short-Circuit and Contingen-cy Analysis	Simulation of short-circuit and contingency cases using validated models for consistency checks	DT Platform	Model validated and approved (SC3)	Dynamic and protection data available	Consistent results across TSO–DSO boundaries
SC7	Offline Dynamic Security Assessment	Offline dynamic simulations using measured and forecast data to assess system stability and inertia	DT Platform	Model validated and approved (SC3)	Dynamic parameters and forecast data integrated	Dynamic stability indicators and recommended actions available
SC8	Feedback and Model Refinement	Comparison of simulation results with simplified models to update data and parameters	TSO / DSO	Simulation results available	Completion of simulation scenarios	Updated models and refined data prepared for next cycle
SC9	Control Room Operator Training	Use of DT simulations for operator training and situational awareness improvement	TSO / DSO	Scheduled training or post-event analysis request	Validated model and simulation cases available	Operators trained; improved coordination and awareness documented

Diagrams of the Use Case

System Architecture and Information Flow



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