D3.1: HIGH-LEVEL DESCRIPTION OF USES CASES AND BUSINESS MODELS

VERSION 1.2

Consortium members from Austria, Germany, and Türkiye

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ERA-Net Smart Energy Systems

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TABLE OF CONTENT

GLOSSARY

- **Digital Twin**: A virtual model of a physical asset, process, or system that allows for real-time monitoring, simulation, and predictive analysis.
- **Distribution System Operator (DSO)**: An organization responsible for operating, maintaining, and developing the electricity distribution network.
- **Energy Provider**: An entity responsible for generating and supplying energy to the grid.
- **Internet of Things (IoT)**: A network of physical devices embedded with sensors and software, enabling data collection and exchange over the internet.
- **Predictive Maintenance**: A proactive maintenance strategy that uses data analysis tools to predict potential failures and perform maintenance before issues occur.
- **Renewable Energy Community (REC)**: A group focused on producing and managing renewable energy for community use.
- **Single-Source-of-Truth**: A data management principle ensuring that all stakeholders refer to the same, consistent data source.
- **Stakeholder**: Any individual, group, or organization impacted by or involved in a project or business activity.

ABBREVIATIONS TABLE

Abbreviation	Full Term
API	Application Programming Interface
CAPEX	Capital Expenditure
DER	Distributed Energy Resources
DSO	Distribution System Operator
DT	Digital Twin
GIS	Geographic Information System
IoT	Internet of Things
KPI	Key Performance Indicator
LEC	Local Energy Community
LV	Low Voltage
MV	Medium Voltage
NDA	Non-Disclosure Agreement
OPEX	Operational Expenditure
PV	Photovoltaic
PQM	Power Quality Monitoring
REC	Renewable Energy Community
RES	Renewable Energy Source
SCADA	Supervisory Control and Data Acquisition
TSO	Transmission System Operator
UC	Use Case

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About ERA-Net Smart Energy Systems

ERA-Net Smart Energy Systems (ERA-Net SES) is a transnational joint programming platform of 30 national and regional funding partners for initiating co-creation and promoting energy system innovation. The network of owners and managers of national and regional public funding programs along the innovation chain provides a sustainable and service oriented joint programming platform to finance projects in thematic areas like Smart Power Grids, Regional and Local Energy Systems, Heating and Cooling Networks, Digital Energy and Smart Services, etc.

Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

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1 EXECUTIVE SUMMARY

Deliverable D3.1, Use Cases and Business Models, encapsulates the collaborative innovation efforts of the GridCloud consortium, involving partners from Austria, Germany, and Türkiye. This document highlights how advanced digital technologies, including digital twins, IoT, and real-time monitoring, are being strategically employed to advance grid resilience, optimize energy efficiency, and facilitate renewable energy integration across Europe's diverse energy systems.

The report details eight foundational use cases, each designed to address unique country-specific requirements while demonstrating the scalability and adaptability of the technologies implemented. Noteworthy examples include Türkiye's StormSafe, an IoT and digital twin-powered system for predictive maintenance, enhancing grid stability in İzmir by identifying potential faults before they lead to outages. In Austria, the NetGen platform employs synthetic distribution grid models to support the planning and integration of decentralized energy resources, catering to Austria's drive towards local energy communities. In Germany, the Schönbrunn Twin use case sets a new standard for data integration and accessibility through a "single-source-of-truth" model, improving decision-making capabilities across multiple operators.

Aligned with the St. Gallen Business Model Navigator framework, the business models within GridCloud focus on four essential elements: Customer, Value Proposition, Value Chain, and Revenue Model. These models ensure distinct value for stakeholders such as distribution system operators (DSOs) and energy providers by enhancing operational efficiency, grid reliability, and environmental performance. For instance, StormSafe's business model leverages a dual revenue approach by offering grid optimization and predictive maintenance services, allowing DSOs to reduce energy losses and prolong infrastructure lifespan. Similarly, Austria's Act4Energie Controls combines high-frequency data analytics and user-focused interfaces to empower energy communities with real-time insights and improved energy management capabilities.

The report also explores country-specific barriers to adoption, addressing issues such as data integration, regulatory compliance, and data privacy concerns. Through active stakeholder engagement—ranging from workshops and interviews to continuous feedback loops—the consortium has ensured that the project outcomes are aligned with local energy policies and operational needs. This collaboration has fortified stakeholder relationships and increased project feasibility and acceptance.

2 CHARACTERISATION OF DEMONSTRATION SITES AND INFRASTRUCTURE

2.1 Overview of Demonstration Sites

Turkey	
Location and Scope	The demonstration site is located in the service area of GDZ Elektrik Dagitim Anonim Sirketi in Turkey. The scope includes grid optimization, real-time monitoring and digital twin integration.
Current Infrastructure	Existing grid infrastructure with some IoT devices (Nodes & Gateways) for monitoring power transmission lines.
Main Goals	▪ Enhance grid reliability and efficiency through digital twin technology. ▪ Optimize energy usage and detect anomalies in the power grid. ▪ Integrate real-time monitoring and IoT.
Planned Technological Integrations	
New Technologies	In this project, LoRaWAN technology will be used for long-range wireless communication. To improve management and maintenance processes of power distribution lines, sensors installed on poles (Node's) will transmit real-time data via Gateway. The nodes will measure various parameters, such as temperature, humidity, tilt, and weather conditions, while gateway will transmit this data to central servers to monitor operational performance. This approach will enable predictive maintenance algorithms to be activated, allowing interventions before failures occur, thereby reducing maintenance costs and enhancing grid security.
Real-time Monitoring & Data Analytics	With algorithms developed using real-time data (for digital twin processes), distribution companies will be able to perform predictive maintenance in the relevant areas. Real-time performance monitoring and forward-looking forecasts will provide added value to distribution companies by offering time savings, ease in planning, and operational efficiency.
Mapping Process	
Infrastructure Mapping	The infrastructure has been mapped through data collection from the grid and power transmission lines. This includes on-site surveys and integration with existing GIS systems.
Tools & Methodologies Used	▪ GIS (Geographic Information System) for mapping grid locations. ▪ Data collection tools for real-time monitoring of grid assets (e.g., IoT devices).
Current State of Infrastructure	
Details on Grid Infrastructure	The grid infrastructure includes power transmission lines with IoT devices for monitoring pole tilt and vibrations, as well as data communication gateways.
Weaknesses or Gaps	▪ Limited integration of predictive analytics. ▪ Need for further automation of data collection and analysis.

	▪ Gaps in anomaly detection and optimization mechanisms.
Technological Readiness	
Technologies Already Deployed	▪ IoT devices for real-time monitoring. ▪ Basic grid control systems.
Planned Implementations	▪ Full integration of Digital Twin technology. ▪ AI-driven predictive maintenance systems. ▪ Anomaly detection tools connected to the grid.
Alignment with Project Goals	The current infrastructure is partially aligned with the project's goals. Planned upgrades, especially in digital twin integration and IoT expansion, will enhance grid management and align with the energy optimization objectives of the project.

Austria	
Location and Scope	The demonstration site is located in Burgenland and focuses on grid control, optimization, and the integration of local energy communities.
Current Infrastructure	Existing grid infrastructure with energy management systems for local energy communities (LECs). Limited integration of digital twins and IoT.
Main Goals	▪ Improve grid control and enhance energy efficiency. ▪ Increase customer engagement through workshops and surveys. ▪ Integrate distributed energy resources (DERs) and enhance grid management using digital twins.
Planned Technological Integrations	
New Technologies	▪ Digital Twin: Augmented control of the grid through real-time data. ▪ AI & IoT: For enhanced decision-making in grid operation and DER optimization. ▪ Act4.Energy Platform: To link grid management tools with local energy communities.
Real-time Monitoring & Data Analytics	Real-time data from grid-connected energy storage systems and DERs to optimize grid operation. The data will also be used to improve consumer participation in energy management.
Mapping Process	
Infrastructure Mapping	The infrastructure has been mapped by integrating local energy community data and grid operational data into a single platform.
Tools & Methodologies Used	▪ Smart grid technologies for data collection. ▪ Local energy community mapping for distributed energy resources. ▪ Geographic and grid data integration.
Current State of Infrastructure	
Details on Grid Infrastructure	The grid includes various DERs (such as solar and battery storage systems) with basic monitoring and control systems. The infrastructure supports flexible grid management.

Weaknesses or Gaps	▪ Limited integration of predictive analytics and automation. ▪ Insufficient engagement tools for consumers in local energy communities. ▪ Limited scalability of the current system.
Technological Readiness	
Technologies Already Deployed	▪ Smart grid components with monitoring systems. ▪ Local energy management tools.
Planned Implementations	▪ Digital twin technology for grid optimization and consumer engagement. ▪ DTs enhancement using smart interfaces with Smart meters. ▪ Full integration with the Act4.Energy platform.

Germany	
Location and Scope	The demonstration site is located in Wunsiedel and focuses on grid data integration, standardization, and validation of digital twin models.
Current Infrastructure	Existing grid infrastructure includes real-time grid monitoring systems, energy storage, and renewable energy integration. There is basic data management for grid optimization.
Main Goals	▪ Integration of standardized grid data for Digital Twin models. ▪ Validation of digital twin data modules for enhanced decision-making. ▪ Improve operational efficiency and grid reliability.
Planned Technological Integrations	
New Technologies	▪ Digital Twin: Implementation of plug-in-based digital twin modules for grid data integration. ▪ Standardization Tools: For ensuring uniformity in grid data formats across various systems. ▪ IoT & AI: For real-time data integration and predictive analysis.
Real-time Monitoring & Data Analytics	Real-time data collection from grid assets (e.g., energy storage systems, renewable energy sources) will be used to validate digital twin models. Data analytics will optimize grid reliability and decision-making.
Mapping Process	
Infrastructure Mapping	The infrastructure was mapped by collecting real-time grid data, renewable energy input, and energy storage data. Standardization of data formats was a key focus.
Tools & Methodologies Used	▪ Data collection tools integrated with grid monitoring systems. ▪ Plug-in modules for grid data standardization. ▪ Testing and validation frameworks for digital twin models.
Current State of Infrastructure	

Details on Grid Infrastructure	The grid includes real-time monitoring systems, energy storage, and renewable energy sources (e.g., solar, wind) with a generation capacity larger than 100 kW. The infrastructure supports basic grid optimization but requires more advanced digital twin integration.
Weaknesses or Gaps	▪ Lack of data standardization across various grid models. ▪ Limited interoperability between grid systems. ▪ Insufficient automation in grid data management.
Technological Readiness	
Technologies Already Deployed	▪ Real-time grid monitoring systems. ▪ Energy storage and renewable energy sources integrated into the grid.
Planned Implementations	▪ Digital Twin plug-in modules for grid data integration and validation. ▪ Standardization tools to ensure uniformity across systems. ▪ AI tools for predictive analytics and operational optimization.
Alignment with Project Goals	The current infrastructure is aligned with the project's goals to some extent. Planned technological advancements, especially in data standardization and digital twin integration, will significantly improve the grid's operational efficiency and align with the project objectives.

3 STAKEHOLDER ANALYSIS AND BARRIERS

3.1 Stakeholder Identification

Türkiye

Key Stakeholders:

- **Distribution System Operator**: GDZ Electricity Distribution Corp.
- **Technology Provider**: EnergyHUB Corp.
- **Academic & Research Institutions**:
  - SCU – Sivas Cumhuriyet University
  - TUBİTAK – The Scientific and Technological Research Council of Türkiye
  - ELDER – Association of Electricity Distribution System Operators

Engagement Activities:

- Online meetings and a workshop held in Izmir at GDZ DSO to coordinate with Turkish partners.
- Continuous online communication among groups to ensure effective collaboration.
- Division of labor and data-sharing arrangements have been established.

Stakeholder Feedback:

- **Integration Needs**: Emphasized the need for clear integration pathways for new technologies.
- **Training**: Stressed the importance of training for teams to familiarize them with new systems and tools.

- **Operational Alignment**: Desire to align technology with current practices to minimize disruptions.
- **Upgrade Concerns**: Raised potential issues related to grid upgrades, including possible outages.
- **Privacy**: Privacy concerns over IoT data collection in residential areas.
- **Transparency**: Requested clear communication on benefits and impacts of the new technologies on energy usage and costs.
- **Regulatory Compliance**: Emphasis on data protection and energy efficiency compliance.
- **Pilot Programs**: Suggested initial pilot programs to ensure new technologies meet regulatory standards.
- **Collaboration**: Encouraged exploration of incentives for smart grid and carbon reduction efforts.
- **Technical Challenges**: Addressed challenges in data integration and real-time monitoring.
- **Phased Deployment**: Recommended gradual deployment to reduce risks during system changes.

Pilot Region:

- The Karaburun-Küçükbahçe feeder was modeled using DigSilent Power Factory. Network topologies were defined and reviewed based on stakeholder feedback.

Germany

Key Stakeholders:

- **Distribution System Operator**: SWW Wunsiedel GmbH
- **Technology Provider**: ef.Ruhr GmbH
- **Academic & Research Institutions**:
  - Technical University Dortmund (TU Dortmund)
  - Hochschule Bonn-Rhein-Sieg (H-BRS)
- **Energy Provider**: SWW Wunsiedel GmbH
- **Energy Sharing Community**: WUNergy

Engagement Activities:

- Design thinking workshops to identify expectations, needs, challenges, and risks.
- Interviews, surveys, and stakeholder-specific meetings for tailored input.
- Stakeholders are interested in integrated renewable energy and new business models and await full involvement.

Austria

Key Stakeholders:

- **Distribution System Operators**:
  - Netz Burgenland
  - Other DSOs in Austria
- **Technology Provider**: Energie Kompass Gmbh
- **Academic & Research Institutions**: Austrian Institute of Technology Gmbh

- **Energy Providers**:
    - Energie Burgenland
    - Other Energy provides in Austria

Engagement Activities:

- In-house collaborations with DSOs and energy providers.
- Workshops to inform stakeholders about AIT's activities and potential applications for GridCloud.
- Participation in national and international consortia to create communication channels among industry and research groups.
- Webinars and newsletters to raise awareness about environmental and financial aspects of the project.

3.2 Barriers to Adoption

Türkiye

- **Technological Barriers:**

The main technological challenges for GDZ in the energy distribution sector are

Data Integration: Integrating data collected from different systems is important to support decision-making processes. This challenge is solved by setting data standards and using integration platforms.

Real-time Monitoring: Real-time data tracking in systems is necessary to monitor the grid status instantaneously. For this purpose, technologies such as advanced SCADA systems and IoT devices are used to quickly observe network status and user demand and make instant interventions.

Cyber Security: With increasing digitalisation, cyber security risks are also increasing. To mitigate these obstacles, security protocols, regular security updates and cyber security trainings for employees are implemented.

Data Storage and Processing Capacity: Large data sets coming continuously from the network require storage and fast processing. Cloud-based solutions and high-performance data processing tools help to overcome this challenge.

These technological challenges are mitigated by innovative solutions and digital tools integrated into business processes.

Vandalism: Damage or theft of the products placed on poles by third parties.

Proposed Solution: Integrating the nodes and gateways as high as possible on the pole to prevent easy access by third parties.

Real-Time Monitoring / Data Transmission Issues: Nodes and gateways becoming offline and unable to transmit data due to lack of power.

Proposed Solution: Solar panels capable of supplying energy for an average of two days will be used on the devices.

- **Regulatory Barriers:**
    - Since energy can be categorized as "critical infrastructure" one of the biggest challenges will be sharing data from GDZ to other stakeholders. Therefore, all the necessary steps are taken into account for data sharing (e.g. NDA, or other agreements).

    - Project objectives and outputs will be shared and evaluated with regulatory bodies such as TEIAS and EMRA.

- **Socio-Economic Barriers:**

The milestones to be implemented during the project process are expected to have a positive impact on consumers. The methods applied in the project will be improved according to the feedback received from consumers.

GDZ takes steps to ensure end-user participation and acceptance, such as raising user awareness, providing training, collecting feedback, running pilots and providing support services. These processes aim to increase user satisfaction while facilitating the adaptation of customers to new projects.

Concern of data sharing due to DSO’s commercial avoidance. The data to be shared will be used with the approval of the DSO within legal limits.

Germany

- **Technological Barriers:**
    - The required data might be provided in data formats that are incompatible with existing standards. In this case, an appropriate conversion method has to be found and applied.
    - Furthermore, required data might not be fully recorded or provided in time for integration into the developed solution. Fully or partly synthetic data can be utilized in place then, which works as a substitute until real data is acquired.
- **Regulatory Barriers:**
    - There is a range of regulatory barriers hindering the adoption of the specified use cases. Firstly, certain roles for owners/operators of private assets have not been introduced yet into regulation. Furthermore, peer2peer trading is not allowed yet and Energy Communities according to EU Commission definition are not implemented in regulation yet.
    - We intend to start discussion with regulatory bodies to achieve proactive regulation on the subjects mentioned above.
- **Socio-Economic Barriers:**
    - SWW follows an “as-open-as-possible" communication policy to stakeholders and public and prepares several integrative approaches for active involvement of every type of stakeholder. Even financial participation is viable from the lowest level.

Austria

- **Technological Barriers:**
    - The main technological challenges identified during the project refer mostly to the data acquisition. Real-time monitoring is very hard to acquire as DSOs owning the data are not able to share it in real-time and are mostly provided after a specific time.
    - The nature of the data that we need to work with have confidential nature (i.e. distribution grids, location of assets etc) and are usually partially provided or not provided at all due to privacy concerns.

  - When grid data is not available, we employ tools and methods to create synthetic realistic grid models which can be used to overcome the lack of sufficient grids.
- **Regulatory Barriers:**
  - In Austria, the integration of digital twins and IoT-based monitoring in energy distribution grids is limited by data privacy regulations. Real-time data access, essential for grid optimization, is often restricted due to GDPR and data privacy laws.
  - The policies governing the operation of distribution grids limit the level of automation and data-driven decision-making for distributed energy resources (DERs). This impacts the deployment of use cases like Austria's Act4Energie, which requires real-time data and seamless integration with energy management systems.
  - Although Austria has a strong focus on local energy communities, existing regulatory frameworks do not fully support the real-time data-sharing and monitoring.
  - Collaborative efforts are underway with the Austrian Institute of Technology (AIT) to provide insights into how digital twin technology can support regulatory goals, such as enhancing grid reliability and integrating renewable energy sources, to advocate for more flexible regulations on data usage within local energy communities.
  - While Austrian policies encourage the integration of decentralized energy resources, there is limited regulatory guidance on the specific role of digital twins and predictive analytics in grid management. Policies lack detailed provisions on how DERs can be autonomously managed within local energy communities, limiting the full potential of platforms like NetGen and Act4Energie.
  - Austria’s current grid operation policies emphasize data protection, often restricting the real-time data-sharing necessary for advanced grid control systems. Standardization across DSOs is needed to ensure that digital twins and IoT sensors can seamlessly interact with various grid management systems, which is a core requirement for Act4Energie's predictive energy management.
  - GridCloud is hosting educational workshops in collaboration with AIT to demonstrate the potential benefits of digital twins and IoT integrations for grid reliability, efficiency, and regulatory compliance.
  - To address privacy concerns, the project implements stringent data security measures, including anonymizing data where possible. This compliance framework will be communicated to regulatory authorities to ensure that all project data practices align with Austria’s data protection regulations, facilitating smoother project operations within legal boundaries.
- **Socio-Economic Barriers:**
  - GridCloud is conducting informational workshops and webinars targeting local energy communities and end-users to demonstrate the tangible benefits of digital twin integration and real-time monitoring, such as improved grid reliability, reduced outages, and optimized energy use.

- Regular surveys and interviews with end-users and local energy community representatives are being implemented to gather insights on user experiences, concerns, and preferences. Feedback loops will enable the consortium to adjust technology deployment based on consumer feedback, making the solutions more user-centered and acceptable.
- To address privacy concerns, GridCloud emphasizes transparency in data handling. Clear communication on data usage policies and strong data protection protocols (such as anonymization and adherence to Austrian data privacy laws) are being prioritized to reassure end-users of their data security.

4 DEFINITION OF USE CASES

4.1 List of use cases

	Use Case name	Country	Short Description
UC1	**StormSafe**	**Turkiye**	A predictive maintenance platform leveraging meteorological data and real-time monitoring along the Karaburun–Küçükbahçe Feeder. StormSafe enhances grid stability by identifying potential faults due to weather impacts, enabling GDZ to execute preemptive maintenance actions.
UC2	**Data Monitoring**	**Turkiye**	Implementation of IoT nodes and gateways for real-time data monitoring and analysis, integrated within a digital twin framework. This system provides continuous oversight of grid health and performance, facilitating predictive analytics for optimized grid operations.
UC3	**Karaburun DT**	**Türkiye**	Digital twin modeling using historical and real-time field data in DigSilent software, employing Python for scenario testing. This model enables comparison with outcomes from StormSafe and Data Monitoring, offering comprehensive insights for predictive maintenance.
UC4	**Schönbrunn Twin**	**Germany**	A digital twin platform that integrates existing data sources based on the Single-Source-of-Truth principle, ensuring unified, reliable data for grid management and enhancing decision-making for grid operators across Germany.
UC5	**Schönbrunn Grid Adaptation**	**Germany**	Automated analysis of grid adaptations, including the integration or replacement of grid assets and feed-ins. This use case incorporates additional data sources, such as real-time measurement data, to support dynamic grid adjustments and improved resource management.

UC6	**NetGen DT**	**Austria**	A tool for generating synthetic distribution grid models using open data to map LV/MV grid configurations, including the geolocation of loads, transformers, and lines. NetGen addresses the limitations of restricted grid data by providing robust, simulated grid models.
UC7	**EnergieAtlas**	**Austria**	A large-scale PV system management platform that uses satellite data for integration, localization, and generation forecasting. The system validates forecasts with real measurements, supporting grid planning and renewable energy distribution.
UC8	**Act4Energie Controls**	**Austria**	A digital twin platform that utilizes high-frequency data from smart meters and customer interfaces to facilitate real-time grid planning and operational adjustments, optimizing energy usage and supporting proactive energy management in local communities.

4.2 Use Case Evaluation and Development

Criteria	Austria	Germany	Turkey
What criteria were used to evaluate the feasibility and scalability of use cases?	The feasibility and scalability of the NetGen, EnergieAtlas, and Act4Energie use cases were evaluated based on their accuracy, adaptability, and integration capabilities within Austria's grid infrastructure. NetGen's feasibility relies on precise grid model generation, validated through power flow analyses, while its scalability is assessed by its performance across large geographic test areas, ensuring adaptability for diverse grid setups. For EnergieAtlas, reliable forecasting of PV integration and its alignment with real-time satellite data are critical for feasibility, with scalability confirmed through the platform's ability to handle extensive geographic data efficiently. Act4Energie's feasibility is tied to its effectiveness in engaging end-users through responsive, interactive features, while its scalability hinges on seamless integration with existing energy management systems and adaptability to meet broader community energy needs	In both use cases the generated models will be evaluated by running power flows and be compared to real grid operation. Scalability will be validated in grid situations of different sizes.	All uses cases with the generated models will undergo evaluation through the execution of power flow analyses, allowing for a comparison with actual grid operations. This assessment will not only gauge the accuracy of the models but also their practical applicability. Additionally, scalability will be tested across a range of grid situations, varying in size and complexity, to ensure that the models can effectively adapt and

			perform under different operational conditions
Stakeholder Involvement			
How did stakeholders contribute to the definition of use cases?	Insights through workshops, surveys, and interviews. Grid operators, energy providers, and local communities identified essential needs like real-time monitoring, data privacy, and regulatory compliance. Their feedback helps shape technical requirements, ensuring each use case addressed key challenges such as scalability for NetGen, accurate forecasting for EnergieAtlas, and user engagement for Act4Energie. This collaborative input aligned the use cases with Austria's energy infrastructure needs and policies.	Feedback from grid operators and energy providers, as well as all other stakeholders	Describe the stakeholder contributions in Turkey's context (e.g., collaboration with local grid operators, community involvement).
What key insights emerged from their participation?	Key insights from stakeholder participation included the need for robust data privacy measures and clear communication on data usage, as privacy concerns were a major barrier to end-user acceptance.	Currently, regulation is not sufficient yet. An inclusive approach needs to be aimed at.	Insights gained from Turkish stakeholders (e.g., grid anomaly detection needs, data management).

Use Case 1: StormSafe	
Purpose and Goal of the Use Case	
Objective	StormSafe is an advanced, versatile tool designed to ensure the reliability and efficiency of power transmission poles in the Izmir region by utilising predictive maintenance and fault detection capabilities. The tool addresses the unique climatic challenges faced by the region by integrating electrical and weather parameters to predict potential failures and optimise maintenance strategies.
Project Alignment	Integrating electricity and weather data, this tool optimises maintenance processes by predicting failures due to climatic conditions. This reduces power outages, reduces the need for emergency intervention and increases the efficiency of grid operations. These predictive capabilities of StormSafe contribute to the project's targeted decarbonisation and energy optimisation, reducing environmental impact and supporting the sustainability of energy supply.
Country-Specific Adaptations	
Turkey	StormSafe has been optimised in several important ways, adapting to the needs of the Turkish grid system: **Consideration of Local Climatic Conditions:** Taking into account the unique climatic challenges of the Izmir region, local weather data and

	electricity demand patterns are integrated. In this way, the impacts of potential weather conditions in the region on the grid are more accurately analysed. **Predictive Maintenance Strategies:** The current maintenance processes of the Turkish power grid often take a reactive approach. StormSafe changes this with fault prediction and predictive maintenance strategies, increasing system reliability while reducing maintenance costs. **Data Integration:** The data management systems and infrastructures of different distribution companies in Turkey utilise a variety of data formats and standards. Taking this diversity into account, StormSafe provides flexible data integration and works in harmony with existing systems. **Increasing Grid Reliability:** The Turkish power grid is occasionally faced with excessive demand and infrastructure deficiencies. StormSafe reduces downtime by increasing the reliability of power transmission poles, thereby securing energy supply. **Decarbonisation Targets:** Decarbonisation targets have an important place in Turkey's energy policy. StormSafe reduces energy losses by increasing grid efficiency, thus supporting a more sustainable energy production and consumption model.
Technological Requirements	
Technologies Needed	Digital Twin Technology Internet of Things (IoT) Big Data Analytics Weather Model
Technological Integration	Digital Twins: It is planned to create virtual models by integrating with the physical properties and performance data of existing energy transmission poles. Internet of Things (IoT): Sensors are integrated into the existing infrastructure and collect data from power transmission poles. These sensors will transfer data to the main systems via wireless communication and provide real-time monitoring. Big Data Analytics: The collected big data is integrated with the existing data processing infrastructure and analysed. These analyses will be used to evaluate grid performance and create decision support systems. Weather Modelling: By integrating with existing weather monitoring systems, it analyses climate data and will be used for performance evaluation of power transmission poles.
Data and System Requirements	Network Data: Power transmission lines, pole locations, connections and existing infrastructure information. Real Time Monitoring Data: Instantaneous tilt, vibration and temperature data from power transmission poles. Weather Data: Current and historical data on meteorological parameters (wind speed, rainfall, temperature, humidity). Consumption Data: Energy demand patterns and user consumption data for analyses based on time periods.

	Failure and Maintenance History: Information about previous fault records, maintenance dates and repairs performed. Sensor Data: Measurement data from IoT sensors placed on energy transmission poles. Geographic Information Data (GIS): Geographical structure of the region, land use and infrastructure information. Efficiency Data: Losses in energy transmission, efficiency rates and performance indicators.
Stakeholder Involvement	
Key Stakeholders	DSOs, energy providers
Stakeholder Contributions	DSOs related to Data Sharing and Integration enable stakeholders to better analyse by providing critical data such as energy flows, demand forecasts and infrastructure status. By assessing the current state of the energy system, DSOs help stakeholders identify their needs. These needs can guide the creation of scenarios to be used to improve the reliability of the system. DSOs provide technical knowledge and experience by collaborating with energy provider stakeholders. DSOs organise pilot projects to test new technologies and usage scenarios, enabling stakeholders to gain practical experience.
Key Insights from Participation	By gaining detailed information about customers' energy consumption habits and expectations, these insights enable energy providers to better tailor their services Stakeholders have developed greater awareness of energy efficiency and environmental sustainability issues. This has encouraged the adoption of innovative solutions and strategies. Participants expressed a desire for the integration of new technologies and digital solutions. This could influence the direction of future projects. Stakeholders emphasised the need to improve existing regulations and develop new policies in the energy sector. This is an important source of feedback for DSOs and other stakeholders. The need for effective communication and co-operation between energy providers and DSOs has emerged. This enables faster and more effective realisation of projects. Participants provided insights on potential risks and safety concerns in energy systems. This contributes to the development of maintenance and preventive strategies. Knowledge was gained about the specific energy-related needs and conditions of local communities. This helps to localise projects and make them more effective.
Key Learnings from Use Case Development	
Lessons Learned	In the process of developing a use case for STORM SAFE, both technical and legal challenges pose significant obstacles. In addition to technical challenges such as data integration, real-time monitoring and weather forecasting, the need to comply with Turkish legislation and regulations must also be taken into account. Going through audits by authorities

	such as the Energy Market Regulatory Authority (EMRA), certification of new technologies, and completing permitting processes can extend the timelines of projects. In addition, data protection regulations such as the Law on the Protection of Personal Data (KVKK) impose restrictions on data collection and processing. Legislation such as sustainability and environmental impact assessment may also affect the viability of projects. All these factors are critical to the success of the project and should be carefully considered.
Addressing Challenges	In order to facilitate data integration, standardisation studies have been carried out and it is aimed to harmonise different data sources. It is envisaged to minimise delay and data loss by using advanced data processing software for real-time monitoring. Collaboration with weather services can be made for weather forecasts, thus increasing the accuracy of meteorological data. In order for stakeholders to adopt new systems, it is aimed to balance the views of different stakeholders through training programmes and regular meetings. In addition, in order for the projects to proceed within the legal framework, legislative changes can be continuously monitored by proceeding with legal units. It is planned to meet with authoritative institutions in Turkey such as ELDER, EMRA, TUBITAK. These strategies are expected to contribute significantly to overcoming the challenges faced by the STORM SAFE project and to the successful implementation of the use cases.
Implications for Scaling and Replication	
Scalability	The STORM SAFE use case has the potential for high scale applicability in other regions or countries. First, key components of the project, such as data integration, real-time monitoring systems and weather forecasting, can be adapted to meet similar needs at a global level. Growing concerns about climate change and energy security, in particular, provide a backdrop that favours the implementation of such projects across the globe. Technologies and processes developed in Turkey can be customised for power grids in regions with different geographical and climatic conditions. For example, energy distribution systems in Europe, Asia or the Americas can be adapted to take into account local weather conditions and energy infrastructures. Finally, taking into account international energy regulations and standards, innovative solutions such as STORM SAFE can be effectively implemented in other countries and contribute to global energy systems. This scalability offers an important opportunity to achieve energy efficiency, reliability and sustainability goals.
Key Considerations for Replication	One of the most important factors to be considered when replicating the STORM SAFE use case is the consideration of local needs and conditions. As the climate, geography and energy infrastructure of each region differ, it is essential to adapt systems to local characteristics. Furthermore, stakeholder engagement and co-operation should be ensured and effective communication should be established with local governments, energy providers and communities. Compliance with the necessary legal regulations on data security and confidentiality should be ensured, and

	data protection laws should be taken into consideration in this context. Training programmes and awareness-raising activities should be organised to increase the applicability of the technology, and stakeholders should be encouraged to adopt new systems.
Future Steps	
Next Steps	▪ To assess the climate and energy needs in the target regions and analyse the topology. ▪ Organising meetings for cooperation with local governments and energy providers. ▪ Organise training and information seminars for stakeholders on the use of the systems and legislative work. ▪ To examine the maintenance and failure history of Karaburun Küçükbahçe Fideri pilot area. ▪ To ensure continuous improvement by analysing the data obtained from the pilot application.
Expected Outcomes	The expected results when the STORM SAFE usage scenario is implemented in Karaburun Küçükbahçe are as follows: Thanks to the early detection of potential faults on electricity transmission poles, outage times will be reduced and grid reliability will increase. With sensor data and weather forecasts, maintenance operations will be planned more effectively and unnecessary interventions will be minimised. Proactive maintenance approach will provide financial advantage to the energy distribution company by reducing the costs arising from emergency fault repairs. With real-time monitoring, field teams will be able to respond to potential problems immediately, which will minimise power outages. Reduced power outages will increase the satisfaction of users by increasing the security of energy supply. The collected data will be used to evaluate grid performance and contribute to the development of future strategies. For GDZ DSO, this use case will improve operational efficiency, facilitate compliance with regulatory requirements and contribute to developing sustainable energy solutions. It will also pave the way for social responsibility projects by strengthening relations with local authorities and communities.

Use Case 2: Data Monitoring	
Purpose and Goal of the Use Case	
Objective	The purpose of this use case is to enable real-time monitoring and predictive maintenance of power transmission lines through a Digital Twin platform and IoT integration. By deploying sensors on utility poles to collect data on environmental and structural conditions, the system aims to detect anomalies, forecast potential failures, and optimize

	maintenance schedules. This setup minimizes downtime, reduces operational costs, and enhances the grid's resilience against external impacts. This use case aligns with the project's goals of increasing grid reliability, efficiency, and operational intelligence. By leveraging advanced analytics, the project aims to support a proactive grid management strategy, ultimately contributing to a more sustainable electricity infrastructure.
Project Alignment	**Enhanced Grid Reliability:** By integrating real-time monitoring and predictive analytics, the system can detect faults early and address them before they escalate. This proactive fault detection reduces unexpected outages, aligning with the goal of increasing the grid's resilience. **Operational Efficiency:** The Digital Twin and IoT sensors enable streamlined operations by continuously monitoring conditions and providing data-driven insights. This setup reduces the need for manual inspections and emergency repairs, helping optimizing grid management and minimizing operational costs. **Data-Driven Decision-Making:** The use of machine learning for anomaly detection and forecasting equips grid operators with actionable insights, allowing them to make informed decisions on infrastructure investments and grid improvements. This aligns with strategic, data-based planning. **Sustainability and Long-Term Planning:** By extending asset life through predictive maintenance and reducing the frequency of repairs, this use case contributes to sustainable grid management practices, which are part of the project's focus on a reliable, long-term energy infrastructure.
Country-Specific Adaptations	
Turkey	In Turkey, studies conducted with stakeholders aim to detect potential problems in electricity poles in advance, such as tipping, bending, and malfunctions, which can lead to material damages. These issues may result in the inability to supply electricity to the region, environmental damages, fire risks, financial losses, and injuries. In this context, sensors placed on the electricity distribution poles will measure tilt angles and vibration data in real-time. This will enable the early detection of potential problems in the poles, allowing field teams to intervene quickly before or immediately after a malfunction occurs. These measures will shorten outage durations, accelerate maintenance operations, and provide faster solutions to customers affected by pole accidents.
Technological Requirements	
Technologies Needed	**Digital Twin Platform:** For creating virtual models of physical assets, enabling real-time monitoring, predictive maintenance, and simulation studies. **LoRaWAN (Long Range Wide Area Network):** Provides long-range, low-power wireless communication between nodes (sensors) and a central server, ideal for remote monitoring.

	Tilt and Vibration Sensors: Detect pole movement and vibrations, aiding in structural monitoring. **Temperature and Humidity Sensors:** Collect environmental data at each pole location. **GPS Modules:** For geolocation data, providing exact coordinates of each node. **Nodes:** Nodes with local processing capabilities for initial data collection and preprocessing before transmission to central servers. **Solar Power Kits:** Power source for nodes in remote locations, ensuring continuous operation without reliance on external power supplies. **Battery Modules:** Provide backup power for each node, particularly useful in low-sunlight conditions. **Gateway Devices:** Central hubs that gather data from nearby nodes and transmit it to the server or Digital Twin platform. **Data Storage and Cloud Infrastructure:** Supports real-time and historical data storage, enabling analysis and long-term trend monitoring.
Technological Integration	**LoRaWAN Network:** The LoRaWAN nodes will be added to transmission poles, facilitating data communication across long distances with low power. This network doesn't interfere with existing control signals or communications but will work in parallel, sending environmental and structural data to a central gateway, which then forwards the information to the Digital Twin or cloud systems for analysis. **IoT Sensors:** Sensors will be installed on utility poles and other critical points in the grid. They will communicate status updates, environmental conditions, and pole stability to the central server via LoRaWAN. These sensors expand the grid's visibility into environmental impacts and infrastructure conditions without altering current electrical flows or system configurations. **Nodes:** These nodes will preprocess data at the sensor level to reduce bandwidth needs, sending essential data only. The nodes allow integration without placing additional computational load on existing infrastructure, acting as independent units that relay necessary insights for maintenance and monitoring. **Solar Power and Battery Kits:** The self-sustaining power systems of the nodes (solar panels and batteries) ensure they can be added to existing poles and remote locations without needing an external power supply. This setup allows continuous monitoring and data transmission without dependency on the grid's power resources. **Gateways:** Acting as intermediaries, gateways will receive data from nodes within their range and transmit it to the cloud or Digital Twin platform. Positioned to complement current substations and monitoring points, they will serve as a bridge between local sensors and central data systems, working independently from but in alignment with existing data acquisition processes.

Data and System Requirements	**Environmental and Weather Data**: Information such as temperature, humidity, wind speed, and precipitation levels at the pole locations. **Structural and Operational Data**: Real-time data from pole tilt and vibration sensors to detect any physical displacement or tilt. **Location Data**: Precise latitude and longitude coordinates for each pole, allowing accurate tracking and mapping of grid assets. **Grid Monitoring Data**: Data on grid faults, and environmental conditions, which are accessible via real-time monitoring. **Anomaly Detection Data**: Predictive analytics based on historical data trends, enabling early warning for potential mechanical failures or environmental impacts. **Communication Data**: Data transmitted through LoRaWAN (Long Range Wide Area Network) nodes, covering device status, configuration, and environmental readings.
Stakeholder Involvement	
Key Stakeholders	DSOs, energy sharing community
Stakeholder Contributions	Design thinking workshops, surveys, interviews
Key Insights from Participation	Regulation not sufficient yet, approach needs to include everybody
Key Learnings from Use Case Development	
Lessons Learned	Scattered grid and assets data make the development and design of the DT implementation on the DSO level a challenge.
Addressing Challenges	A standard for parsing different files format is under development.
Implications for Scaling and Replication	
Scalability	Fully
Key Considerations for Replication	Capex, Opex,
Future Steps	
Next Steps	Production (ongoing), Installation, Testing, Data Transfer, Validation
Expected Outcomes	Improved grid reliability and reduced operational costs.

Use Case 3: Karaburun DT	
Purpose and Goal of the Use Case	
Objective	Briefly describe the purpose of the use case and how it aligns with the project’s goals. Example: Optimize grid control using digital twins.
Project Alignment	How does this use case support the project's overall goals (e.g., decarbonization, energy optimization)? Example: Improved grid reliability.
Country-Specific Adaptations	

Turkey	Distribution grid operators in Turkey are faced with increasing demands and regulatory requirements. The fact that different operators use different data management concepts and software depending on their historical processes reveals the need for standardization for grid efficiency. Accordingly, the GridCloud project aims to increase reliability, sustainability and efficiency in the energy distribution grid. Considering the effects of environmental effects, especially meteorological changes, on poles in Izmir Karaburun DT with which are GDZ application regions, the project analyzes the data from sensors with simulation models on the digital twin platform and predicts possible anomalies in advance. In this way, field teams can intervene before a fault occurs or quickly reach a solution when a problem occurs.
Technological Requirements	
Technologies Needed	The development of functionalities necessitates a thorough consideration of the heterogeneous structure of input data and the legacy data management systems in place. Existing data must undergo plausibility checks, validation, and, where necessary, transformation into a machine-readable format to enable seamless integration. For instance, cable length data may be referenced in the description of electrical parameters and corroborated with geospatial information, while machine learning techniques can be employed to systematically link data and identify anomalies. Following data processing and validation, an appropriate storage format should be established to act as the digital twin's "single source of truth." This storage format must also accommodate potential requirements from users, such as Distribution System Operators (DSOs), to continue utilizing existing software, ensuring accurate data references through pointers in the data management system to maintain compatibility with legacy programs. Ultimately, the development of new functionalities must align with the chosen data storage structure to ensure compatibility with the digital twin framework.
Technological Integration	To integrate the digital twin effectively, an initial, validated starting point must first be established. This should be followed by defining processes for ongoing data maintenance, ensuring that any modifications to data occur exclusively at the single source of truth. When data is added or updated, it is essential to assess and monitor its impact on other data within the digital twin, enabling the identification of potential errors or improvements introduced by the new information. In this context, it is crucial to accurately register physical changes in the grid—such as expansions or new connections—at the correct location within the digital twin.
Data and System Requirements	The necessary data varies according to the pilot field and primarily includes grid-related information, such as topology data (e.g., GIS data) and electrical parameters, along with real-time monitoring, metering, PQM data, and load data from GDZ.
Stakeholder Involvement	

Key Stakeholders	DSOs, energy providers, Energy Sharing Community, prosumers and customers
Stakeholder Contributions	Thinking workshops, surveys, interviews
Key Insights from Participation	Regulation not sufficient yet, approach needs to include everybody
Key Learnings from Use Case Development	
Lessons Learned	Scattered grid and assets data make the development and design of the DT implementation on the DSO level a challenge.
Addressing Challenges	A standard for parsing different files format is under development.
Implications for Scaling and Replication	
Scalability	Fully
Key Considerations for Replication	What should be considered when replicating this use case? Local setup of stakeholders, grid, RES
Future Steps	
Next Steps	Testing, validation
Expected Outcomes	Improved grid reliability and reduced operational costs.

Use Case 4: Schönbrunn Twin	
Purpose and Goal of the Use Case	
Objective	The primary aim of this use case is to optimize grid control through the implementation of a digital twin. By leveraging existing data sources, we can create an accurate representation of the grid and connected units. This approach adheres to the single-source-of-truth principle, ensuring that all stakeholders have access to consistent and reliable data. Functions, that rely on the data of the digital twin, get the requested data for the specific scenario, that should be analyzed.
Project Alignment	By optimizing grid planning and integrating data from operation through a digital twin, we can facilitate a more efficient and streamlined integration of renewable energy sources. With a single-source-of-truth approach, all data is consistent and accurate, which enhances decision-making in planning and operation.
Country-Specific Adaptations	

Germany	There are around 900 different distribution grid operators in Germany, many of which use different historically evolved data management concepts and calculation software. The distribution system operators have to fulfill a variety of requirements (regulatory, technical), so that different methods and solutions have been developed to meet the challenges. This results in a variety of different input data, functions and output data formats when comparing different grid operators. Standardization is therefore desirable in order to develop functions efficiently. The demands on distribution grid operators are constantly increasing, and Redispatch 2.0 also requires systems with low installed capacity to be controlled in a grid-beneficial manner. This also requires knowledge of the grid state. This is also necessary for the implementation of § 14a EnWG in order to intervene efficiently in the behavior of connected units to prevent congestion in the low voltage level, for example. Due to the slow rollout of smart meters, the measurements available for estimating the grid status are often limited.
Turkey	This use case is designed to address the specific needs of the Turkish grid system by tackling its distinct operational challenges, including variable energy demand, increasing integration of renewable energy sources, and the necessity for improved grid stability.
Technological Requirements	
Technologies Needed	As a basis for the development of functionalities, the heterogeneous structure of the input data and historically evolved data management concepts must be taken into account. Existing data must be checked for plausibility and validated. For this purpose, data may have to be converted into machine-readable form so that it can then be linked together. For example, the cable length can be used in the description of electrical parameters and compared with geoinformation data. Machine learning approaches are one methodical way of linking data and identifying outliers. Once the existing data has been processed and validated, a suitable data storage format must be developed that meets the requirements of the digital twin (single source of truth). It must also be considered that the users (DSOs) may wish to continue using existing software and thus refer to the correct data with pointers in the data management. This ensures that the necessary programs can continue to be used by departments and that there is still a single source of truth. When developing functions, it must be taken into account that these must be compatible with the selected data storage concept of the digital twin.
Technological Integration	When integrating the digital twin, a validated starting point must first be implemented. This is followed by requirements for the process definition for continuous data maintenance: the respective data may and must only be changed at the single source of truth. If data is added or changed, the

	impact on the other data of the digital twin must be evaluated and monitored. This makes it possible to identify whether incorrect data has been added or the data in the digital twin can be improved by the information added to the new data. In this use case, it is therefore important, for example, to identify the physical changes in the grid (grid expansion, new connected units, ...) at the right point in the digital twin
Data and System Requirements	The required data depends on the respective application, examples of required data are as follows: Grid data (topology (e.g. GIS data) and electrical parameters), real-time monitoring, metering and PQM-data together with load data from Control Center.
Stakeholder Involvement	
Key Stakeholders	DSOs, energy providers, Energy Sharing Community, prosumers, prostormers and customers
Stakeholder Contributions	Design thinking workshops, surveys, interviews
Key Insights from Participation	Regulation not sufficient yet, approach needs to include everybody
Key Learnings from Use Case Development	
Lessons Learned	Scattered grid and assets data make the development and design of the DT implementation on the DSO level a challenge.
Addressing Challenges	A standard for parsing different files format is under development.
Implications for Scaling and Replication	
Scalability	This use case is applicable throughout all distribution grid operators in Germany.
Key Considerations for Replication	The local setup of stakeholders, particular properties of the grid at hand and the amount of RES to integrate need to be considered.
Future Steps	
Next Steps	Testing, validation
Expected Outcomes	Improved grid reliability and reduced operational costs.

Use Case 5: Schönbrunn Grid Adaptation

Purpose and Goal of the Use Case	
Objective	Briefly describe the purpose of the use case and how it aligns with the project's goals. Optimize grid control using digital twins. Automated analysis of adaptations of the grid, e.g. in the form of addition or replacements of grid assets or feed-ins. Additional data sources, such as measurement data, have to be included.
Project Alignment	By optimizing grid planning and integrating data from operation through a digital twin, we can facilitate a more efficient and streamlined integration of renewable energy sources. With a single-source-of-truth approach, all data is consistent and accurate, which enhances decision-making in planning and operation.
Country-Specific Adaptations	
Germany	There are around 900 different distribution grid operators in Germany, many of which use different historically evolved data management concepts and calculation software. The distribution system operators have to fulfill a variety of requirements (regulatory, technical), so that different methods and solutions have been developed to meet the challenges. This results in a variety of different input data, functions and output data formats when comparing different grid operators. Standardization is therefore desirable in order to develop functions efficiently. The demands on distribution grid operators are constantly increasing, and Redispatch 2.0 also requires systems with low installed capacity to be controlled in a grid-beneficial manner. This also requires knowledge of the grid state. This is also necessary for the implementation of § 14a EnWG in order to intervene efficiently in the behavior of connected units to prevent congestion in the low voltage level, for example. Due to the slow rollout of smart meters, the measurements available for estimating the grid status are often limited.
Technological Requirements	
Technologies Needed	As a basis for the development of functionalities, the heterogeneous structure of the input data and historically evolved data management concepts must be taken into account. Existing data must be checked for plausibility and validated. For this purpose, data may have to be converted into machine-readable form so that it can then be linked together. For example, measurement data can be validated by comparison to expected values. Machine learning approaches are one methodical way of linking data and identifying outliers. Once the existing data has been processed and validated, a suitable data storage format must be developed that meets the requirements of the digital twin (single source of truth). When developing functions, it must be taken into account that these must be compatible with the selected data storage concept of the digital twin.

Technological Integration	When integrating the digital twin, a validated starting point must first be implemented. This is followed by requirements for the process definition for continuous data maintenance: the respective data may and must only be changed at the single source of truth. If data is added or changed, the impact on the other data of the digital twin must be evaluated and monitored. This makes it possible to identify whether incorrect data has been added or the data in the digital twin can be improved by the information added to the new data. In this use case, it is therefore important, for example, to identify the physical changes in the grid (grid expansion, new connected units, …) at the right point in the digital twin.
Data and System Requirements	Grid data, real-time monitoring, GIS data, metering and PQM-data is needed. For this use case, future grid expansion plans are required in digital form as well.
Stakeholder Involvement	
Key Stakeholders	DSOs, energy providers, Energy Sharing Community, prosumers, and customers
Stakeholder Contributions	Design thinking workshops, surveys, interviews
Key Insights from Participation	What key insights emerged from stakeholder participation? Lack of understanding inter-dependencies in grid ops on stakeholder side
Key Learnings from Use Case Development	
Lessons Learned	All existing data sources and systems that need to be included have to be compiled and a data format conversion has to be found.
Addressing Challenges	How were these challenges addressed? Workshop with grid ops staff and stakeholders
Implications for Scaling and Replication	
Scalability	This use case is applicable throughout all distribution grid operators in Germany.
Key Considerations for Replication	CAPEX, OPEX, fears of future users about their job
Future Steps	
Next Steps	Testing, validation
Expected Outcomes	Improved grid reliability, faster reaction times and reduced operational costs.

Use Case 6: NetGen DT
Purpose and Goal of the Use Case

Objective	NetGen is an automated tool for generating synthetic distribution grid models, particularly useful for scenarios where actual grid data is unavailable or restricted due to privacy concerns. By utilizing open data sources like OpenStreetMap and Austrian demographic databases, NetGen provides low-voltage (LV) and medium-voltage (MV) grid models that support grid planning, renewable integration, and risk assessment, aligning with GridCloud's vision to enhance decision-making in distribution grids.
Project Alignment	This use case supports the project's goals of grid optimization by enabling the simulation of renewable energy integration, grid expansion, and other planning scenarios. NetGen's synthetic grid models facilitate the testing of digital tools and renewable solutions, contributing to more resilient, efficient, and sustainable grid systems.
Country-Specific Adaptations	
Austria	NetGen is tailored to Austria's grid infrastructure needs by utilizing locally relevant open data sources like OpenStreetMap for street layouts and Statistik Austria for demographic information. These sources provide accurate representations of grid components, including transformers and building footprints, crucial for generating realistic grid models for Austrian DSOs and energy communities.
Technological Requirements	
Technologies Needed	Open-source data platforms (e.g., OpenStreetMap, Statistik Austria), AI for load estimation, bio-inspired algorithms (e.g., ant colony optimization) for grid topology generation, and Python-based power flow analysis tools like PandaPower for validation.
Technological Integration	The generated grid models are fully compatible with existing grid planning tools and can be directly integrated with DSOs' simulation environments. The synthetic models incorporate realistic load profiles and transformer characteristics, allowing DSOs to test various grid scenarios without requiring sensitive data.
Data and System Requirements	Essential data includes open-source geographic and demographic information, such as street layouts, transformer locations, and building footprints. Additionally, historical load profiles and transformer capacity data are used to create realistic energy consumption patterns across the synthetic grid.
Stakeholder Involvement	
Key Stakeholders	DSOs, renewable energy providers, technology partners (e.g., AIT), local government agencies, and research institutions.
Stakeholder Contributions	Stakeholders provided insights into operational constraints, the importance of realistic load estimation, and validation requirements. Their input ensured that NetGen's synthetic models align closely with the real-world needs of DSOs, allowing accurate simulation of grid expansion and renewable integration.

Key Insights from Participation	Stakeholders emphasized the necessity of accurate load estimation and the inclusion of typical grid topologies to ensure realistic model outputs. They also highlighted the value of having models that could adapt to varied grid infrastructures, making NetGen a versatile tool for multiple grid scenarios.
Key Learnings from Use Case Development	
Lessons Learned	Challenges included managing incomplete data from open-source platforms and ensuring accurate load estimation for different building types. Additionally, ensuring the scalability of synthetic models across different grid sizes required refined validation techniques.
Addressing Challenges	Data gaps were addressed by employing assumptions for missing building information (e.g., average building heights), and virtual transformers were placed to complete grid topologies where data was sparse. Validation techniques, such as electrical and topological testing, ensured the models closely represented real-world grids.
Implications for Scaling and Replication	
Scalability	NetGen is highly scalable across different regions and countries due to its reliance on open-source data and adaptable algorithms. The tool can generate realistic synthetic grid models for any location with accessible geographic and demographic data.
Key Considerations for Replication	To replicate NetGen effectively, regions must have reliable open data sources and standardized load profiles. It's also essential to calibrate the algorithms to align with local building and infrastructure characteristics for accurate grid model outputs.
Future Steps	
Next Steps	Immediate next steps include further validation with real-world grid data, if available, and pilot testing with Austrian DSOs to refine the tool's load estimation and grid topology generation. Additional testing in diverse regions will help assess scalability and model accuracy.
Expected Outcomes	Once implemented, NetGen is expected to provide DSOs with a reliable tool for grid planning, enhancing their ability to simulate renewable integration and assess grid expansion scenarios. This will support more efficient and sustainable grid operations, aiding in Austria's energy transition goals.

Use Case 7: EnergieAtlas	
Purpose and Goal of the Use Case	
Objective	EnergieAtlas serves as a comprehensive tool for analyzing and managing photovoltaic (PV) system data across Austria. By leveraging GIS-based data integration, it facilitates data-driven insights for grid planning, PV system distribution, and real-time resource management.

Project Alignment	Optimizing renewable energy resource allocation. It enables stakeholders to monitor PV generation, analyze system distribution, and integrate satellite-based weather data for improved forecasting, thus contributing to grid reliability and renewable integration.
Country-Specific Adaptations	
Austria	It aggregates PV system data and aligns it with local grid infrastructure, including substations and transformers, providing insights into renewable generation capacity per district. This use case is essential for Austria's energy communities and DSOs, as it helps allocate resources and manage PV power distribution.
Technological Requirements	
Technologies Needed	GIS platforms (e.g., GeoServer, GeoNetwork), PostGIS database for data management, metadata cataloging (ISO 19115 standard), and satellite data integration for weather and cloud cover analysis.
Technological Integration	EnergieAtlas directly integrates GIS data with metadata catalogs to store and manage PV system details. The platform allows third-party access via APIs for tools like QGIS, ensuring compatibility with existing GIS and energy management systems, which makes it a scalable solution for other geographic and operational areas.
Data and System Requirements	Key data includes PV system size, distribution, output per district, satellite weather data, and cloud cover forecasts. This information is used for real-time monitoring, historical analysis, and production forecasting, allowing effective grid management and PV power allocation.
Stakeholder Involvement	
Key Stakeholders	DSOs, TSOs, local governments, PV system operators, energy providers, and GIS technology providers.
Stakeholder Contributions	Stakeholders contributed insights on data privacy, the need for high-resolution PV data, and real-time system integration. Their feedback helped design a robust data management structure that meets operational needs while ensuring secure access and usability.
Key Insights from Participation	Stakeholders highlighted the importance of accurate, district-level data for effective PV system management. They also emphasized the need for real-time access to data, especially for DSOs and TSOs, to optimize grid allocation and stability.
Key Learnings from Use Case Development	
Lessons Learned	Challenges included scaling data from diverse sources and ensuring compatibility with grid infrastructure at multiple levels (substation, transformer, and community). There were also technical challenges in integrating high-resolution satellite data for accurate PV forecasting.
Addressing Challenges	Data scaling and compatibility were addressed through careful alignment of PV system data with local infrastructure in GIS. Satellite-

	based forecasting was validated against real-time PV production data, ensuring reliability.
Implications for Scaling and Replication	
Scalability	EnergieAtlas is highly scalable within Austria and can be extended to other countries with similar renewable energy goals. By integrating local grid infrastructure and PV data, it can support effective renewable integration across various geographic scales.
Key Considerations for Replication	Replication requires access to reliable local PV data and grid infrastructure information. Adapting the GIS framework and metadata storage to align with each country’s regulatory and operational standards is crucial for successful implementation.
Future Steps	
Next Steps	Include further validation of satellite and PV data alignment, as well as enhancing the scale of the forecasting model. Expansion efforts are focused on incorporating real-time PV production data and refining grid allocation methods to improve predictive capabilities.
Expected Outcomes	EnergieAtlas aims to deliver an accurate, real-time PV monitoring and management tool for Austria. This will enable DSOs and energy communities to optimize grid stability, increase renewable energy efficiency, and support Austria’s energy transition through precise PV distribution and forecasting.

Use Case 8: Act4Energie Controls	
Purpose and Goal of the Use Case	
Objective	Act4Energie aims to optimize grid control and enhance energy management for local energy communities (RECs) in Austria. By using digital twin technology and real-time data integration, Act4Energie enables energy communities to manage resources more effectively, supporting predictive maintenance, grid optimization, and proactive engagement of end-users.
Project Alignment	This use case supports the overall goals of decarbonization and energy optimization by integrating renewable energy resources into community grids. The platform facilitates real-time decision-making and predictive analytics.
Country-Specific Adaptations	
Austria	Act4Energie is specifically tailored for Austria’s energy community framework, aligning with the Austrian government's support for local energy communities. It utilizes the team4.energy platform, which connects around 20 RECs, helping communities manage and monitor energy production and consumption in line with national policies and regulations on energy data privacy.
Technological Requirements	

Technologies Needed	Digital Twins, IoT (smart meters and sensors), cloud infrastructure for data storage and processing.
Technological Integration	The technologies will be directly integrated with existing grid infrastructure, utilizing smart meters and IoT sensors to collect real-time data, which will be processed through the digital twin model. The data backend, ensures secure data handling without reliance on third-party cloud services.
Data and System Requirements	Key data includes real-time grid data, REC consumption and production data, smart meter data (e.g., 15-minute intervals), and historical usage patterns. This data enables precise monitoring, anomaly detection, and optimization of grid operations.
Stakeholder Involvement	
Key Stakeholders	DSOs, energy providers, REC members, technology partners (e.g., Energie Kompass), and local government agencies.
Stakeholder Contributions	Stakeholders provided essential input on privacy concerns, integration requirements, and end-user engagement strategies. They helped shape the design by identifying the need for real-time monitoring, data privacy assurances, and streamlined integration with existing grid systems.
Key Insights from Participation	Stakeholders emphasized data privacy, highlighting the importance of transparent data handling. They also noted that clear value propositions for end-users would encourage engagement, and efficient integration with current DSO systems is essential for scalability.
Key Learnings from Use Case Development	
Lessons Learned	Challenges included balancing data privacy with the need for real-time data access, as well as ensuring compatibility with diverse grid infrastructures. Managing stakeholder expectations for seamless and secure data flow was also a key challenge.
Addressing Challenges	Data privacy concerns were addressed by implementing virtual data spaces that allow data access without permanent storage. Compatibility issues were mitigated through flexible data management tools and standardized formats to align with existing systems.
Implications for Scaling and Replication	
Scalability	Act4Energie is highly scalable across regions with similar regulatory environments and grid structures. Its modular design allows for adjustments based on local data policies and grid requirements.
Key Considerations for Replication	Considerations include local regulatory compliance, especially regarding data privacy and DSO interoperability. Ensuring community engagement and a clear understanding of grid-specific needs are critical for successful replication.
Future Steps	

Next Steps	Immediate steps include deploying a pilot in Burgenland with approximately 25 smart meters to test real-time data capabilities and refine community engagement practices. Further integration of advanced predictive tools will enhance data insights for proactive grid management.
Expected Outcomes	Act4Energie aims to improve grid reliability, optimize energy usage, and increase user satisfaction. It will empower communities with actionable insights, reduce downtime through predictive maintenance, and contribute to Austria's renewable energy goals by supporting efficient resource management within RECs.

5 DEFINITION OF BUSINESS MODELS

The St. Gallen Business Model Navigator is a strategic framework developed by researchers at the University of St. Gallen. It aims to support companies in innovating or refining their business models by identifying and utilizing recurring business model patterns. The Navigator categorizes 55 proven business model patterns—such as Subscription, Add-On, Digitalization, and Guaranteed Availability—and encourages companies to adapt these patterns to create new business models or enhance existing ones. The core idea is that most successful business models are recombinations or adaptations of these established patterns.

In the GridCloud project, the St. Gallen Business Model Navigator is applied to develop sustainable business models tailored to digital grid management and renewable energy integration. For example, GridCloud uses the Subscription model for real-time data services, the Add-On model for customizable sensor upgrades, and the Digitalization model to offer digital twins of grid infrastructure. By leveraging these business model patterns, GridCloud creates a flexible, scalable approach to providing energy distribution services, predictive maintenance, and grid optimization—aligning with goals of sustainability, grid efficiency, and reliability. For each use case, revenue models are provided.

	Use Case	Customer	Value Proposition	Value Chain	Revenue Model
UC1	**Data Monitoring**	DSOs, TSOs - Main target customers - Segments: DSO, TSO field operators	- Real-time data monitoring for predictive maintenance - Reduces outages, improves grid reliability - Supports renewable energy flow through efficient grid management	Delivered through IoT-enabled real-time monitoring of grid assets - Key activities: sensor data integration, predictive analytics - Resources: IoT devices, cloud storage - Partners:	**Add-On:** Basic devices with optional sensor upgrades, including lightning sensors, current monitoring, etc. **Subscription**: Monthly/annual fees for real-time data access and alerts

				IoT providers, analytics firms	
UC2	**StormSafe**	DSOs, Energy Providers, Field Staff - Segments: technology providers, institutions in digitalization	- Provides environmental and operational benefits - Reduces outage times, improves power quality - Proactive maintenance and fault detection align with renewable energy integration - Increases flexibility and resilience of energy infrastructure for sustainability goals	- Digital Twin and IoT integration for real-time anomaly detection and monitoring - Key resources: sensors, data analysis tools, cloud platforms - Partners: energy distribution companies, tech providers, research institutions	**Grid Optimization:** Real-time data monitoring for efficient energy distribution **Digitalization:** Digital twins with AI-driven fault detection, mobile accessibility for field teams
UC3	**Karaburun DT**	DSOs, Investors, Startups - Segments: energy providers, digitalization-focused institutions	- Reduces outages, improves power quality - Provides digital demonstration of grid for renewables, helps planning - Aligns with energy transition through efficient grid operation and support for renewable integration.	- Digital twin, real-time monitoring, and network optimization - Key resources: data from GDZ DSO, monitoring use case - Partners: SCU for data modeling and processing	**Digitization:** Predictive maintenance and energy savings from reduced downtime **Guaranteed Availability:** Provides near-zero downtime to ensure continuous energy flow
UC4	**Schönbrunn Twin**	DSOs, Grid Ops, Maintenance Teams - Segments: institutions focused on digital grid ops	- Improves grid reliability, reduces CAPEX for software - Facilitates RES integration, enhances data accuracy - Provides environmental benefits through grid efficiency and reliability	- Single-source-of-truth method for reliable data integration - Key resources: data management platforms, technical staff	**Digitization:** Faster distribution and improved grid ops efficiency **Make More of It:** Offer knowledge to other companies for additional revenue

UC5	**Schönbrunn Grid Adaptation**	DSOs, Field Ops - Segments: tech providers, institutions in digitalization	- Improves grid reliability, reduces outages, enhances sustainability - Facilitates RES integration, minimizes data errors	- Real-time monitoring and anomaly detection through digital twin - Key resources: single-source-of-truth data management	**Cross Selling:** Additional services and data for partner companies **Leverage Customer Data:** Revenue from data sales or analytics insights for third parties
UC6	**NetGen DT**	DSOs, Renewable Energy Providers - Segments: local government agencies, research institutions	- Facilitates synthetic grid models for planning and risk assessment - Enables testing and expansion planning for renewables - Aligns with Austria's energy goals by simulating grid optimization	- Uses open-source data and AI to create synthetic grid models - Key resources: demographic and geographic data, AI algorithms - Partners: AIT, local government agencies	**Consulting Model:** Project fees for custom model generation and analysis **Licensing Model:** License fees for software tools supporting grid simulation and planning
UC7	**EnergieAtlas**	DSOs, PV Operators, Local Governments - Segments: energy providers, GIS technology providers	- Provides real-time insights into PV system distribution - Supports grid stability and renewable energy goals with accurate data - Environmental benefits from optimized resource management	- GIS platforms for real-time monitoring and PV data analysis - Key resources: PV data, satellite weather data - Partners: GIS providers, local government agencies	**Data Access Fees:** Subscription for real-time and historical data access **API Integration Fees:** API access for third-party applications needing PV data
UC8	**Act4Energie Controls**	DSOs, RECs, Energy Providers - Segments: local energy communities, technology partners	- Enhances grid control and resource management for energy communities - Supports decarbonization and real-time energy optimization	- Digital twin with IoT integration for real-time monitoring - Key resources: smart meters, cloud infrastructure - Partners:	**Subscription Model:** Monthly/annual fees for digital twin access and analytics

			- Allows proactive user engagement and predictive maintenance for sustainable energy management	Energie Kompass, local government agencies	

6 AT A GLANCE

6.1 GridCloud Involved/Target stakeholders

Stakeholder Type	Role/Responsibility
Distribution System Operators (DSOs)	Operate, maintain, and develop electricity distribution networks; ensure grid reliability and integrate new technologies.
Transmission System Operators (TSOs)	Manage high-voltage transmission networks; support grid stability, real-time monitoring, and renewable energy integration.
Technology Providers	Supply technical solutions like IoT devices, digital twin platforms, data integration tools, and analytics software.
Energy Providers	Generate and supply energy to the grid; support renewable integration and grid efficiency.
Academic & Research Institutions	Conduct research, provide technical expertise, and support innovation in grid optimization and digital technologies.
Government & Regulatory Bodies	Set regulatory standards, ensure compliance, and support the adoption of smart grid technologies.
Industry Associations	Represent sector-specific stakeholders (e.g., DSOs) and facilitate discussions on regulatory compliance and best practices.
Energy Sharing Communities	Engage local communities in energy production, sharing, and renewable energy adoption.
Local Government Agencies	Support regional energy projects, community engagement, and regulatory alignment.
End-Users & Prosumers	Consumers and small-scale energy producers who provide feedback on new technologies and participate in energy sharing.

6.2 Use Cases and Technological Components

Use Case	Country	Key Technologies Used	Purpose
StormSafe	Türkiye	IoT Sensors, Digital Twin, Big Data	Predictive maintenance and fault detection
Data Monitoring	Türkiye	LoRaWAN, Tilt/Vibration Sensors, IoT	Real-time monitoring of transmission lines and predictive analytics
Karaburun DT	Türkiye	Digital Twin, GIS, Python (DigSilent)	Grid simulation and anomaly prediction

Schönbrunn Twin	Germany	Digital Twin, Data Standardization	Grid data integration and decision support
Schönbrunn Grid Adaptation	Germany	AI, IoT, Data Analytics	Real-time grid monitoring and anomaly detection
NetGen DT	Austria	Open-Source Data, AI, GIS	Synthetic grid model creation for planning and renewable integration
EnergieAtlas	Austria	GIS, Satellite Data	PV system management and grid stability
Act4Energie Controls	Austria	Digital Twin, Smart Meters, IoT	Optimized grid control for local energy communities

6.3 Country-Specific Challenges and Solutions

Country	Key Challenges	Proposed Solutions
Türkiye	Data integration, privacy, cyber security	Standardized data formats, secure IoT networks, pilot projects for compliance
Germany	Data standardization, interoperability	Digital twin model validation, standardized data modules
Austria	Real-time data access, GDPR compliance	Collaborative regulatory alignment, synthetic grid modeling for privacy

6.4 Stakeholder Contributions to Use Cases

Stakeholder	Contribution to Use Cases	Examples of Input
Distribution System Operators (DSOs)	Grid data, real-time monitoring needs	Feedback on grid stability, data privacy requirements
Academic & Research Institutions	Technical expertise, model validation	Support in data integration, digital twin model development
Technology Providers	Technical infrastructure, IoT solutions	IoT sensor integration, digital twin platforms, cloud storage options
Energy Providers	Renewable integration, operational feedback	Recommendations on grid optimization and renewable energy adoption
Energy Sharing Communities	User experience, local insights	Suggestions for user engagement, privacy concerns, real-time needs

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