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# AISOP

## AI-assisted grid situational awareness and operational planning

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**The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.**

# Zusammenfassung

AISOP entwickelt ein **KI-basiertes Entscheidungsunterstützungswerkzeug für Verteilnetzbetreiber (VNB)** welches auf **fortgeschrittener digitaler Technologie** abgestützt ist, um die Dekarbonisierung voranzutreiben. Das Entscheidungsunterstützungswerkzeug akquiriert, verarbeitet, interpretiert und verwertet Daten für die Betriebsplanung von V. In diesem Zusammenhang erweitert AISOP datengesteuerte Methoden für verbesserte Betriebsplanung, Situationserkennung und Marktanreiz in lokalen Verteilnetzen mit hohen Anteilen von dezentralen Energieressourcen durch KI/ML basierte Entscheidungsunterstützung. Im geplanten Projekt werden (i) Datenzugriff und -aufnahme, (ii) Verteilnetz Situationserkennung, (iii) Entscheidungsunterstützung für Verteilnetzbetrieb, (iv) dynamische Tarife, (v) Integration einer digitalen Plattform mit Auswertung via von Test- und Trainingsumgebungen vereint. Die entwickelten Lösungen werden innerhalb von EXPERA verbreitet und anhand von Demostandorten und Living Labs in der Schweiz und Deutschland validiert.

Das Projekt startete im Mai 2022. Die Arbeiten im aktuellen Berichtszeitraum umfassten die Strukturierung und Definition des Workflows für die operative Planung, die Identifizierung von Werkzeugen für die Aufnahme in den Workflow, die erste Definition von Anwendungsfällen und Projektinitiierungsaufgaben.

Im nächsten Berichtszeitraum werden die Definition und Anforderungen des digitalen Prozesszwillings sowie die Datenanforderungen und Prozesse für den Datenzugriff durch den digitalen Prozesszwilling abgeschlossen. Die Anwendungsfälle und Konzepte für LV-Situationsbewusstsein werden unter Berücksichtigung von Edge- und Embedded-Geräten sowie der in den vorherigen Abschnitten beschriebenen heterogenen Datenquellen vollständig entwickelt. Ein KI-basiertes Modell zur Netzsituationserfassung wird vorgeschlagen und auf Offline-Simulationen angewendet. Des Weiteren wird die Fehlererkennungs- und Klassifizierung vorangetrieben. Die Arbeiten im Rahmen der Risikoanalyse werden weiterentwickelt, um einen ersten Prototyp des Risikoanalyseinstruments und einer vollständigen Definition des Risikoquantifizierungsansatzes auszuarbeiten. Schließlich wird die Entwicklung der dynamischen Tarifumsetzung auf der Grundlage von Daten aus anderen Modulen vorangetrieben.

# Résumé

AISOP vise à créer un système d’aide à la décision alimenté par l’IA pour les opérateurs de réseaux de distribution d’électricité (DSO) afin de favoriser la décarbonisation soutenue par une technologie numérique avancée. Le système d’aide à la décision collecte, traite, interprète et utilise les données de manière sécurisée et privée au profit de la planification opérationnelle des SOPDI. Dans ce contexte, AISOP étend les techniques basées sur les données pour améliorer la planification opérationnelle dans les réseaux de distribution / locaux avec des parts de DER élevées grâce à l’intégration de solutions basées sur l’IA / ML, une meilleure connaissance de la situation et des incitations au marché. Dans le cadre du projet proposé, nous combinons (i) l’accès et l’ingestion des données, (ii) la connaissance de la situation pour le réseau de distribution, (iii) l’aide à la décision pour la gestion du réseau de distribution, (iv) les tarifs dynamiques, (v) l’intégration de plateformes numériques avec utilisation par des environnements de test et de formation. Les solutions développées seront distribuées au sein d’EXPERA et validées à l’aide de sites de démonstration et de laboratoires vivants en Suisse et en Allemagne.

Le projet a débuté en mai 2022. Au cours de la période de reporting actuelle, le travail comprenait la décomposition et la définition du flux de travail pour la planification opérationnelle, l’identification des

outils à inclure dans le flux de travail, la définition initiale des cas d'utilisation et les tâches de lancement de projet.

Au cours de la prochaine période de rapport, la définition et les exigences du jumeau de processus numérique et les exigences et processus de données pour l'accès aux données par le jumeau de processus numérique seront achevées. Les cas d'utilisation et les concepts de connaissance de la situation BT sont entièrement développés en tenant compte des dispositifs de périphérie et embarqués ainsi que des sources de données hétérogènes décrites dans les sections précédentes. Un modèle basé sur l'IA pour la connaissance de la situation du réseau est proposé et appliqué aux simulations hors ligne. La recherche sur la détection des erreurs et la classification est encouragée. Les travaux sur le cadre d'analyse des risques progresseront, conduisant à des premiers prototypes de l'outil d'analyse des risques et à une définition complète de l'approche de quantification des risques. Enfin, le développement d'une mise en œuvre tarifaire dynamique basée sur les données fournies par d'autres modules sera encouragé.

# Summary

**AISOP** aims to create an **AI-assisted decision support system for the electric distribution system operators** (DSOs) to drive decarbonisation that is underpinned by **advanced digital technology**. The decision-support system securely and privately acquires, processes, interprets, and exploits data for the benefit of DSO operational planning. In this context, AISOP expands data-driven techniques for improved operational planning in distribution/local grids with high shares of DERs by integrating AI/ML-based solutions, enhanced situational awareness and market incentives. Within the proposed project we combine *(i)* data access and ingestion, *(ii)* distribution grid situational awareness, *(iii)* decision-support for distribution grid management, *(iv)* dynamic tariffs, and *(v)* digital platform integration with exploitation through test and training environments. The developed solutions will be disseminated within EXPERA Knowledge Community, ERA-Net-organised workshops, internet platforms (e.g., website, Linkedin), and national/international workshops/events and conferences, and validated using demo sites and living labs in Switzerland and Germany.

The project started in May 2022. Work in the current reporting period included decomposing and defining the workflow for operational planning, identifying tools for inclusion in the workflow, initial definition of use cases, and project initiation tasks.

During the next reporting period the definition and requirements of the digital process twin will be completed, along with the data requirements and processes for accessing data by the digital process twin. The use cases and concepts for LV situational awareness will be fully developed, considering edge and embedded devices, and the heterogenous data sources such as grid sensors, aggregated smart meter data, weather forecasts, etc. An AI-based data-driven model for grid situational awareness will be proposed and applied to offline simulations. Fault detection and classification research will be progressed. Work on the risk analysis framework will progress, leading to initial prototypes of the risk analysis tool and a full definition of the risk quantification approach. Finally, development of the dynamic tariff implementation will progress, based on data inputs from other workflows.

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# Abbreviations

| | |
|---|---|
| AI | Artificial Intelligence |
| DER | Distributed Energy Resources |
| DG | Distributed Generation |
| DSM | Demand Side Management |
| DSO | Distribution System Operator |
| LV | Low Voltage |
| ML | Machine Learning |
| MLT | Machine Learning Technique |
| MV | Medium Voltage |
| OPF | Optimal Power Flow |
| PMU | Phasor Measurement Unit |
| PQ | Power Quality |
| RES | Renewable Energy Sources |
| SCADA | Supervisory Control and Data Acquisition |
| SFOE | Swiss Federal Office of Energy |
| SM | Smart Meter |
| ToU | Time-of-Use |
| TSO | Transmission System Operator |

# 1 Introduction

## 1.1 Background information and current situation

To achieve the objectives of the Energy Strategy 2050, the Swiss Federal Office of Energy (SFOE) has laid out the Energy Research Masterplan 2021-2024. One of the key objectives is to ensure the efficient overall operation of the electric power grids on an interoperable, safe and reliable basis [1]. In particular, the integration of large quantities of distributed energy resources is having a significant impact on the operation of distribution networks and is creating new operational challenges for the Distribution System Operator (DSO). Furthermore, SFOE laid out plans for a “digital strategy” in 2020, aiming to contribute to the UN’s sustainable development goals with five key objectives: (i) enabling equal participation for all, (ii) guaranteeing security and transparency, (iii) continuing to strengthen people's digital empowerment and self-determination, (iv) ensuring value creation, and (v) reducing environmental footprint and energy consumption.

Digitalisation of the electric energy systems creates opportunities to improve grid situational awareness and operational planning. Also, it will strengthen digital empowerment, and ensure value creation from existing data streams. However, digitalisation also creates challenges: it will tighten requirements for privacy, for guaranteeing data security, and for transparency. In delivering the Energy Strategy 2050, all customers will be equipped with intelligent metering systems, resulting in an unprecedented number of data points from the distribution network. As DSO grid monitoring expands, the volume of data will increase further. The data quality is often unsatisfactory: incorrect data records create issues for downstream processes and actors, and much of the data cleaning is still performed manually from centralised platforms. In combination, these factors mean that automated processes are required to support the management and exploitation of energy system data by the DSO. These processes need to ensure data protection and security and be designed in a way that improves the quality of underlying data sources.

In this context, AISOP creates an AI-assisted decision support system for the DSO to drive decarbonisation that is underpinned by advanced digital technology. The decision support system securely and privately acquires, processes, interprets, and exploits data for the benefit of DSO operational planning. The primary use case is to support the DSO’s distribution grid situational awareness, focusing on grid state analysis, fault prediction, and identification of problematic consumption patterns. When combined with risk analysis, AISOP is then able to support DSO operational planning through data-driven dynamic tariff setting. In this way, AISOP advances the green energy transition in all sectors by leveraging artificial intelligence and machine learning in the DSO, and by integrating and linking data platforms and driving interoperability between them, including those relating to electricity, heat, transport, and storage.

## 1.2 Purpose of the project

AISOP expands data-driven techniques for operational planning in distribution/local grids with high shares of DER, combining (i) data access and ingestion, (ii) distribution grid situational awareness, (iii) decision-support for distribution grid management, (iv) digital platform integration, and (v) exploitation through test and training environments.

In support of the above objectives, AISOP research questions are:

**Data access and ingestion**

- **Insights:** How can data-driven analytics improve and optimise operational planning within the DSO by employing decision-support systems in a practical manner?
- **Data privacy:** How can privacy be maintained using distributed approaches to data access and exploitation, avoiding the centralisation of data while supporting the close-to-real-time operations of DSO?

**Distribution grid situational awareness**

- **Grid state forecasting:** How can the DSO synthesise and utilise temporally and spatially heterogenous data from available smart meters, distribution system sensors, and measurements from DER to extract knowledge relevant to grid violations to increase situational awareness for secure grid operational planning?
- **Fault detection:** How can the DSO synthesise and utilise heterogenous data from available metering infrastructure and measurements from DER to identify component or grid failures (intermittent/temporary)?
- How can the abovementioned grid state forecasting and anomaly detection provide inputs to an AI assistant to support the DSO operational planning process?

**Tariff-driven operational planning decision-support**

- **Tariff design:** How can tools such as dynamic tariffs be adapted to drive prosumer behaviour and what is their impact on operational planning (i.e., day-ahead, or intraday)?
- **Data relevance and quality:** What data is the most relevant (e.g., determining time-variant price signals such as feed-in pricing, retail pricing)? What are the required levels of quality, accessibility, and transparency?
- **Business integration:** What processes and business models, including engagement of consumers, are best suited for the decision support?
- **Operational interfaces:** How can other stakeholders (e.g., TSOs, aggregators) benefit from such data-driven decision support tools for operational planning?

## 1.3 Objectives

AISOP's overarching mission is to create an AI-assisted decision support system to drive decarbonisation in electricity distribution systems. AISOP project objectives are to:

1. Increase grid observability by using data from multiple sources and in different time resolutions,
2. Help DSOs operate the grid using data-driven decision support tools,
3. Improve the efficiency of network operations,
4. Reduce curtailment of renewable energy and distributed energy resources,
5. Improve options for tariffs for DSO's and prosumers.

AISOP's solutions will acquire, process, interpret and exploit data for the benefit of DSO operational planning, integrating AI/ML-based solutions, enhanced situational awareness, and market incentives. The project aims to create actionable, tangible, and applicable outcomes for distribution systems to improve operational planning and support decarbonisation. The outcomes will take the forms outlined in Table 1.

Table 1 – AISOP project outcomes

| Methodologies and knowledge | Technologies | Services |
|---|---|---|
| Accessing and combining heterogenous, dispersed datasets<br>Developing grid situational awareness using edge and embedded network devices<br>ML-based risk analysis and risk quantification<br>AI/ML-based identification of dynamic tariffs for congestion management | Data analytics (forecasting, local optimisation)<br>ML-based anomaly detection and fault prediction<br>Digital process twin for distribution systems<br>Embedded and distributed sensors for LV and MV networks | Dynamic tariffs<br>DSO congestion management<br>Fault detection and prediction<br>Operational risk management<br>Integration of community in digital platforms |

In addition to the outcomes described above, AISOP will deliver environmental and socio-economic impacts as described in Figure 1.

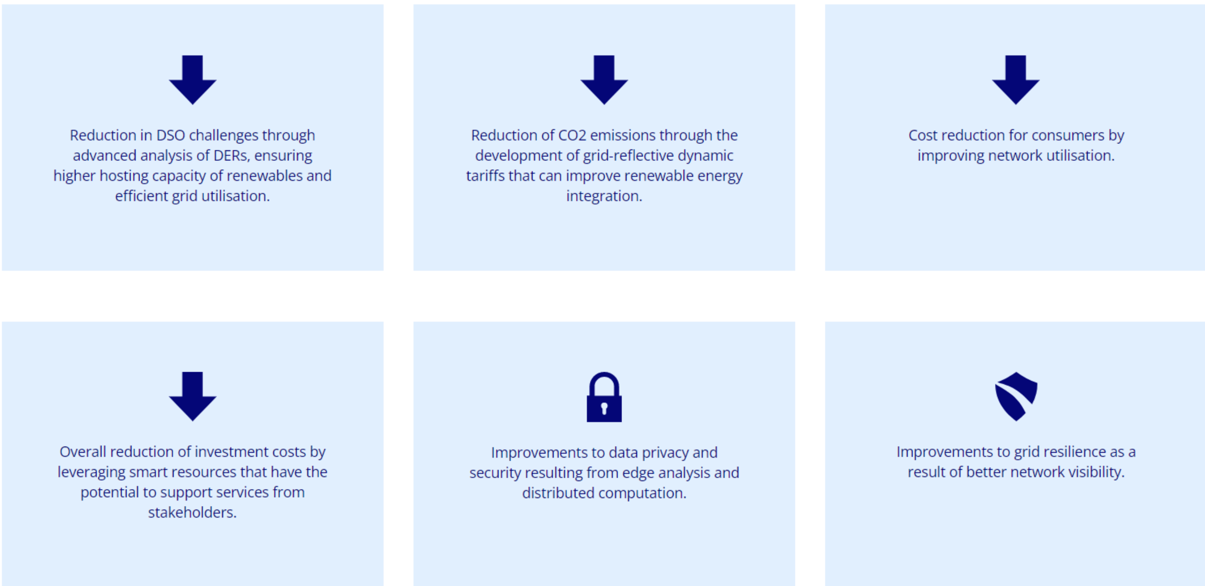


Figure 1 – Environmental and socio-economic objectives in AISOP

# 2 Description of facility

AISOP progresses operational planning in the DSO from TRL 2 (formulation of the concept and / or the potential application of the technology) to TRL 6 (verification of an engineering model and prototype in a relevant environment). The project therefore intends to make use of ‘virtual test beds’ or ‘virtual demonstrations’, rather than deploy to field trials. In Switzerland, Romande Energie is expected to provide data collected at two locations: Rolle and Chapelle-sur-Moudon, subject to further discussion on detailed project requirements.

Activities relating to Rolle will use selected infrastructure from the project P+D REel Demo – FURIES (SFOE contract SI501523-01). The site at Rolle includes 70 phasor measurement units (PMU's), 100 GridEye units, 750 smart meters, a battery energy storage system, integrated PV, seven remotely controlled stations and a data management system, spread within 36 local LV systems.

The activities within the Chapelle-sur-Moudon test site will also make use of facilities developed in relation to the FURIES contract. These include PV installations with a capacity of more than 300 kVA; two boilers of 800 litres for hot water (7.6kWp each); 1 boiler of 2000 litres (18kWp) for heating; and a heat pump for both space and water heating (27kWp). Also, this district consists of 57 residential blocs and 9 farms, amounting to a total of 88 consumers. 10 Grid Eye units are installed in the site. The soft open point described in the AISOP proposal has been decommissioned due to operational constraints and so will no longer form part of the analysis.

In Germany, DSO Westfalen-Weser Netz will provide static and dynamic data and will support the practical implementation of the digital process twin.

# 3 Procedures and methodology

## 3.1 Project Approach

This section describes the overall methodology for the project. A conceptual architecture for AISOP is provided in Figure 2. Further decomposition of the methodology is provided in Chapter 4.

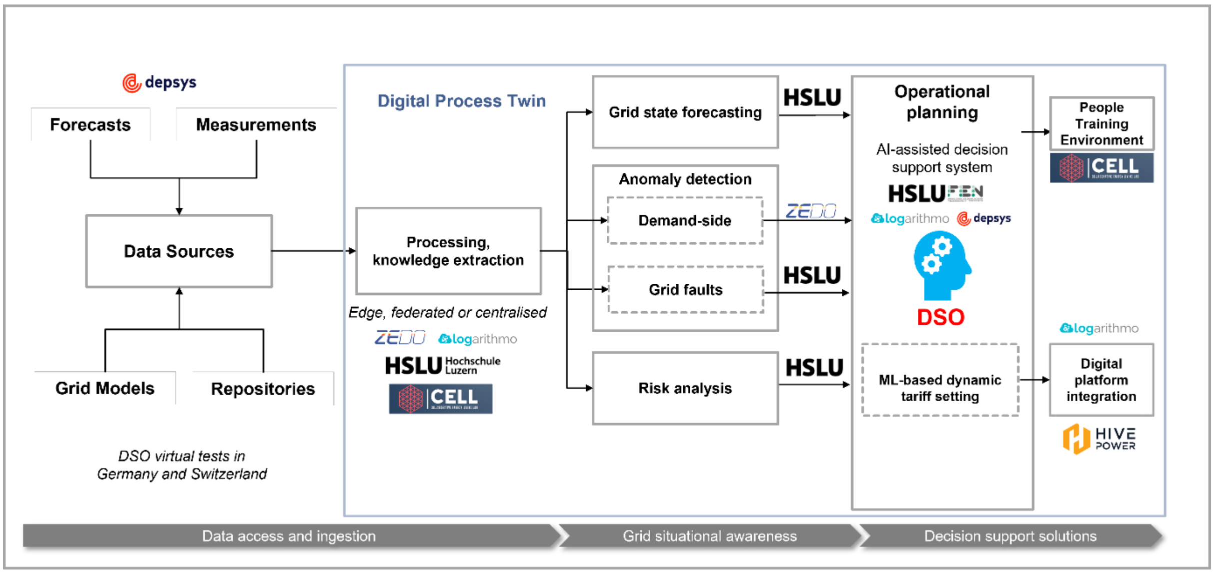


Figure 2 – AISOP conceptual architecture

### 3.1.1 Data access and ingestion

Partners will extract knowledge from heterogenous data sources by means of statistical clustering, classification, and correlation methods. Non-sensitive data will be centralised into a project repository. Federated, distributed, or edge-based processes will be applied to sensitive data where feasible to maintain privacy and demonstrate the value of such approaches to the DSO. The framework includes the collection and processing of data that is available through deployed conventional and new grid measurements (e.g., PMUs), measurements from distributed energy resources (DERs), as well as advanced metering infrastructure (AMI), combining advanced tools and protocols for acquisition and exploitation of data from distributed sensors.

### 3.1.2 Tools for situational awareness

Data are used for forecasting the grid state (nodal voltages, branch loadings); predicting asset failure; and forecasting intermittent grid faults. ML and conventional techniques will be exploited to assess benefits. Decision-support tools will be developed, and scenarios will be generated to test and increase the performance of the proposed tools.

### 3.1.3 Dynamic tariffs

The developed “operational planning framework” includes determining dynamic price signals to steer the customer and prosumer behaviour temporally and spatially in a time-variant manner. Boundary conditions imposed by local energy markets will be investigated using techno-economic simulations on the Hive Platform.

### 3.1.4 Integrating digital architecture

The system is integrated with a digital process twin provided by the international partner ZEDO (Germany). This acts as the digitised representation of (i) the tasks performed by grid operators, (ii) tasks engineered by grid operators but performed by software, and (iii) the secure acquisition and representation of network and consumer data, building upon and expanding the definition of “digital twin” to address the needs of the DSO.

## 3.2 Research Team

AISOP brings together an international consortium of highly qualified partners. An overview of the composition of the individual partners is shown in Figure 3.

The consortium comprises need owners, scientific partners, digital platform providers, demo sites, and two SMEs. Partner nationalities are indicated in the diagram. The Swiss consortium comprises a need owner (Romande Energie), two scientific partners (ETH Zurich FEN and Lucerne University of Applied Sciences and Arts, HSLU), an SME (Depsys), and a digital platform provider (Hive). HSLU contributes the living lab CELL, and Romande Energie provides SCCER-FURIES sites at Rolle and Chapelle-sur-Moudon for data and field activities. LKW participates as an observer of the project. The German consortium comprises two need owners (WWN, ASEW), one scientific partner (ZEDO at TU Dortmund), and a digital platform provider, Logarithmo.

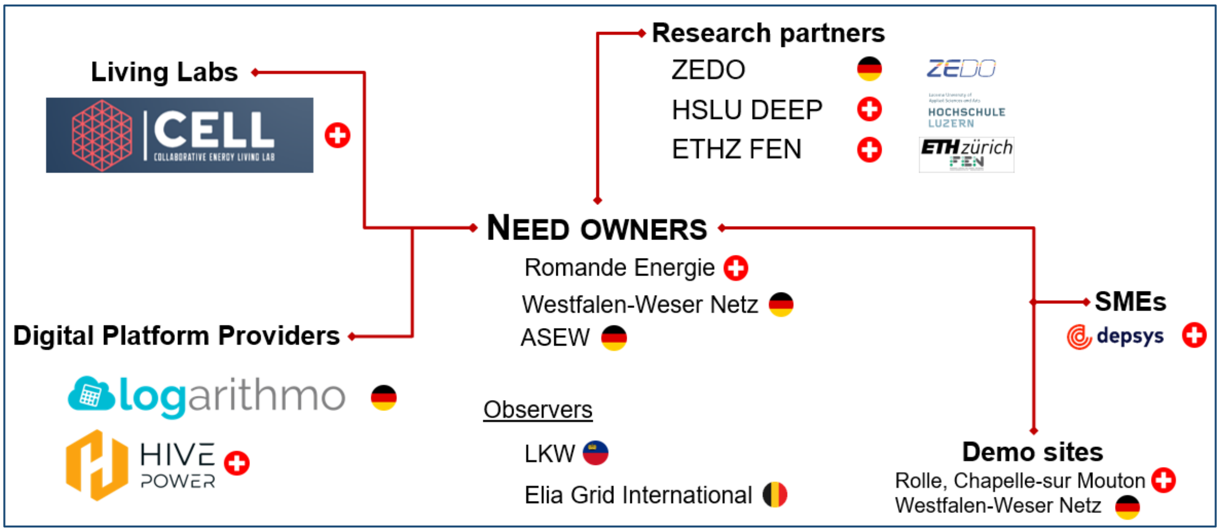


Figure 3 – AISOP research team

The Swiss academic partners focus on the bottom-up integration of grid state forecasting, anomaly detection, and risk analysis that leads to grid situational awareness (HSLU). The grid situational awareness is exploited in a decision support solution (FEN), comprising data-driven dynamic tariffs. In combination, this creates an enhanced situational awareness for the DSO, empowering them to make informed decisions. Data is acquired using privacy-preserving protocols such as grid edge-based data processing and federated learning (HSLU) in combination with centralised approaches.

# 4 Activities and results

AISOP started in May 2022, meaning activities constitute less than one full reporting period. Planned work for the period included:

1. Decomposing and defining the workflow for operational planning and identifying possible tools for inclusion in the operational planning workflow,
2. Definition of initial use cases,
3. Project initiation (website, factsheet, EXPERA profile, project handbook).

Details of the progress associated with each are provided in this chapter.

## 4.1 Decomposing the workflow for operational planning

The operational planning logical workflow was developed in the context of the AISOP objectives, as shown in Figure 4.

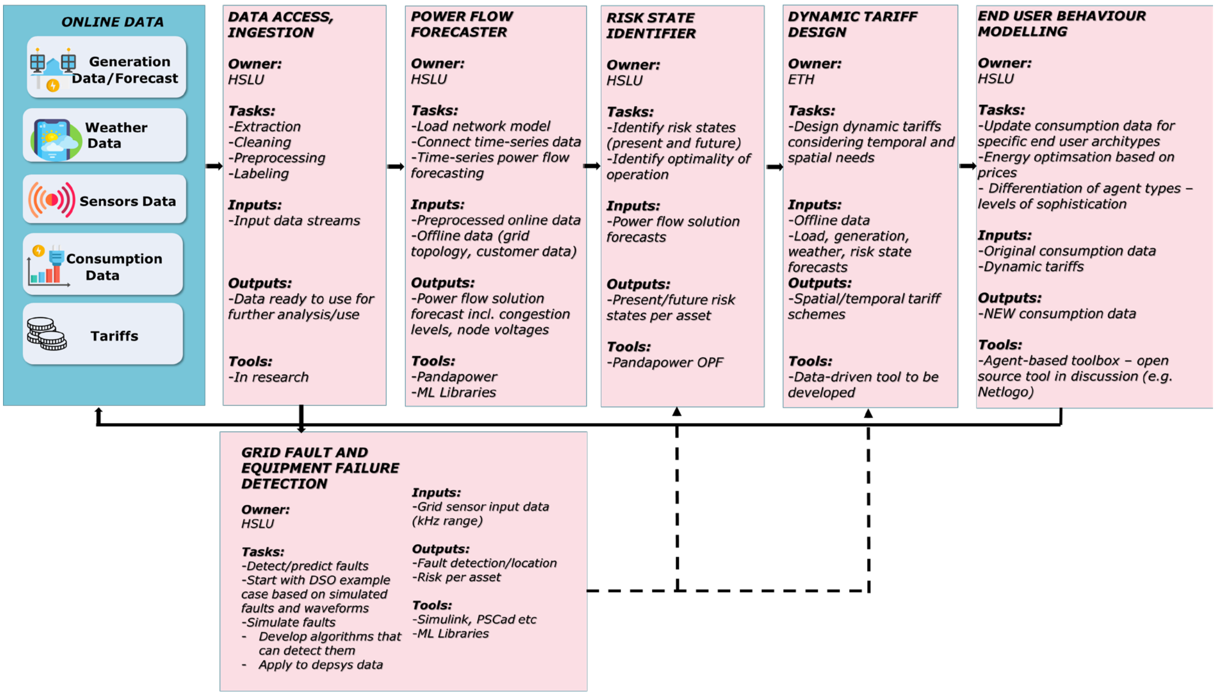


Figure 4 – Decomposed logical workflow for operational planning (tasks in Switzerland)

The workflow is reformulated in a simplified schematic in Figure 5 to highlight data inputs and outputs. Data categories are also expanded to differentiate between offline and online data more clearly.

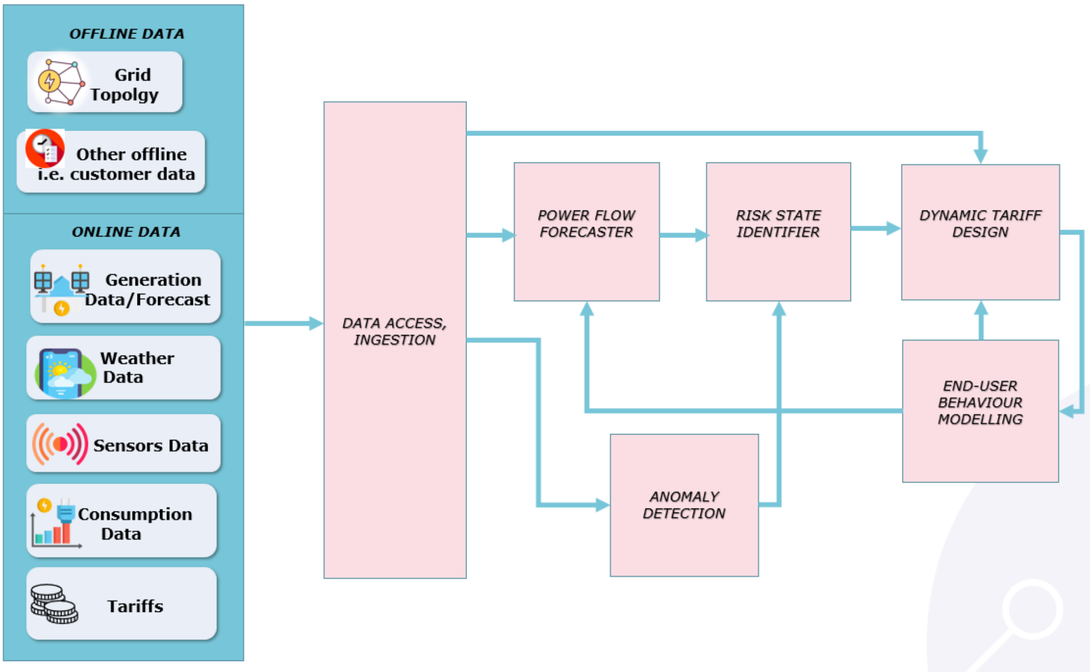


Figure 5 – Simplified logical workflow for operational planning

### 4.1.1 Data access and ingestion

There is an increasing amount of data that may be leveraged by distribution system operators to enable operational planning. On the grid side, these include:

- Emerging smart grid technologies such as advanced monitoring infrastructure (e.g., AMI and DMS systems),
- Distribution-level phasor measurement units and other real-time data acquisition devices capable of collecting voltage and current waveforms at high sampling frequencies,
- Smart meters,
- Sensors deployed with distributed energy resources which collect and are capable of telemetering status information (e.g., power set-point) on the demand-side.

In addition, spatially and temporally more granular weather data and forecasts offer additional insight into potential renewable energy generation and end consumer energy consumption. Moreover, data such as grid topology information, and data defining user behaviour (e.g., calendar events, types of flexible loads behind the metering point), need to be assimilated. This results in a massive amount of data which could be considered: a meaningful subset must be extracted as input for the simulation modules in AISOP that will support the operational planning process. A spatial and temporal integration perspective should be adopted due to the different values and structures of these energy data sources [2].

Within AISOP, in a first step, heterogenous data is collected from various data sources. Data is processed (cleaning, labelling, reformatting) and made available for use by subsequent steps. An additional objective is to synchronise data streams at different timescales to extract meaningful features from them. Online data is referred to in Figure 4, as referring to time series-type of data, which in a prototyping stage may be ingested from a file-based system. The data ingestion and assimilation process are approached as follows. Open questions are shown in italics:

1. Creation of data catalogue and ranking of availability and sensitivity of data sources. *What are the necessary data and how to access them?*
2. Mapping of data sources to use cases. Identify if there are gaps. *Can we access data for specific uses cases? What generic data can be used as a starting point?*
3. Definition of data ingestion pipelines. This step prepares the data for assimilation. *How should the framework access, parse, and store data?*
4. Data assimilation. We mainly refer to two categories of datasets (a) configuration data; and (b) stream data. *What datasets can be merged? From which of them can we synthetise information to update configuration inputs, and which of them are time dependent inputs for simulations? What data assimilation tasks are necessary between modules of the simulation workflow?*
5. Definition of data serving schemes. *How shall the data be passed on to the different simulation modules?*

AISOP develops modular and small data ingestion objects that are tightly developed in connection to the simulation framework. Alignment to process twin requirements and implementation will be done periodically. These processes will rely on automated data quality checks when possible and provide merged data sets upon settings such as time resolution, or geographical location. Methods for generation of synthetic data with desired statistical characteristics will be applied when needed to fill data gaps or due to lack of data for specific use case.

#### 4.1.2 Power flow forecaster

A power flow forecaster is proposed that connects time series data to the network model and conducts power flow forecasting. The algorithm results in forecasts for the power flow, revealing congestion levels and nodal voltages in the distribution network.

Within the Power Flow Forecasting building block, the objective is to calculate the state of the grid and predict its evolution. Therefore, it is necessary to link nodal consumption and generation data to grid topology. Active and reactive power flows are calculated in distribution system delivery equipment (transformers, distribution lines, switches, etc.). Based on active and reactive power flows, an operator obtains access to present and future (e.g., day-ahead) congestion levels of the different grid components. The congestion levels provide significant insight into overall grid loadings, which is critical in operational planning.

Additionally, the power flow forecasting building block provides present and future (e.g., day-ahead) voltage levels at all nodes in the network. The voltage boundaries are hard constraints for operational planning as the grid operators need to maintain voltages within the admissible voltage band (average 10 minutes rms values should not deviate more than ±10% from the nominal level for 95% of week, according to EN50160).

The power flow forecasting building block, at its core, calculates the operating conditions of a grid, neglecting transient dynamics. It relies on a power flow solver, which would ideally be an open-source tool such pandapower[1]. However, due to the modular approach to build the blocks illustrated in Figure 5, proprietary tools could be included at a later stage.

To forecast power flows and voltage levels, there are two main approaches which will be investigated in upcoming research work. Both methods can be implemented and compared based on performance and complexity:

1. Forecast nodal loads/generation, then solve the power flow problem on the forecasted time-series. This yields the active and reactive power flows in the different grid components and voltage levels at different nodes for the forecasting horizon,
2. Forecasting target values directly, based on historic power flow solutions. This could be achieved by feeding a forecasting model with historic power flow solutions, and from that obtain the future active and reactive power flows in the different grid components and voltage levels at different nodes.

Steps to build models for specific use cases involve:

- Parse grid topology,
- Parse various datasets to represent consumption and generation at distinct nodes in the grid.
- Configure the use case (e.g., define dynamic tariff schemes, user profile behaviours to be model),
- Link nodal consumption and generation data to a grid topology,
- Estimate system state (compute power flow and perform updates based on data).

[1] http://www.pandapower.org/

The power flow forecasting building block will rely on the network model description, ideally in a form that can be readily processed in pandapower, for example Matpower MPC or the native pandapower model. In case a different input network model is provided by the DSO partner, a conversion needs to be completed. End-consumer / prosumer load and generation profiles should be ingested within the power flow forecaster. These profiles also need to have connectivity information, i.e., where in the network they are connected, so that they can be linked to the network model. It can be envisioned that additional data streams can be ingested in the power flow forecaster to improve the forecasting.

### 4.1.3 Grid fault and equipment failure detection

In parallel to power flow forecasting, high resolution data are used from embedded distribution network sensors to identify and predict incipient or developing faults in the distribution network. An ML-based method will be developed to detect the incipient faults using voltage and current waveforms that have been collected by GridEye sensors. Different criteria for voltage and current waveforms will be considered.

MATLAB-Simulink will be used to simulate repetitive, sub-cycle, and multi-cycle electric faults in LV networks with a 10KHz sampling frequency. Features will be calculated and selected for anomaly detection and classification. An appraisal of ML techniques will be undertaken to find the most compatible solutions for identifying and classifying faults. Models will be trained and tested on field data to understand the performance of models in detecting incipient LV faults.

### 4.1.4 Risk state identifier

Results from the power flow forecaster and the equipment failure detection are combined and applied to a risk state identifier, leading to a quantified risk state per asset that can be linked to the conditions in the network.

Within this building block the objective is to identify a risk state per asset in a distribution network. The risk state metric should provide a time-varying indication whether there is a risk of overloading an asset, of violating voltage boundaries, or if an asset is prone for a future fault. In addition, it is envisioned to indicate some information on the “optimality” of the operation within the network. These KPIs will then feed the dynamic tariff calculation, which will in turn set tariffs dynamically which 1) compensate for the actual cost of procuring energy for the DSO, and 2) motivate end-users to adopt a more grid friendly behaviour (c.f. Section 4.1.5).

The risk state identifier building block relies on outputs of the power flow forecasting building block and the anomaly detection building block:

- Present and future (day-ahead) active and reactive power flows in distribution system delivery equipment (transformers, distribution lines, switches, etc.),
- Present and future (day-ahead) voltage levels at all nodes in the network,
- Faults per asset in the network for a given time,
- Likelihood for future faults in an asset (based on past occurrences).

Outputs from the risk state identifier comprise:

- Present and future (day-ahead) risk states per asset in the form of a risk score,
- Metric representing the “optimality” of operation, which may indicate how close a parameter (voltage or congestion level) is from operational boundary.

### 4.1.5 Dynamic tariff implementation

The risk state is used as an input to the computation of dynamic tariffs, in combination with other available data. Dynamic tariffs can be implemented in a digital platform and presented to users.

Preparatory work has been performed during the first six months of the project. The definition and use of dynamic tariffs had been elaborated among the project partners while performing a thorough review of the state-of-the-art in academic literature as well as industry experiences and developments [3-15]. Even though a dynamic tariff is generally defined as “charging of different electricity rates at different times of the day and year to reflect the time-varying cost of supplying electricity” [16,17], there are various types of tariffs described in literature, including time-of-use (ToU), real-time pricing (RTP), critical peak pricing (CPP), peak time rebates (PTR). In addition, the term "dynamic tariff" is often used in different contexts. For example, the term can signify retail electricity tariffs (paid for energy consumption) which directly follow the variability of wholesale electricity prices, or network tariffs that reflect the cost to deliver electricity to the end consumer.

It has been agreed that the focus of AISOP shall be on distribution network tariffs charged by the DSO to its customers. The term "dynamic" encompasses the fact that the tariff can be different during different points of time (e.g., hourly tariffs, or dependent on the day, month, season) as well as over time at a regular basis (e.g., every month, week, day). In addition, dynamic tariffs could charge based on different components (typically energy and power, but other options could be envisaged, such as power factor or local voltage). Whether the term "dynamic" can include spatial differentiation (e.g., different tariff for different feeders or even connection points) has been discussed. Industrial project partners expressed the concern that this will act against equal network access and, hence, could be considered politically unacceptable. The project could investigate whether such differentiation could have benefits, but it is not the focus nor the priority in the envisioned research scope. A more realistic option is tariff differentiation for specific demand segment (e.g., EV chargers or heat pumps), and this concept will be taken forward in AISOP.

Following the discussions with project partners, a two-fold final objective for putting a dynamic tariff system in place has been identified:

1. Act as an indirect way to trigger end-customer flexibility thus allowing DSO to manage congestion in its network indirectly, and
2. Achieve a fair allocation of costs required for network expansion/upgrades where congestion is mostly observed (or forecasted).

In both cases, it has been agreed among the project partners that the way that end customers would react to the dynamic tariffs will be via automatic systems such as Building/Home Energy Management Systems.

Figure 5 demonstrates the overview of the data-driven dynamic tariff identification.

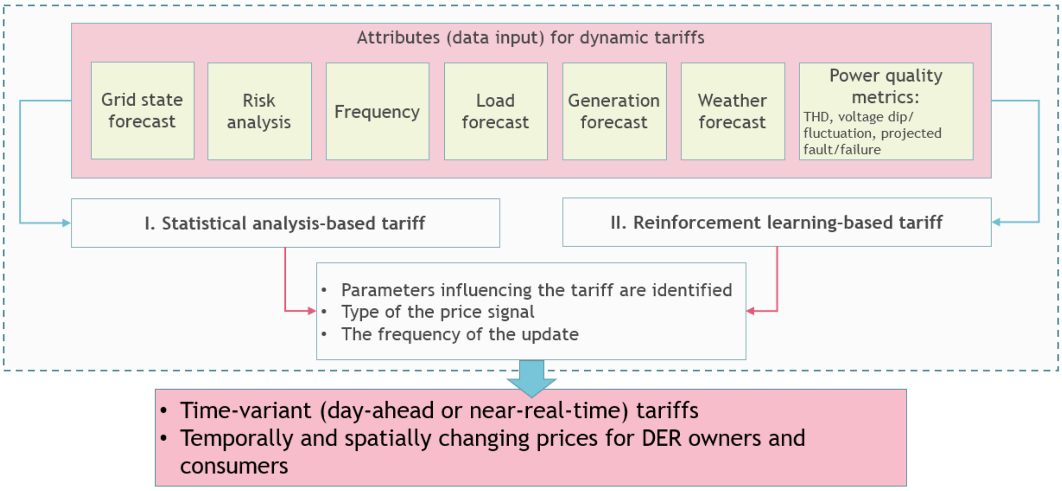


Figure 6 – An overview of the steps for data-driven dynamic tariff identification

The use of statistical correlation analysis as well as machine learning techniques in identifying dynamic tariffs are mainly inspired by the successful adoption of such algorithms in the e-commerce industry [18,19]. In the next reporting period, the methodologies will be elaborated, and data will be identified that is the most relevant for the above objectives.

### 4.1.6 End user behaviour modelling

AISOP does not include actual implementation of dynamic tariffs with customers. It is therefore necessary to simulate the response of network users to changes in dynamic tariffs. The final block in the operational planning logical workflow is therefore proposed as an agent-based model of end-users. User responses lead to a change in the data that is recorded from the system, hence a feedback loop exists, and the process can repeat. Further research is required into the feasibility of deploying an agent-based model in this context.

## 4.2 Identifying possible tools for inclusion in the operational planning workflow

An objective of AISOP is to test and illustrate how the different modules described in the previous section would interact with each other and with the ‘physical environment’, i.e., the grid, measurement equipment and the sites / customers connected to the grid. To this end, models will be integrated in a software platform, allowing their interactions to be properly represented. In addition, modules representing the physical environment will be developed and integrated into the software platform.

ReSIM, a multi-energy district-level system Simulation Framework developed by ETHZ-FEN within the scope of the ReMaP project[2], funded by SFOE (Project # SI/501810)[3], has been selected to be used as the integration platform. ReSIM features a selection of component models, control algorithms and an archive of demand and renewable generation data. The software was written in Python and can interconnect with other software tools if needed. It is highly modular and open for the addition of new models, algorithms, and data.

[2] https://remap.ch
[3] https://www.aramis.admin.ch/Grunddaten/?ProjectID=41788&Sprache=en-US

ReSIM can be used to build a digital twin of an arbitrary energy system that can in turn be used to test new designs or new operational rules and/or control strategies. Within the context of AISOP, the researchers in FEN shared the codebase with the researchers in the HSLU team and are guiding them towards integrating their modules into ReSIM. In addition, FEN researchers will integrate their own developed modules in ReSIM. The resulting “digital process twin”, modelled in ReSIM will act as a deliverable of AISOP, while it will be used for testing and improving the developed solutions and applications. A schematic representing the approach is provided in Figure 7.

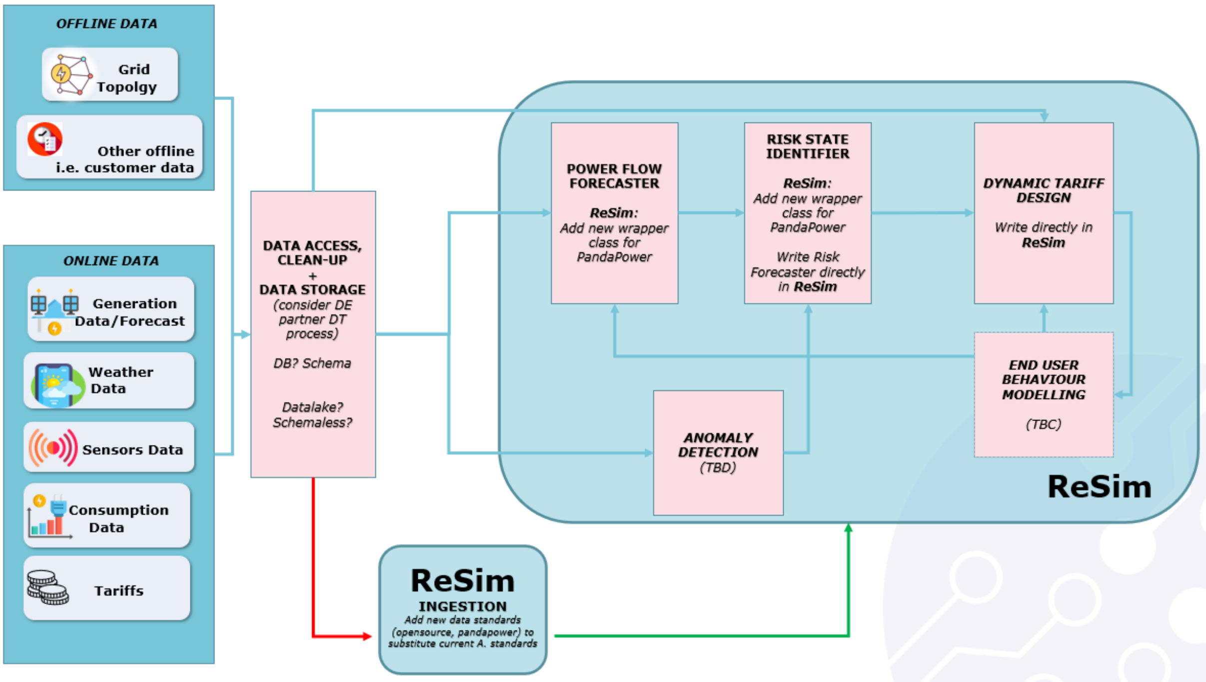


Figure 7 - Implementation of ReSIM as integrating framework for AISOP

Open-source tools such as Pandapower and optimization routines from Gurobi are envisaged for the power flow forecaster and agent-based tools respectively. Matlab / Simulink and modern machine learning libraries such as scikit-learn are the main frameworks planned for the analysis of faults. Further research is required on the suitability and accessibility of tools for the project.

Further integration will be required with the digital process twin platform developed by Logarithmo (DE) and Hive Power (CH). This will be defined in the next reporting period.

## 4.3 Definition of initial use cases

The identification and definition of use cases depend on:

1. the vision for “operational planning for distribution system operators”, and
2. the vision for a “digital process twin” that is performing all or part of the tasks of an “operational planning” process automatically, without the need for intervention by operators/engineers.

Both visions are being laid out as part of our activities in close collaboration with our industrial partners. As a by-product of this process, the initial use case development was completed with need owners in Switzerland (i.e., Romande Energie) and Germany (i.e., WWN). Use cases and UML diagrams will be developed further during the next reporting period.

### 4.3.1 Definition of operational planning for distribution system operators

Traditionally, operational planning has been a process employed by transmission system operators to prepare for real-time operation such that the probability of experiencing unexpected deviations in the balance of supply and demand is minimised. Up to now, such operational planning has not been necessary for distribution systems as the end-customers are only “consumers” of electricity and the network has been designed/dimensioned such that it can accommodate the highest expected electricity demand. However, as the paradigm is shifting, and the distribution systems are preparing for unprecedented levels of “prosumers” who will own (i) intermittent sources to generate electricity which may not temporally match the time of consumption at all times, and (ii) newly electrified demand, the stochasticity of the end-customer “net demand” profiles (i.e., the difference between the demand and the local generation at the point of connection) will substantially increase. Therefore, the distribution system operator will need to adapt to such paradigm shift to ensure the reliable and secure operation of the grid.

As part of AISOP project, within the first reporting period, the tasks within the building blocks of such an “operational planning” framework for future distribution systems were elaborated. The framework is envisioned to be performed on intra-day and day-ahead timescales. The list of these tasks can be summarised as:

- Voltage control (distributed or decentralised),
- Online security assessment,
- Assessment of available flexibility,
- Assessment of network configuration changes (switches, tap changer-equipped substation),
- Assessing load (and *internal* flexibility) controls: ripple control, load shifting,
- Additional component monitoring and maintenance,
- Assimilating data from smart meters and grid sensors,
- Sustaining scarcity / autarky.

The relevant applications of the above-listed tasks can be summarised as follows:

- DSO congestion management and investment deferral,
- DSO: curative congestion management,
    - Day-ahead (or x-hour-ahead) preparation for probable events and preparing the steps – based on forecasts: weather, solar generation,
    - Feeder reconfiguration: emulating (n-1) redundancy,
- Operational risk management, including FLISR,
- Data assimilation and information security,
- DSO voltage management,
- Forecasting, including of new loads (i.e., HP, EV charging) and solar generation
- Coordinating, designing (or helping to design) market or tariff mechanisms
- DSO-DSO interactions
- TSO-DSO interactions: data exchange, coordination of utilization of resources in distribution, providing services (e.g., Redispatch 2.0 in Germany: DSO contributing to redispatch)

This list can be expanded based on our interactions with industrial partners and we are in the process of defining data and ICT requirements for such process.

### 4.3.2 Definition of digital process twin in operational planning

The vision for a “digital process twin” consists of identifying

- The tasks that can be digitally represented,
- The tasks that can be automated,
- The decision space of the DSO for a selected use case,
- The characteristics of the grid, and
- How much the human-in-the-loop tasks can be reliably reduced.

Further elaboration of such a “digital process twin” and entailing ICT requirements is a work in progress and will be described in upcoming deliverables.

## 4.4 Project initiation

The following initiation activities were completed during the reporting period:

1. A consortium agreement and IPR management approach were concluded,
2. AISOP logo and branding were defined,
3. Website was created and implemented,
4. A project factsheet was created,
5. Various ERA-NET reporting requirements were satisfied, including creation of a profile on the EXPERA platform,
6. A project handbook was initiated, including quality plan, data management plan, and risk management plan.
7. A technical advisory board is being formed. **BKW (Yamshid Farhat)** and **Elia Grid International (Lavjit Singh)** confirmed their participation. 1-2 more member(s) is/are expected to join in Germany, to be arranged by our partner, Zedo, in coordination with industrial partner, ASEW (Netzwerk von Stadtwerken für Stadtwerke).
8. AISOP project is represented in the annual ERA-Net Joint Programming Conference Smart Energy Systems in 18 – 22 October 2022.

National and international project partners meet regularly and established project operating procedures (communication approaches, document storage etc). In summary:

- Quarterly meetings are held with the participation of all partners,
- Academic partners in Switzerland (HSLU & FEN) have monthly technical meetings with the participation of all researchers,
- Swiss coordinators (Ben Bowler and C. Yaman Evrenosoglu) hold bi-weekly meetings,
- Swiss coordinators hold monthly synchronization meetings with the German coordinators (Ulf Häger and Razieh Balouchi),
- A Teams space is created, hosted by HSLU, for documenting the progresses and for communication among the project partners.

# 5 Evaluation of results to date

The project has been running for six months. No deliverables, milestones or KPI’s were due for evaluation during the reporting period, therefore this section is not completed.

# 6 Next steps

During the next reporting period:

- The definition and requirements of the digital process twin will be completed, along with the data requirements and processes for accessing data by the digital process twin,
- The use cases and concepts for LV situational awareness will be fully developed, considering edge and embedded devices, and the heterogenous data sources described in previous sections,
- An AI-based model for grid situational awareness will be proposed and applied to offline simulations,
- Fault detection and classification research will be progressed and is expected to be completed in the reporting period, ahead of the dates proposed in the research plan,
- Work on the risk analysis framework will progress, leading to initial prototypes of the risk analysis tool and a full definition of the risk quantification approach,
- Development of the dynamic tariff implementation will progress, based on data inputs from other modules.

Communication, dissemination, and exploitation activities will continue, including release of biannual newsletters, participation in ERA-NET activities, and publishing of news items and deliverables on the project website.

# 7 National and international cooperation

In person and virtual meetings were conducted between Swiss and German partners during the reporting period. A consortium agreement was successfully concluded.

# 8 Communication

This section only applies to flagship projects.

# 9 Publications

No scientific publications were created during the reporting period.

# 10 References

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# 11 Appendix

No appendices are provided with this report.