# OPENTUNITY asset and planning developments (v2)

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DSO, Advanced Asset Management, Anomaly Detection, Investment Deferral, Non-Technical Losses detection, Investment Planning, User Interface, User Manual

# Executive Summary

This deliverable presents the latest developments carried out within the OPENTUNITY to ensure a proper long-term management of the operations and assets under the control of DSOs and TSOs. A suite of modules has been developed to provide advanced capabilities for asset management and distribution system planning, aiming to improve the reliability of the equipment and the overall resilience of the system. These modules extend the functionality of existing SCADA and AMI systems, taking advantage of the great amount of data that are available from control centers and field devices.

The long-term asset management module utilizes statistical reliability models and machine learning (e.g., XGBoost) to predict the end-of-life and failure probability of smart meters, reducing inspection costs and enabling data-driven replacement strategies. The short-term asset management module focuses on real-time monitoring and anomaly detection, to assess the health status and issue timely alerts for critical grid assets, such as transformers. The module supports a prediction of top-oil temperature that can facilitate system operators in identifying critical operating conditions that could lead to equipment failure. Both modules utilize data from SCADA, AMI, as well as historical logs to enhance the system's reliability through early-stage malfunction detection.

Additionally, a non-technical losses detection module has been developed to identify energy theft and unregistered consumption. This module uses hybrid machine learning and network analysis techniques, enabling the accurate detection of anomalies and illegal connections.

The network planning tool offers Distribution System Operators (DSOs) an intelligent, flexible platform for long-term planning of electrical distribution networks. It addresses multi-year planning problems using advanced optimization techniques (Mixed-Integer Linear Programming 'MILP'/ Mixed-Integer Second-Order Cone Programming 'MISOCP') solved with GUROBI, enabling DSOs to simulate alternative grid strategies.

The DSO user, via the developed UI, provides information to the network planning tool, such as the system topology, load curves, and equipment data that should be considered in future upgrades. The user also defines specific settings for the analysis that the tool performs, such as the location and capacity of future PV installations, the future horizon in years to run the analysis, load growth rate, etc. The optimization problem also considers constraints related to the flexibility offered by the demand and Renewable Energy Sources (RES). The formulation of the optimization problem (along with the relevant objectives/constraints), the identification of data availability across pilot sites, the development of supporting functions and the creation of the underlying database have been described in D5.3. This deliverable focuses on describing the tool's user interface, which allows scenario testing based on user-defined goals such as investment deferral, cost minimization, and RES maximization.

This deliverable emphasizes the presentation of the latest version of the User Interfaces that have been developed for the WP5 modules and tools. Since the design and implementation aspects of each module were documented in D5.3, the present document (D5.4) highlights the functional features of each module and provides a detailed User Manual to guide the tools/modules' users in deploying and operating them effectively.

# Copyright statement

# 1 INDEX

# List of Figures

# 2 INTRODUCTION

## 2.1 Purpose of the document

The purpose of this deliverable is to provide a clear explanation about the developments of Task 5.4 "Advanced Asset Management" and Task 5.5 "Network Planning and Investment deferral from optimal use of flexibility". A short description is provided for each module, followed by a detailed User Manual for the relevant User Interface.

## 2.2 Scope of the document

The scope of the first version of this deliverable (D5.3) has focused on the technical description of the different modules developed under Task 5.4 "Advanced Asset Management" and Task 5.5 "Network Planning and Investment deferral from optimal use of flexibility". In deliverable D5.3, the description of the design and implementation of the modules is provided, alongside preliminary mock-ups of the relevant User Interfaces.

This deliverable (D5.4) focuses on displaying the functionalities of the final version of the modules and their User Interface, alongside a detailed User Manual for the developed modules. In this respect, the design and implementation aspects of each module are not explained, since they are available in D5.3.

## 2.3 Structure of the document

Apart from this introductory section, the current document is structured as follows:

- A summary of all the developed technologies that provide valuable functionalities for system operators, is provided in Section 3.
- In Section 4 "TECHNOLOGIES" a short description is provided for each developed module, followed by a detailed user manual.
- Concluding remarks are presented in the "Conclusions" section.

# 3 SUMMARY OF THE DEVELOPED TECHNOLOGIES

Within the scope of T5.4 and T5.5, a suite of tools has been developed to enhance power system operations, specifically targeting advanced asset management and distribution network planning. The tools are organized into modules, each addressing specific needs of system operators with the aid of machine learning and data analytics.

The **Long-Term Asset Management** module focuses on predicting the end-of-life (EoL) of smart meters, a relatively under-researched aspect of digital infrastructure. Instead of relying on costly and labor-intensive manual inspections, this module utilizes data from Advanced Metering Infrastructures (AMI) and failure logs. It generates EoL curves using statistical models like Weibull and Normal distributions to forecast equipment failures based on historical age and operational data. A submodule employing XGBoost machine learning models analyses trends leading up to failures to identify high-risk meters, estimating their failure probabilities by combining data-driven insights with equipment-specific reliability profiles.

The **Short-Term Asset Management** module addresses the health of critical infrastructure, particularly high-power transformers. This module uses real-time sensor data to detect early warning signs such as abnormal gas concentrations and oil temperature deviations, leveraging Dissolved Gas Analysis (DGA) techniques and bushing condition assessment according to relevant IEEE standards. Machine learning models provide real-time alerts performing anomaly detection at top-oil temperature and six-hour top-oil temperature forecasts for short term assessment of equipment condition. The system is designed to help operators make informed, proactive maintenance decisions through two interfaces — one for immediate alerts and another for short-term forecasts.

The **Non-Technical Losses Detection** module combats energy theft and unbilled consumption using a hybrid approach of machine learning and network analysis. ETRA's ETER software utilizes advanced models, including autoencoders and Convolutional Neural Networks (CNNs), to analyze weekly energy consumption data for anomalies indicative of fraud. For detecting illegal, unregistered connections, the system applies thermal loss estimation and power flow analysis to identify mismatches between actual and computed losses. The tool is implemented in Python with machine learning frameworks like Keras, PyTorch, and TensorFlow, and uses Panda Power for network modelling. It is deployed using Docker containers with InfluxDB and MongoDB for scalable, efficient fraud detection.

The **Network Planning Tool** aids DSOs in strategic infrastructure development by optimizing both investment and operational decisions. It applies fast load-flow algorithms and time series clustering to rapidly simulate and evaluate different scenarios based on objectives such as cost reduction, renewable energy integration, and investment postponement. Utilizing mathematical programming techniques, including mixed-integer linear and second-order cone programming, the module solves complex planning problems via the GUROBI optimizer. An interactive interface allows DSOs to input grid topology and demand data, enabling quick analyses and data-driven decision-making for future network configurations.

# 4 TECHNOLOGIES

## 4.1 Long-Term Asset Management

### 4.1.1 Description

The **Long-Term Asset Management tool** is a predictive maintenance solution designed to help power system operators estimate the remaining useful life of digital grid components, with a particular focus on smart meters. Traditional maintenance strategies typically target core equipment like transformers and substations, but as the grid digitalizes, attention must also turn to auxiliary digital devices such as smart meters. These devices are widely deployed, often numbering in the millions, and their failures—although individually less critical—can accumulate into significant operational and financial disruptions. Moreover, because of their sheer volume and distributed nature, inspecting smart meters manually is costly and time-consuming. This tool addresses that challenge by automating risk assessment through predictive analytics.

At the core of the tool is the generation **of EoL** curves, which are statistical models that estimate the likelihood of failure for each meter brand over time. These curves are built using historical data collected from both failed and operational smart meters, considering attributes such as installation age, operational stress, environmental conditions (e.g., temperature and humidity), and grid disturbances. The tool applies reliability modelling techniques, including Weibull and Normal distributions, which are widely used in failure rate analysis, to forecast how many devices of a certain model or batch are expected to fail within a specific period. This enables asset managers to plan replacements more strategically, avoiding reactive maintenance and minimizing service disruptions.

In addition to statistical modelling, the tool includes a **machine learning submodule** that identifies meters most likely to fail in the near future. It uses pre-failure operational data to train models—most notably XGBoost, a high-performance decision tree-based algorithm—capable of detecting subtle warning signs before actual breakdowns occur. The algorithm evaluates features such as abnormal usage patterns, power quality issues, and temperature anomalies to assign a probability of failure to each individual meter. These predictions allow operators to prioritize inspections or replacements based on risk rather than age alone, significantly improving resource efficiency.

By combining traditional statistical reliability models with modern machine learning, the Long-Term Asset Management tool provides a robust framework for predictive maintenance. It empowers utilities to move from reactive to proactive asset management, reducing costs, increasing system reliability, and supporting smarter deployment strategies for large-scale digital infrastructure like smart meters.

Figure 1 illustrates a data flow architecture for managing and analyzing smart meter data. Measurement data from the AMI is sent daily via SFTP to a server, which then stores the data in a centralized database. Separately, users upload static smart meter data in CSV format, which contains non-dynamic information such as meter IDs, installation dates, and locations. This static data is combined with the measurement data within a user interface (UI) that facilitates data integration and analysis. The UI processes this combined dataset and provides users with key outputs, including information for calculation of KPIs (e.g. accuracy on the condition assessment of smart meters), failure forecasts, identification of critical smart meters, and end-of-life curves. This setup enables users to gain actionable insights into smart meter performance and reliability, supporting predictive maintenance and informed decision-making.

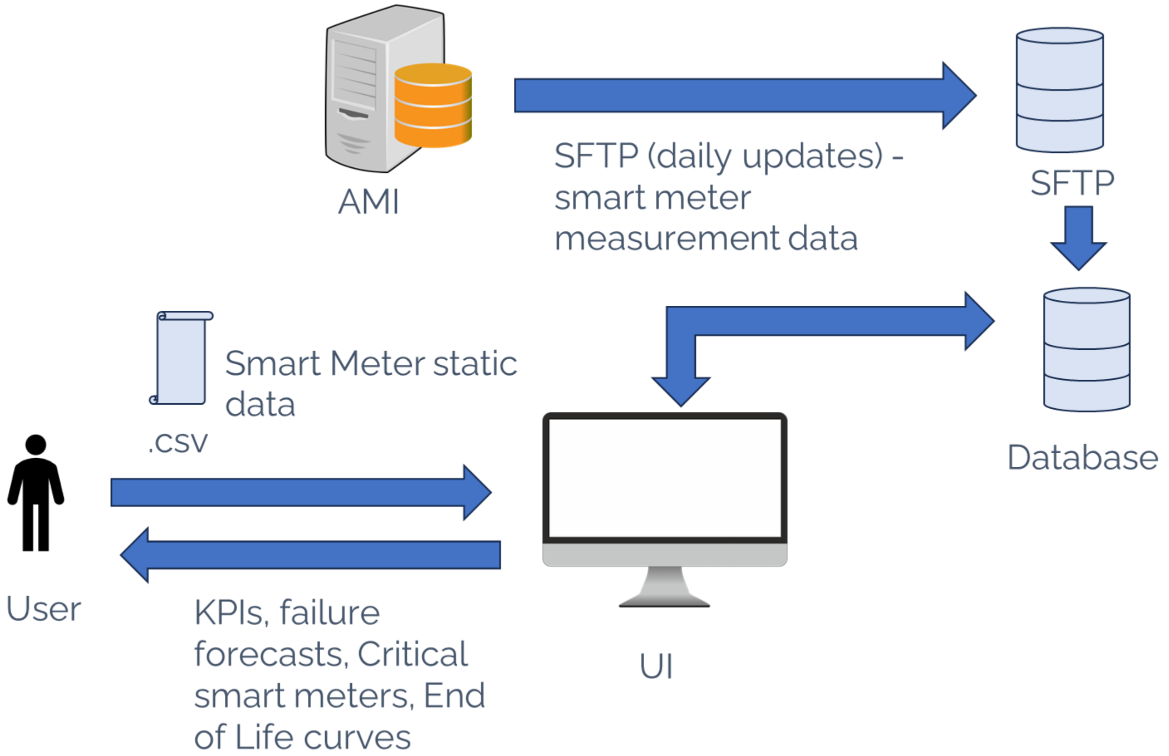



*Figure 1: Structure of the long-term asset management module*

### 4.1.2 User's Manual and Interface.

The **Long-Term Asset Management** tool is designed to operate in greater time intervals (considering the next couple of months to multiple years), informing the system operator of the estimated number of upcoming smart meter failures and the criticality of smart meters.

When the user logs for the first time only the home tab called "Import Smart Meter data & Failure logs" is presented. In this tab of the Long-Term Asset Management platform, the user is guided through the initial step of importing smart meter installation and failure data. The interface is designed for ease of use, allowing the user to drag and drop a CSV file or browse their system to upload it. This is the primary step for enabling downstream analytics such as failure forecasts and end-of-life modelling.

When the file is uploaded the user is notified whether the file format is correct or not. In Figure 2 the case of a wrong input file is presented. The system automatically validates the file structure and flags an error, indicating that a required column, *installation_date*, is missing. This feedback is clearly presented in a red banner, helping the user quickly identify and correct the issue before proceeding.

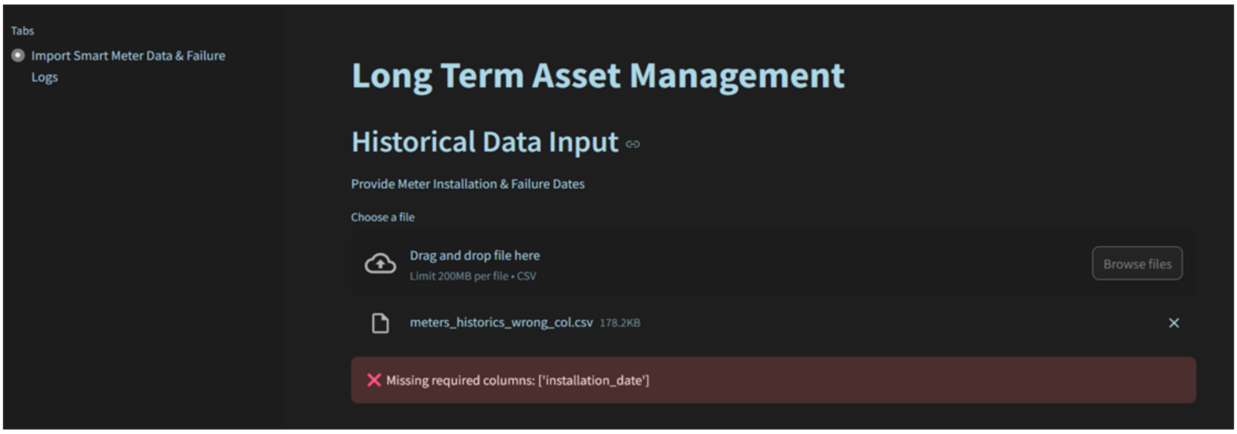



*Figure 2: Incorrect file upload of smart meter data*

In Figure 3, the user successfully uploads a corrected file named meters_historics.csv. A green confirmation banner confirms that the file has the correct format, and the contents are displayed in a tabular preview. The table includes key fields such as smart meter ID, delivery point ID, brand, model, installation date, substation, feeder number, and customer type. At the bottom of the screen, the platform indicates that it is generating End of Life curves based on the uploaded data, showing that the file has been accepted and analytical processing is underway. Together, these views demonstrate a robust and user-friendly data intake and validation process.

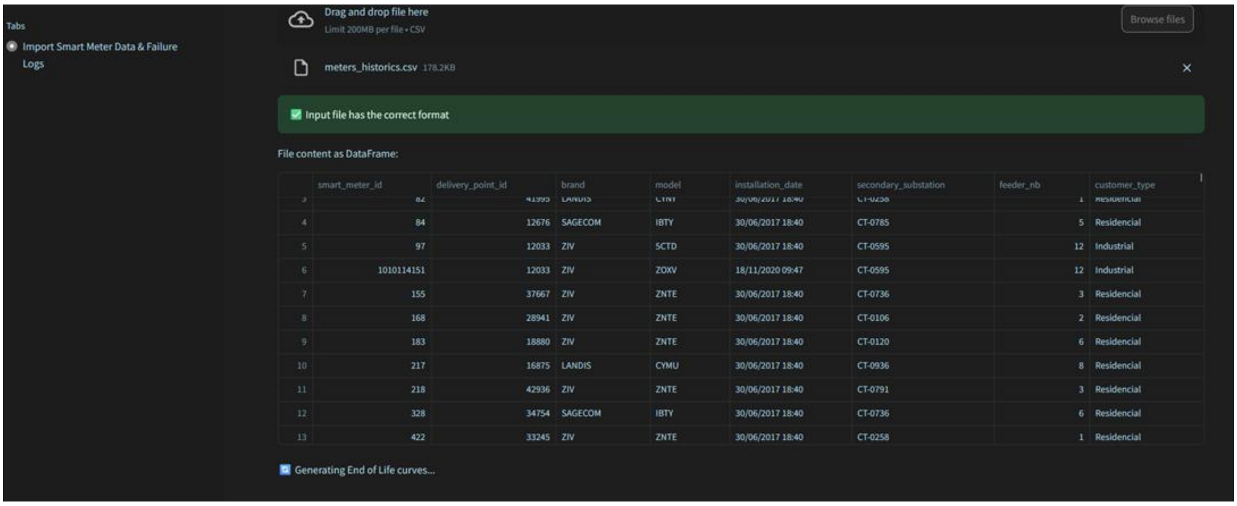



*Figure 3: Correct file upload of smart meter data.*

The input CSV file for smart meter data must follow a specific format to be accepted by the system. The file should be encoded in UTF-8 and include the following required columns: *smart_meter_id* (integer), *delivery_point_id* (integer), model (string), and *installation_date* in the format dd/mm/yyyy hh:mm:ss. Additionally, the file may optionally include the *secondary_substation* (string) and *feeder_nb* (integer) columns. These optional fields, while not mandatory, can enhance the depth of analysis if provided. Ensuring the correct structure and format of this data is essential for successful upload and accurate processing.

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | smart_meter_id | delivery_point_id | brand | model | installation_date | secondary_substation | feeder_nb |
| 2 | 51 | 27173 | LANDIS | CYKY | 30/06/2017 18:40:00 | CT-0107 | 2 |
| 3 | 78 | 6734 | ZIV | ZNTE | 30/06/2017 18:40:00 | CT-0785 | 7 |
| 4 | 81 | 31325 | SAGECOM | IBTY | 30/06/2017 18:40:00 | CT-0315 | 1 |

*Figure 4: Meter data file format example*

Once the smart meter data has been successfully uploaded and validated, the user gains access to two additional tabs: **End of Life Curves Dashboard** and **Critical Smart Meters Dashboard**. These dashboards provide advanced analytics and visual insights derived from the uploaded smart meter data.

In the **End of Life Curves Dashboard**, the user can explore the failure behavior of different smart meter models over time. The interface allows users to filter by **smart meter brand** and **model**, enabling focused analysis on specific device groups. When historical failure data are available for the selected group, the platform generates and displays an **End of Life curve**, showing how the failure rate progresses over the lifecycle of the meters (Figure 5).


*Figure 5: End of Life curves presentation*

An important feature of this dashboard is the ability to **compare different models** based on how quickly they approach a 20% failure rate, providing a clear, quantitative view of relative reliability. To compare the models at least 5% of their installed population should have failed to have enough asset failures to compute the end of life curves.


*Figure 6: Smart meters models life expectancy horizon.*

Finally, in the End of Life Curves Dashboard, users can **select a time horizon measured in months** to view **predicted failures** that occur for the entire installed population within the smart meter brands.

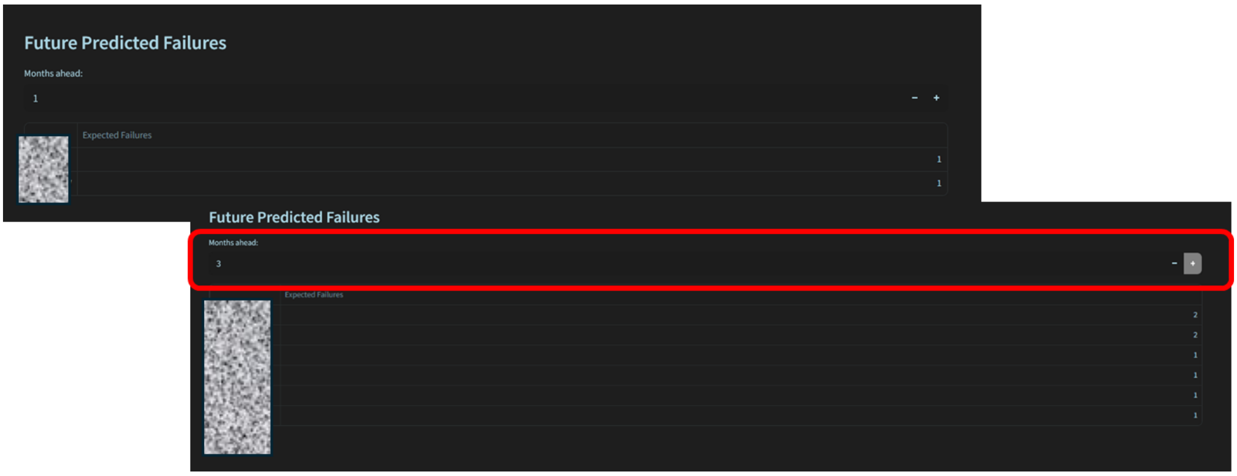



*Figure 7: Smart meters models future number of expected failures per smart meter model.*

The Critical Smart Meters Dashboard leverages advanced machine learning techniques to identify high-risk smart meters within the network. Specifically, it uses an XGBoost model trained on the most recent 30 days of smart meter measurement data to predict which meters are likely to fail soon. This enables utilities to act preemptively, minimizing downtime and service disruptions.

In this dashboard, users are presented with a list of Critical Smart Meters—those with a predicted failure probability greater than 70%. Specifically, the meter point ID, the failure probability, the model and substation (if provided) are presented (Figure 8). This actionable insight allows maintenance teams to prioritize interventions based on real-time risk.

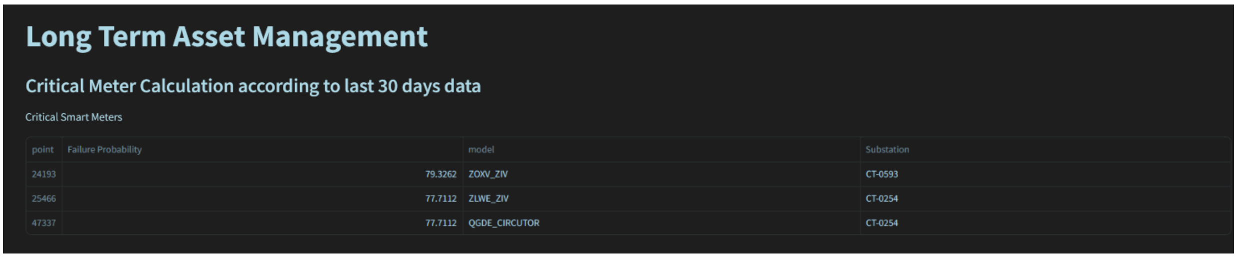



*Figure 8: Critical smart meters models visualization.*

Additionally, the dashboard displays XGBoost attribute importance (Figure 9), offering transparency into the factors driving the model's predictions, such as communication failures, and energy consumption metrics.

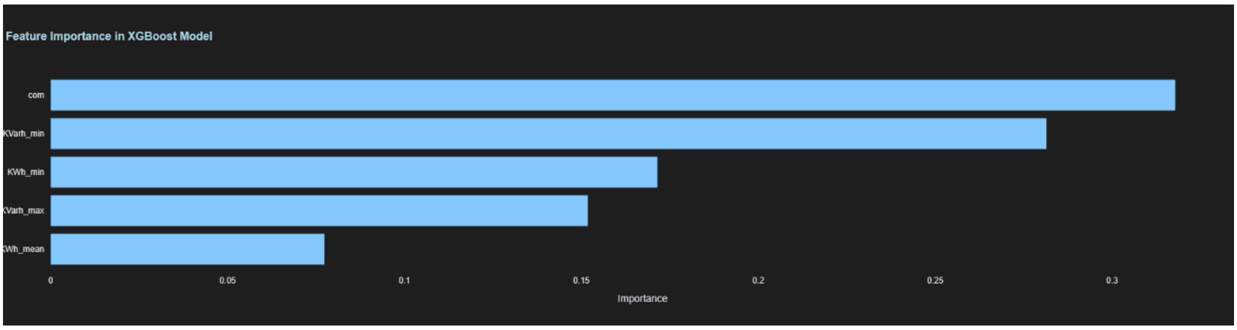



*Figure 9: XGboost feature importance visualization.*

To support spatial planning and resource allocation, the dashboard also supports a visual distribution of critical meters by substation, along with a map-based representation that provides geographic context. This helps operators quickly pinpoint vulnerable areas in the grid and coordinate field responses efficiently. To support this functionality the user must upload in the meter data a mapping of the smart meters to secondary substations and in the UI in the critical smart meters tab the substation coordinates file. The final map representation has all the secondary substations, highlighting in red the substations with critical smart meters. By clicking on the pin point of the substation, the substation name appears as well as the number of critical smart meters,

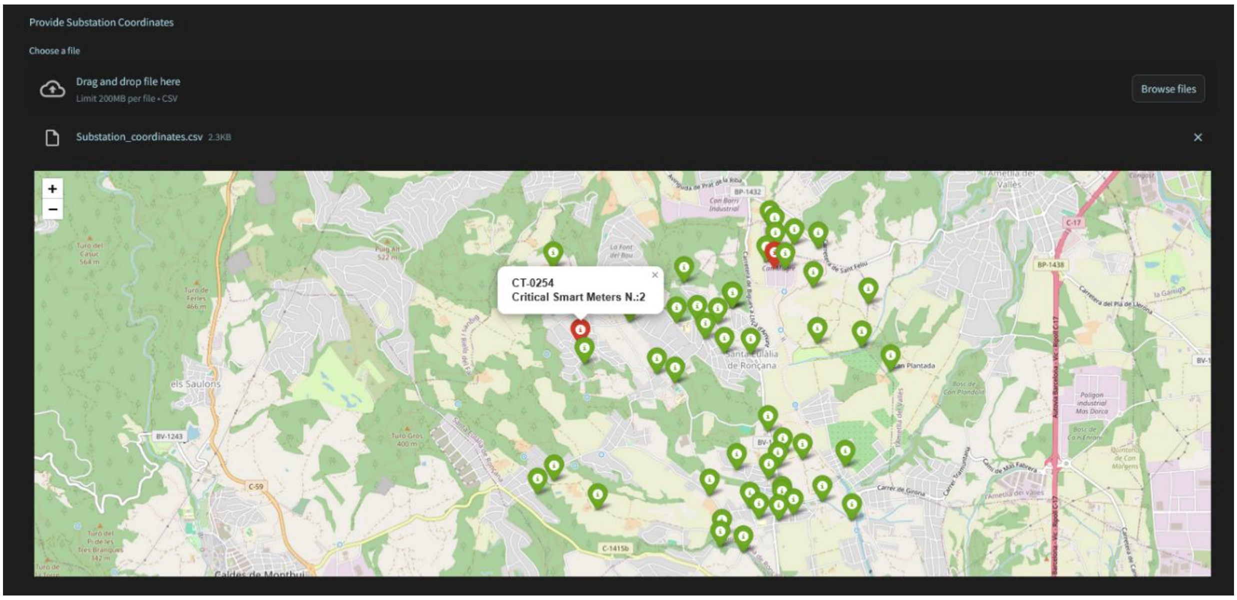



*Figure 10: Critical smart meter representation on map.*

The Substation Coordinates File must follow a specific format to ensure seamless integration with the smart meter data and accurate geographic mapping. The file must be encoded in UTF-8 and contain the following columns: ID, NAME, LAT, and LON (Figure 11). The ID field must exactly match the substation identifiers used in the smart meter dataset to allow proper linking. The NAME column should be a string representing the substation's name. The LAT and LON fields must be floating-point values that define the geographic coordinates of the substation, using the EPSG:4326 coordinate reference system (standard GPS latitude and longitude). Adhering to this structure ensures that substations are correctly mapped and aligned with the smart meter infrastructure in the visualization tools.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | ID | NAME | LAT | LON |
| 2 | CT-0106 | E.T SAGRE | 41.65573 | 2.224907 |
| 3 | CT-0107 | E.T RIERAL | 41.6391 | 2.23799 |
| 4 | CT-0108 | P.T CA L'HI | 41.65913 | 2.236804 |
| 5 | CT-0112 | E.T SERRA | 41.63972 | 2.223849 |

*Figure 11: Substation coordinates file format.*

## 4.2 Short-Term Asset Management

### 4.2.1 Description

The **Short-Term Asset Management** tool is designed to operate within a near real-time context, offering predictions over the course of hours rather than months or years. Its purpose is to identify critical power system equipment — particularly transformers — that may be on the verge of failure. This early identification is important to mitigate potentially severe consequences such as equipment damage, service interruptions, or widespread outages. In the context of OPENTUNITY, the tool focuses on HV/MV and MV/LV transformers managed by Distribution System Operators (DSOs) and UHV/HV transformers used by the Greek Transmission System Operator (TSO), since these assets are essential to maintaining the integrity and stability of power networks.

More specifically, transformers are among the most valuable and vulnerable assets in a power system. They are subjected to a range of electrical, thermal, and mechanical stresses, and a single failure can trigger cascading effects across the grid. Transformer failures are most frequently associated with tap changers and windings, but they can also result from insulation breakdowns, bushing faults and leaks. Given their critical function and high replacement costs, conventional time-based maintenance strategies often fall short, either missing hidden developing issues or causing unnecessary maintenance interventions. Short-Term Asset Management addresses these limitations by using real-time condition monitoring and predictive analytics to ensure maintenance is timely and targeted.

The tool also leverages machine learning techniques, especially anomaly detection. Unlike traditional fault classification, anomaly detection builds a model of each transformer's unique operational behavior, allowing deviations from this "normal" baseline to be flagged even when there's no clear historical record of faults. This is especially useful for newer assets where insufficient fault data exists. Artificial Neural Networks (ANN) are applied to classify and interpret these deviations. By focusing on behavioral changes rather than just fixed thresholds, the system enhances predictive capabilities and reduces false positives. As a result, engineers can prioritize their attention on genuinely suspicious behavior, facilitating fault detection and improving the overall reliability of the grid.

Additionally, the tool supports functionalities like Dissolved Gas Analysis (DGA), a widely recognized method for detecting internal transformer faults. During fault conditions, specific gases—such as hydrogen ($H_2$), carbon monoxide (CO), and hydrocarbons like methane ($CH_4$), acetylene ($C_2H_2$), and ethylene ($C_2H_4$)—are generated inside the transformer. By analyzing the type and concentration of these gases, the system can identify not only whether a transformer is malfunctioning, but also what kind of fault may be occurring. The IEEE Standard C57.104 provides diagnostic frameworks such as the Duval Triangle and Roger Ratios for interpreting DGA data, and these are incorporated into the tool's decision-making process. This enables operators to receive real-time alerts and initiate preventive actions before a fault escalates into a critical failure.

Finally, the module supports a 6 hour ahead prediction of top-oil temperature that can be used as the thermal limit of the transformer and help system operators identify critical operating conditions in order to act proactively.

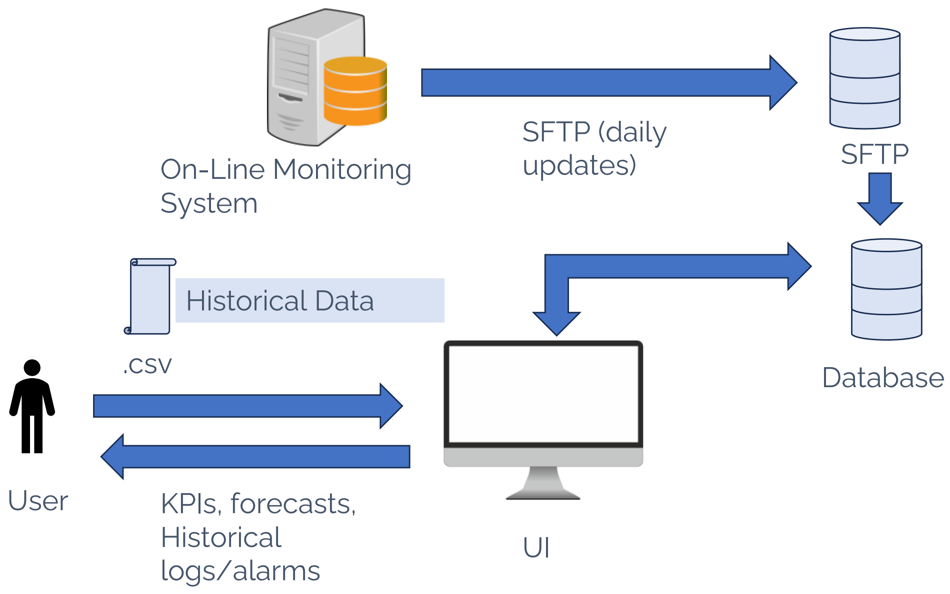



*Figure 12: Structure of the short-term asset management module*

The structure of this module is depicted in Figure 12. The user of the tool interacts with the UI by providing historical data and getting results, such as forecasts and historical logs/alarms, as well as information for the calculation of KPIs, like the accuracy on the assessment of asset's condition. The on-line monitoring system provides data, via SFTP, to the module's database which interacts with the UI.

### 4.2.2 User's Manual and Interface.

When the user logs in the short asset management module, they can view the available dashboards (Figure 13):

- Home
- Import Historical Logs
- Historical Data Dashboard
- Real Time Data Dashboard

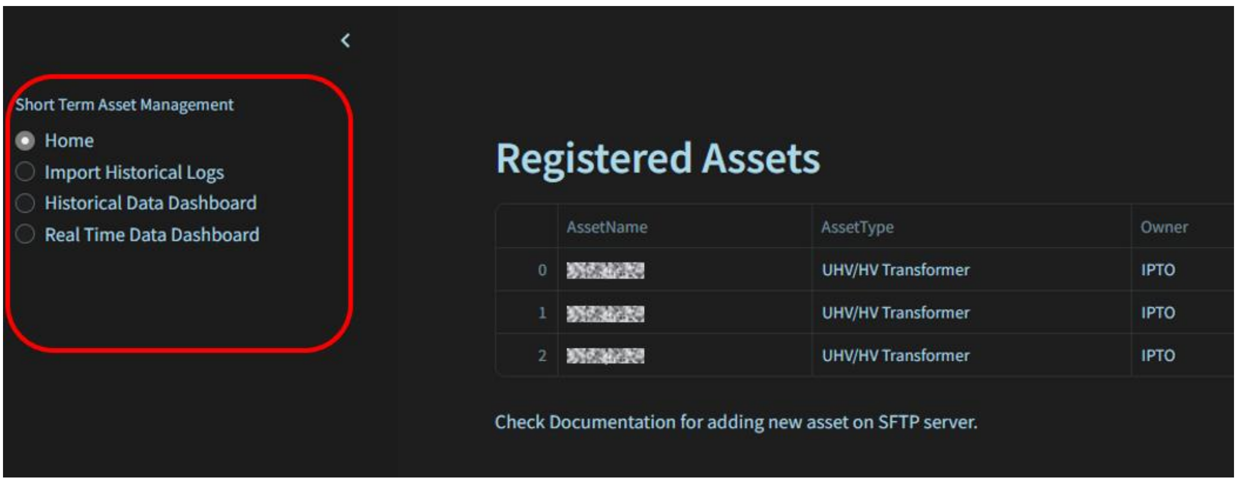



*Figure 13: General view of the dashboards*

#### 4.2.2.1 Home

The Home dashboard provides an overview of the registered assets. A table is presented, as depicted in Figure 14, with the following information:

- ID Number
- Asset Name: The name of the asset (within the short management tool)
- Asset Type: The type of asset e.g. UHV/HV Transformer
- Owner: The owner of the asset. For instance, in Figure 14, the owner of the relevant assets is the Greek TSO – IPTO.


*Figure 14: General view of the 'Home' dashboard*

At the bottom of the screen in Figure 14, the user is informed that they can check documentation for adding new asset(s) on the SFTP server. Specifically, the user should create in the SFTP server directory "transformer_olms_data" a dedicated folder, e.g. Asset 1, where the On-Line Monitoring System (OLMS) data of that specific transformer are uploaded. According to this folder name a new asset is generated in the tool database.

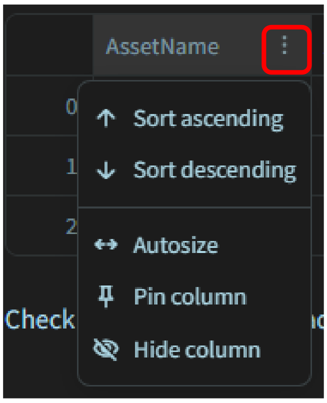
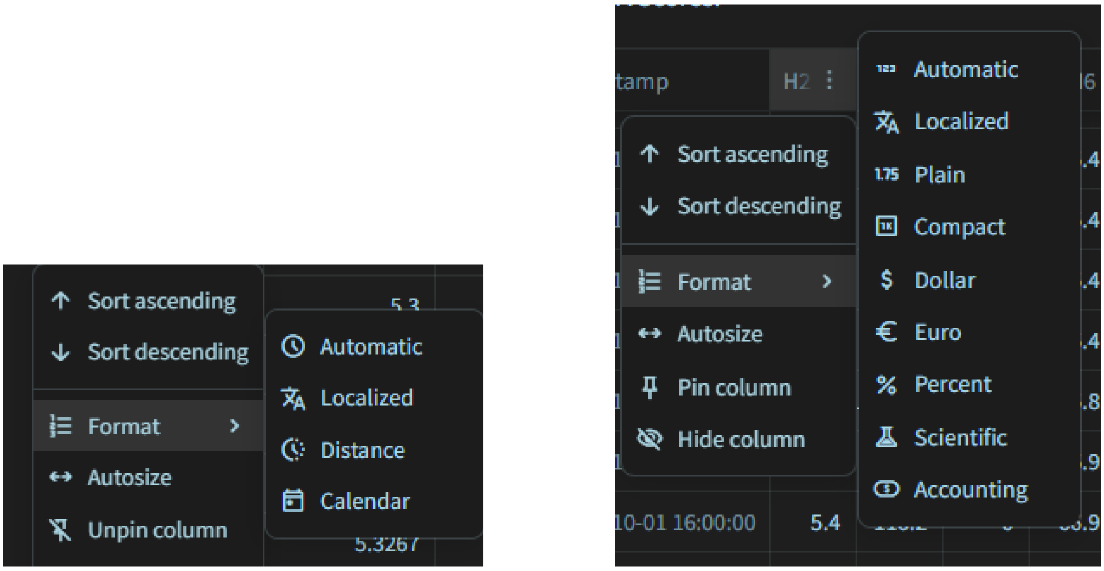



*Figure 15: Options when the user clicks on the three dots next to the name of each column*

Additional options are available when the user clicks on the three dots next to the name of each column, like sort in Ascending/Descending order, autosize, etc. (Figure 15). In case of dates or numerical values additional 'format' options are available as displayed in Figure 16. These options are available for all tables in all dashboards of the short-term management tool.




(a) (b)

*Figure 16: Format options when the user clicks on the three dots next to the name of each column: (a) date, (b) numerical value*

Options are also available for the user when clicking on the icons at the upper right side of the table (Figure 17):

- Download as csv: The user can download a csv file with the information of the table. The format of the csv file represents the table as depicted in Figure 17.
- Search: When the user clicks on the 'Search' icon, they can search for an asset name, an asset type, or an owner (Figure 18).
- FullScreen: The user can view the table in full screen. The user can exit the full screen mode, by clicking the icon 'close fullscreen'.

The abovementioned options are available for all tables that are presented on all dashboards within the short-term asset management module.

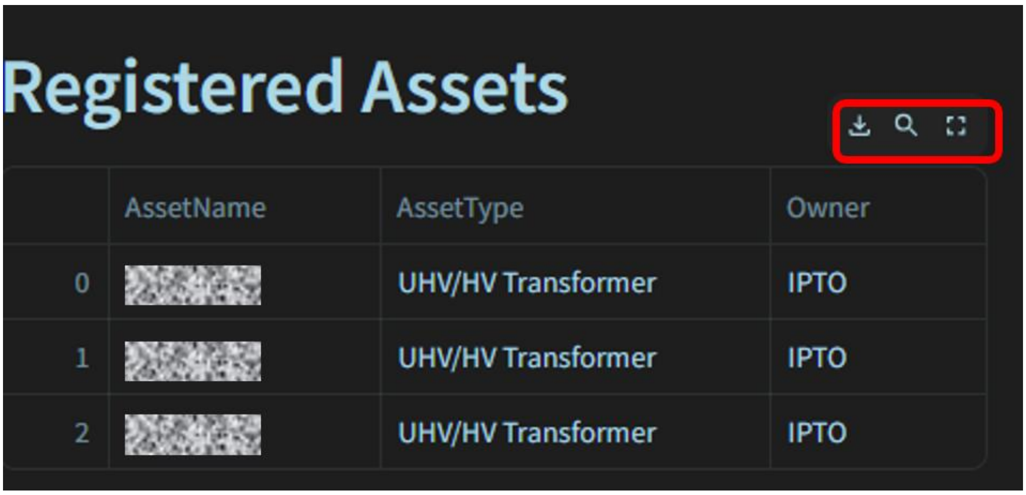



*Figure 17: Options for the table of the registered assets in the 'Home' dashboard*

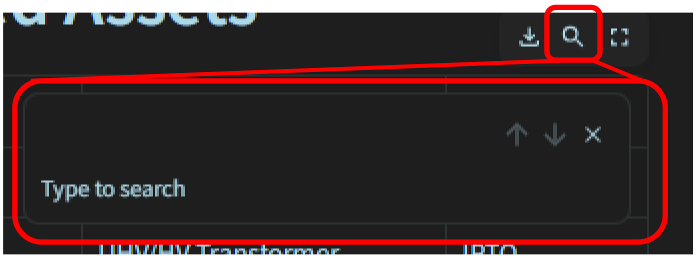



*Figure 18: The user can search for an asset name, an asset type, or an asset's Owner*

#### 4.2.2.2 Import Historical Logs

In the 'Import Historical Logs' dashboard the user is instructed to provide historical data. The user should first choose the asset for providing the relevant data, by clicking on 'Choose an option'. A drop-down list appears with the available assets, as depicted in Figure 19.

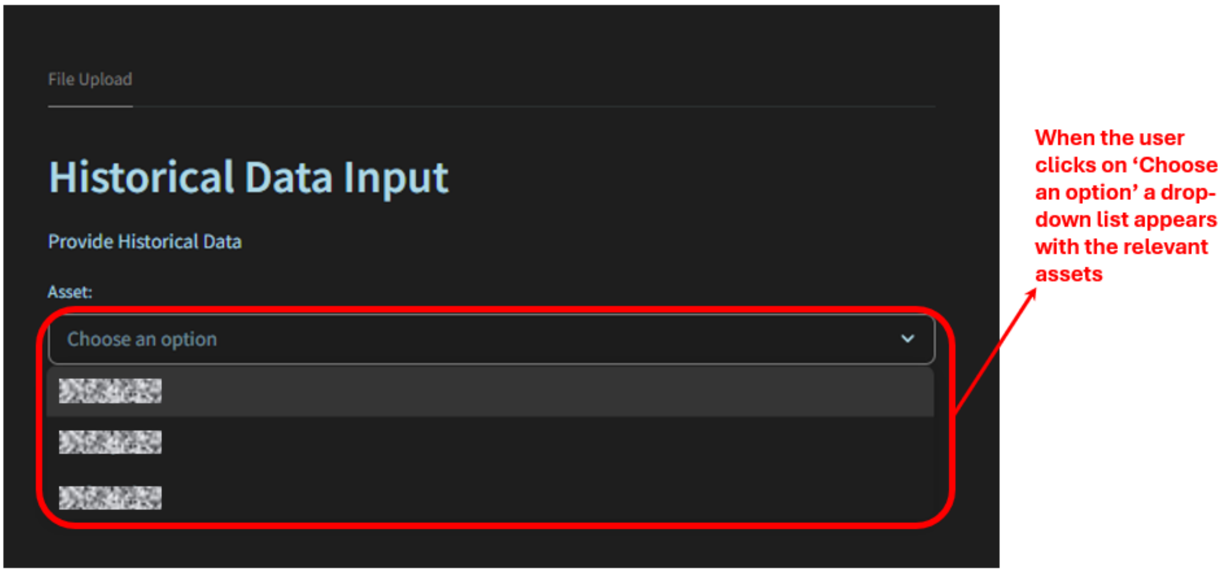



*Figure 19: Initial view of the 'Import Historical Logs' dashboard*

Afterwards, the user should choose a file with the available data. The file should be in csv format. There is a limit of 200MB per file as indicated in Figure 21.

The expected format of the relevant csv file is depicted in Figure 20. The relevant file should be in UTF-8 encoding. The format for the information to be included in the file should be:

- Timestamp: dd/mm/yyyy hh:mm:ss
- Measurement: string
- Value: float

| A | B | C | D |
|---|---|---|---|
| Timestamp | Measurement | Value | |
| 01/09/2023 05:14:00 | Current (phase R 40kV) | 67.4 | |
| 01/09/2023 05:14:00 | Current (phase S 40kV) | 69.3 | |
| 01/09/2023 05:29:00 | Current (phase R 40kV) | 79.8 | |
| 01/09/2023 05:29:00 | Current (phase S 40kV) | 81.3 | |
| 01/09/2023 05:44:00 | Current (phase R 40kV) | 77.7 | |

*Figure 20: Expected format for the Historical Data*

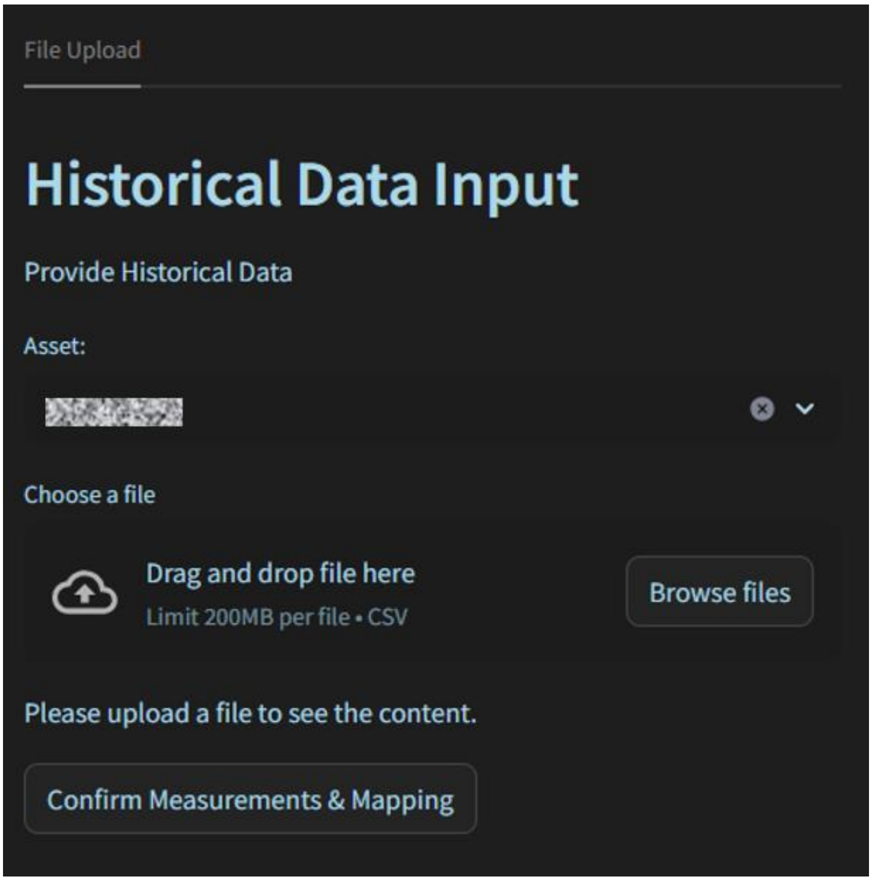



*Figure 21: 'Import Historical Logs' dashboard: the user should provide a file with the required data*

The user can either drag and drop the file in the relevant field in the screen or click on 'Browse files'. When the user has selected the file to be uploaded, a progress bar indicates the upload status (Figure 22).

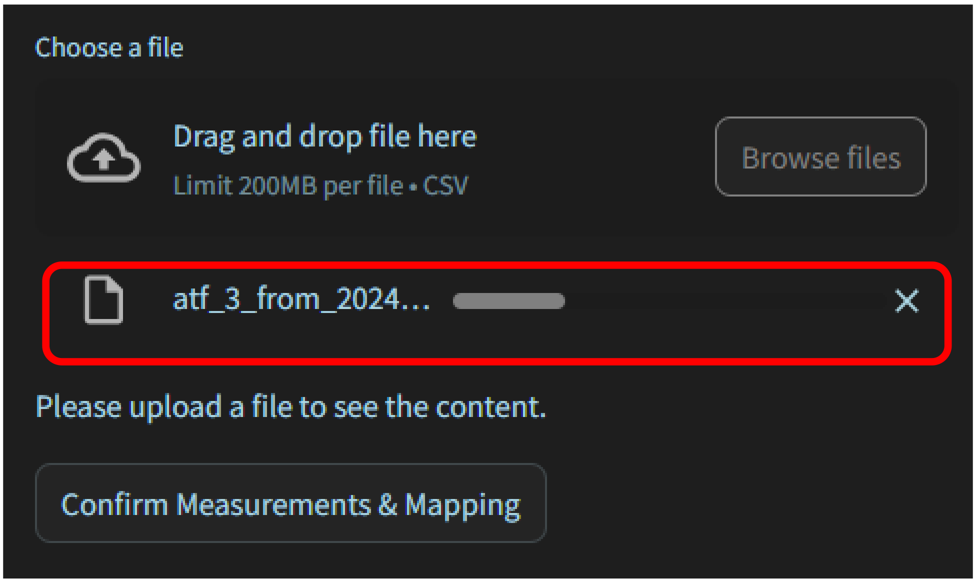



*Figure 22: A progress bar indicates the upload status of the file provided by the user*

After the file has been uploaded, the user has the option to delete it, in case they would like to upload a new one (Figure 23).

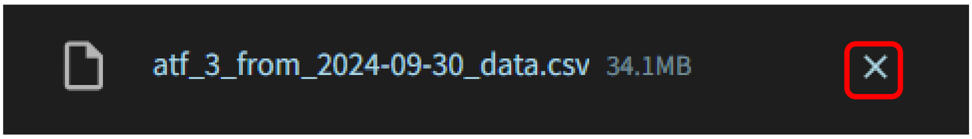
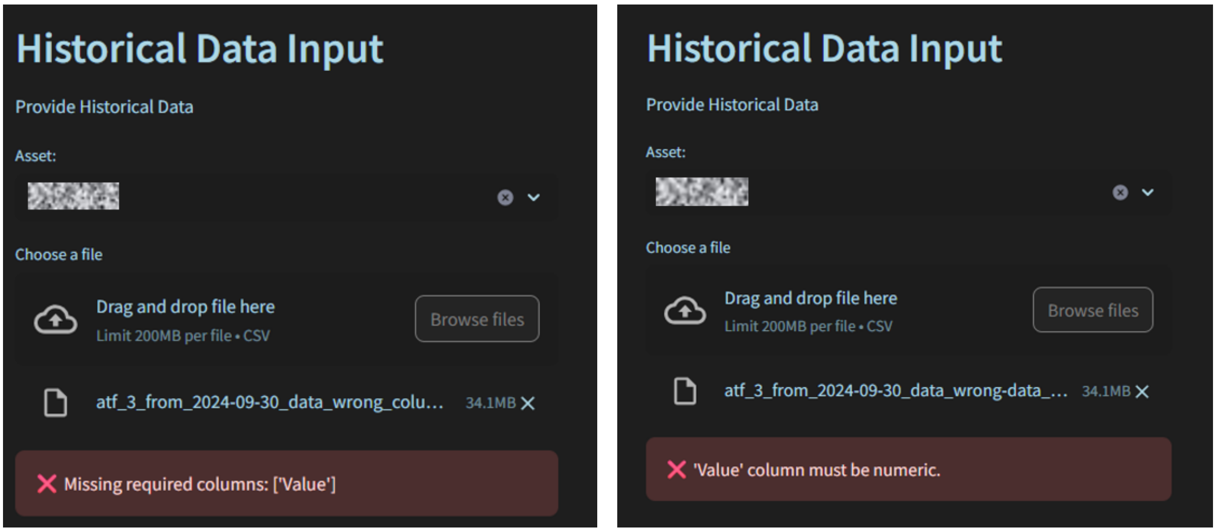



*Figure 23: The user has the option to delete the uploaded file*

In case the user uploads a file with incorrect format, a wrong-message appears as indicated in Figure 24.




*(a)* *(b)*

*Figure 24: The user has uploaded a csv file with incorrect format: (a) the file is missing required columns ['Value'], (b) the 'Value' column must be numeric.*

When the user has uploaded the csv file with the correct format, they are instructed to map the relevant fields, as depicted in Figure 25. There are 3 tabs for mapping:

- Measurement Mapping
- Bushing Mapping
- DGA Mapping

The whole range of On-Line Monitoring System data is presented to the user, however, if the whole range of measurements is not available, e.g. for distribution transformers, the user can select the option None.

For each field, a drop down list for the selected signals configuration appears when the user clicks on 'Choose an Option', where the user has to select the mapping of signal names to signals (Figure 26).

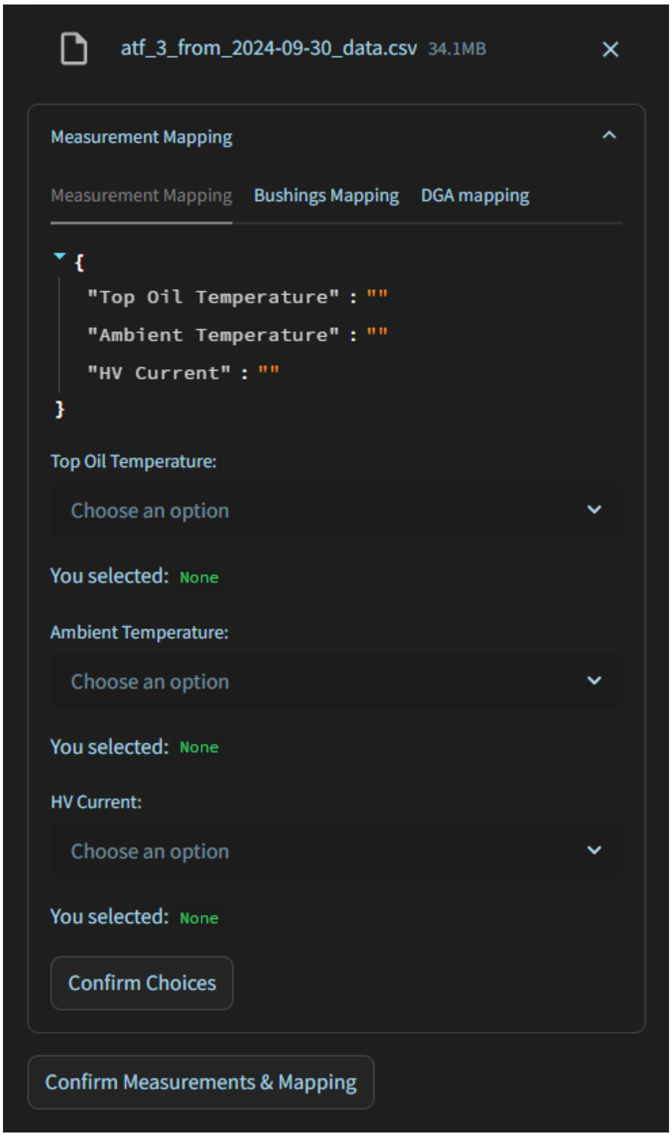



*Figure 25: When the user has uploaded the csv file with the correct format, they are instructed to map the relevant fields*

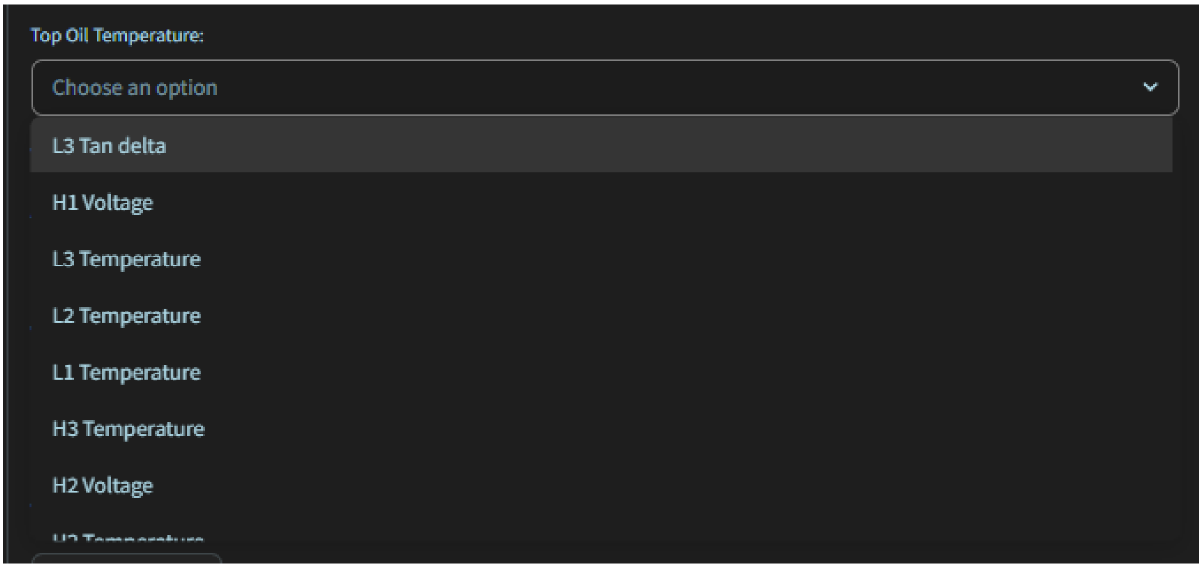



*Figure 26: Drop-down list that appears when the user clicks on 'Choose an option', in order to map the relevant fields.*

In the 'Measurements Mapping' Tab, the user should map or select Nan for the 'Top Oil Temperature', 'Ambient Temperature' and 'HV Current'.

In the 'Bushing Mapping' Tab, the user should map or select Nan for Capacitance HV1/HV2/HV3, Capacitance LV1/ LV2/ LV3, tand HV1/ HV2/ HV3, tand LV1/ LV2/ LV3.

In the 'DGA Mapping' Tab, the user should map or select Nan for H2, CH4, C2H2, C2H6, C2H4

The user should then click on the 'Confirm Choices' button, to confirm their choices (Figure 27). The mapping is presented to the user, as depicted in Figure 28.

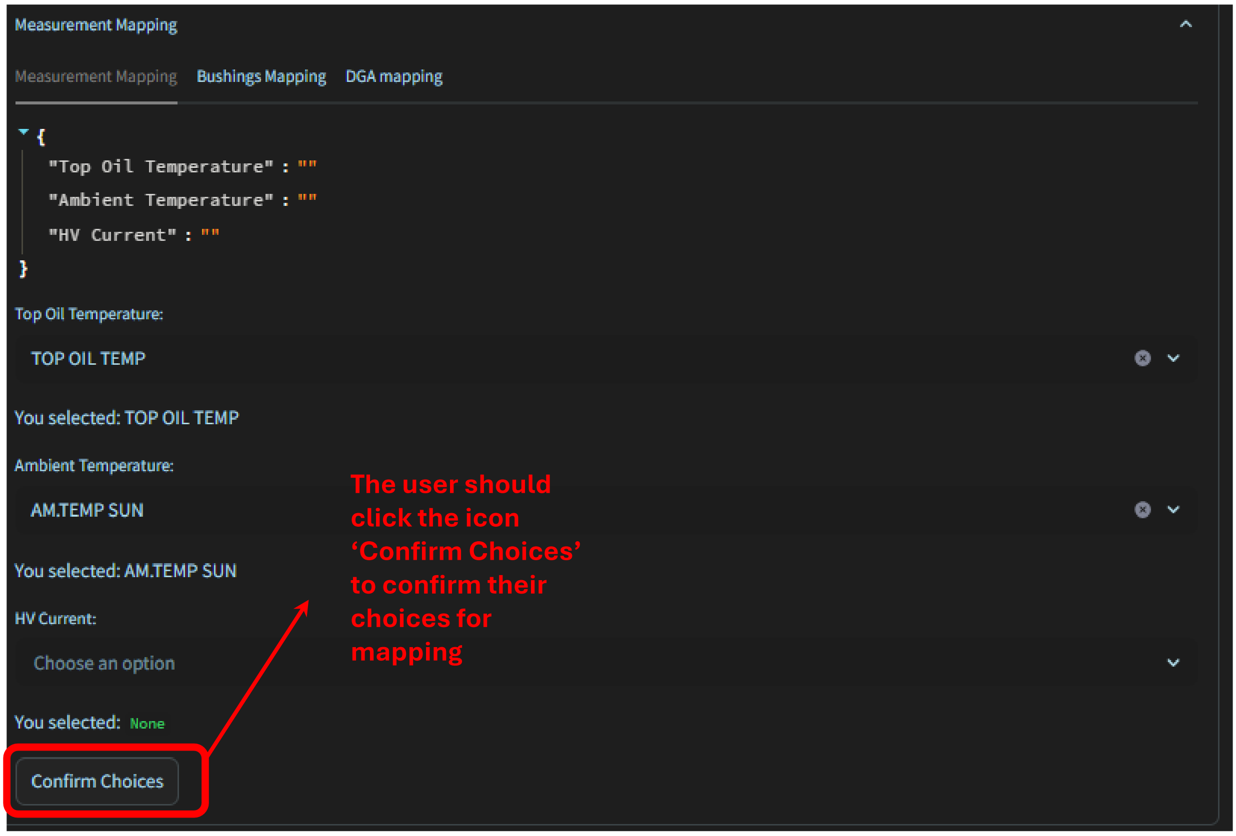



*Figure 27: Clicking on 'Confirm Choices', confirms the mapping choices and allows the user to proceed to the next step.*

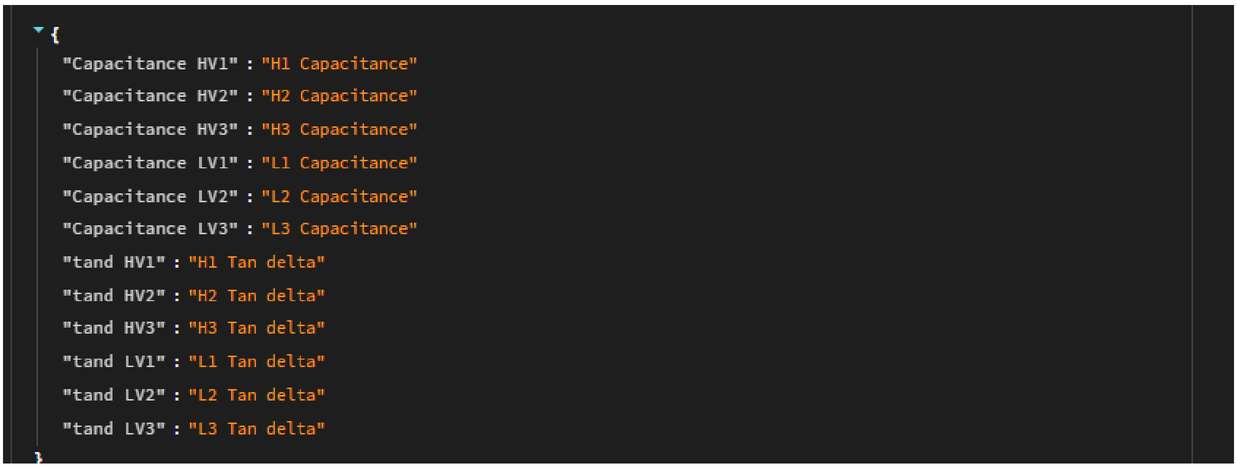



*Figure 28: The mapping is presented to the user*

Finally, the user should click on the 'Confirm Measurements & Mapping' icon, as depicted in Figure 29 to upload the measurements in the tool database and retrain the asset machine learning models.

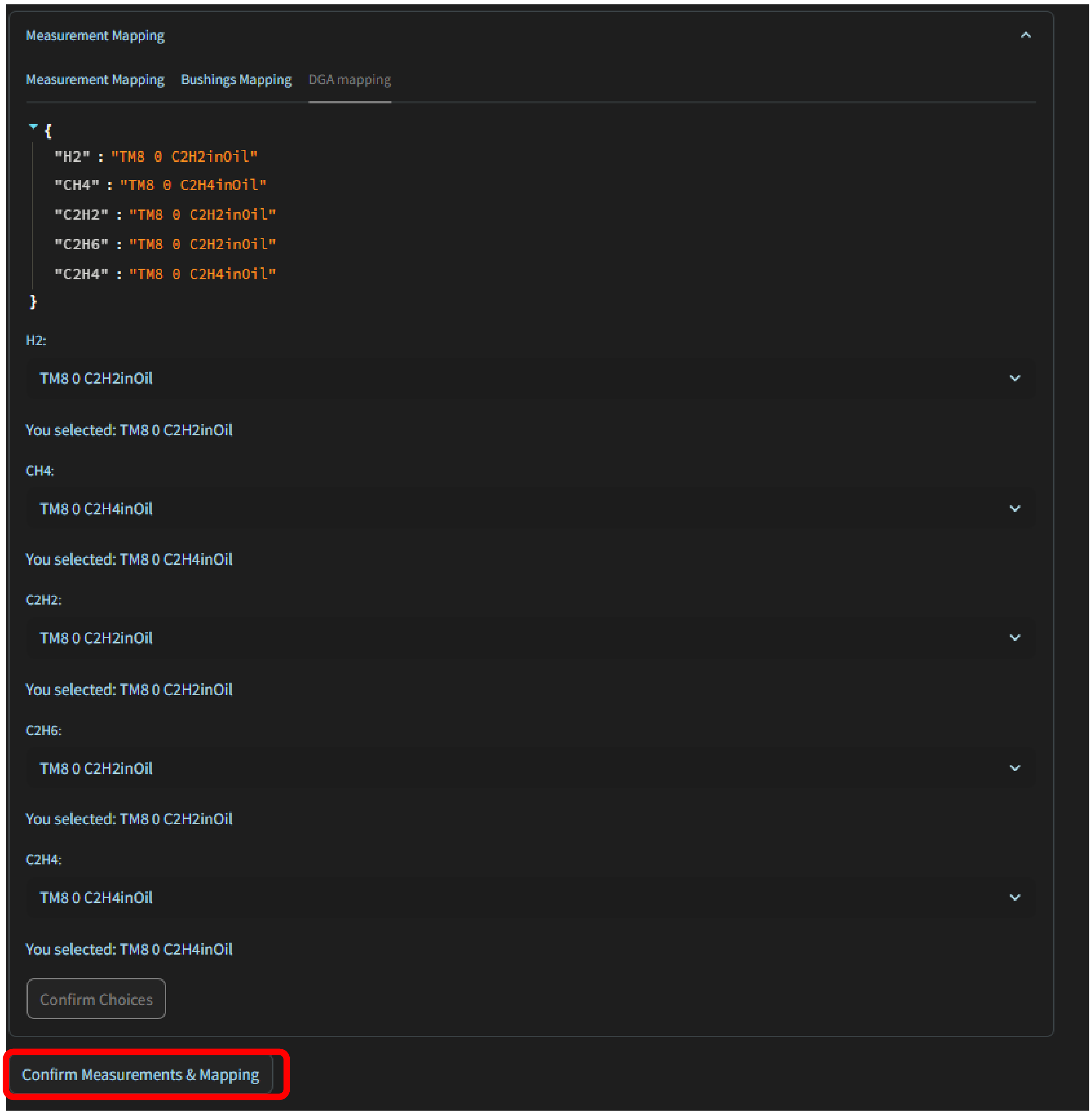



*Figure 29: The user should click on the 'Confirm Measurements & Mapping' icon*

#### 4.2.2.3 Historical Data Dashboard

In the 'Historical Data' dashboard, the user can view historical information that is available for the assets in the tool (Figure 30). In the left side of the screen, the user should select the time-period they would like to view information for (Figure 31), by defining:

- Start Date
- Start time
- End Date
- End time

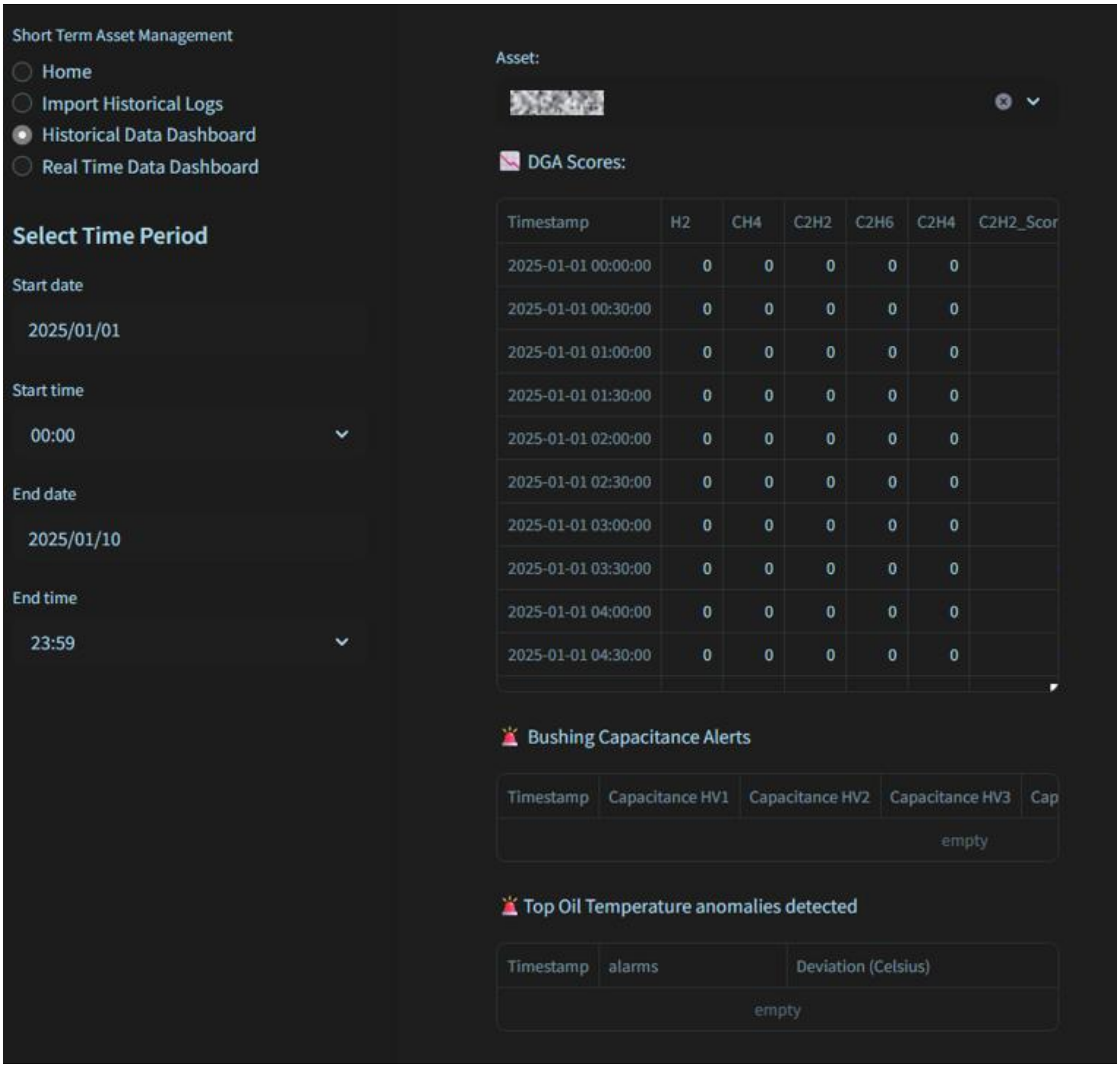



*Figure 30: Initial view of the 'Historical Data' dashboard*

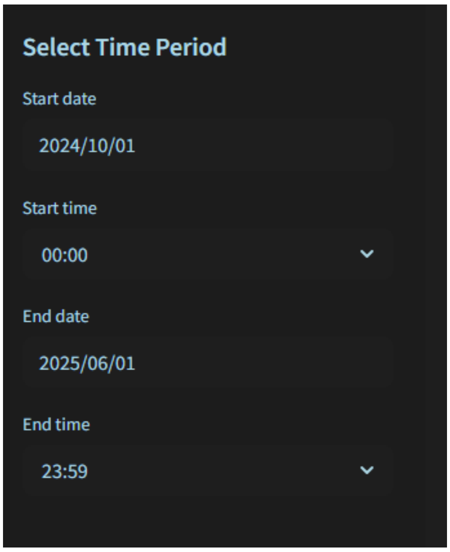



*Figure 31: At the left side of the screen the user should select the period they would like to view information for*

At the main screen the user should initially select the asset they would like to view historical information for, as depicted in Figure 32.

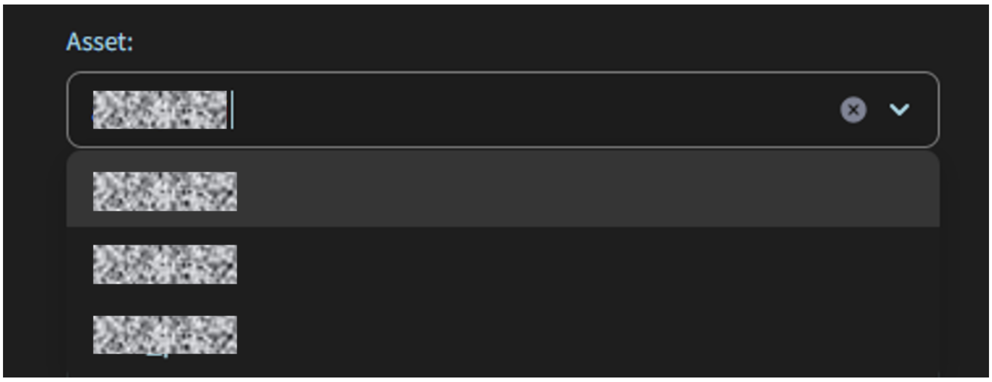
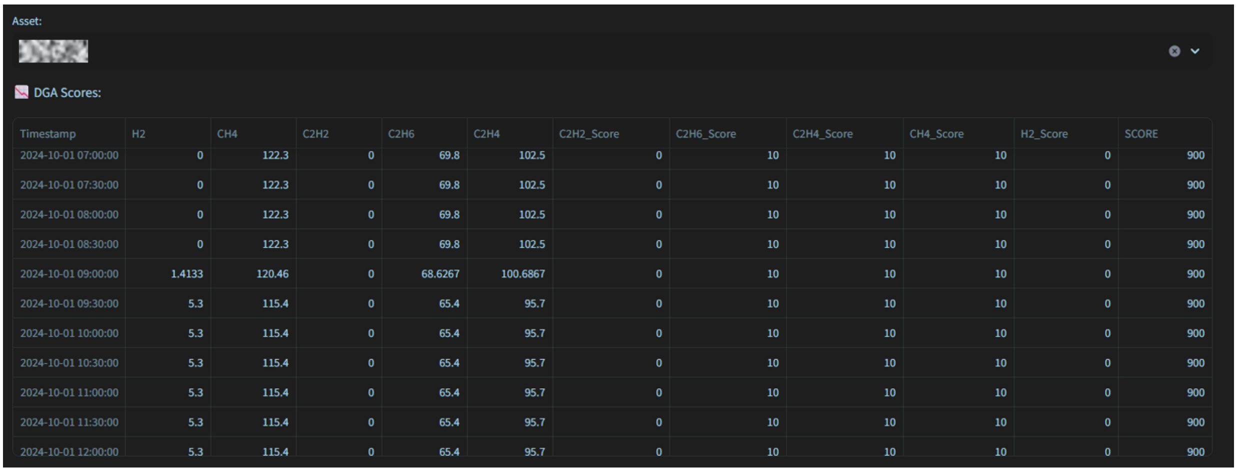



*Figure 32: the user should initially select the asset*

After the user has selected the asset, they can view historical information, at the top of the screen, for the DGA, as depicted in Figure 33. Measurements are available, alongside the score for each gas. Regarding the scores the approach recommended by OFGEM[1] is followed, setting a score for each gas (C2H2, C2H6, C2H4, CH4, and H2). Next, a total score is calculated based on the weighted sum of the gases' condition states. The score is normalized by dividing with 120; in case the score is less than three the condition is considered normal, otherwise an alarm is triggered. Detailed information on the scores can be found in D5.3.




| Timestamp | H2 | CH4 | C2H2 | C2H6 | C2H4 | C2H2_Score | C2H6_Score | C2H4_Score | CH4_Score | H2_Score | SCORE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2024-10-01 07:00:00 | 0 | 122.3 | 0 | 69.8 | 102.5 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 07:30:00 | 0 | 122.3 | 0 | 69.8 | 102.5 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 08:00:00 | 0 | 122.3 | 0 | 69.8 | 102.5 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 08:30:00 | 0 | 122.3 | 0 | 69.8 | 102.5 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 09:00:00 | 1.4133 | 120.46 | 0 | 68.6267 | 100.6867 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 09:30:00 | 5.3 | 115.4 | 0 | 65.4 | 95.7 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 10:00:00 | 5.3 | 115.4 | 0 | 65.4 | 95.7 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 10:30:00 | 5.3 | 115.4 | 0 | 65.4 | 95.7 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 11:00:00 | 5.3 | 115.4 | 0 | 65.4 | 95.7 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 11:30:00 | 5.3 | 115.4 | 0 | 65.4 | 95.7 | 0 | 10 | 10 | 10 | 0 | 900 |
| 2024-10-01 12:00:00 | 5.3 | 115.4 | 0 | 65.4 | 95.7 | 0 | 10 | 10 | 10 | 0 | 900 |

*Figure 33: Historical Results for DGA Scores*

The user can also view historical data on Alerts for Bushing Capacitance (Figure 34). More information on the method for assessing the condition of bushings according to capacitance changes can be found in D5.3.

[1] https://www.ofgem.gov.uk/sites/default/files/docs/2021/04/dno_common_network_asset_indices_methodology_v2.1_final_01-04-2021.pdf

🚨 Bushing Capacitance Alerts

| Timestamp | Capacitance HV1 | Capacitance HV2 | Capacitance H |
|---|---|---|---|
| 2025-03-07 12:00:00 | -42.84% | -41.07% | -42.16 |
| 2025-03-07 16:00:00 | -42.84% | -41.12% | -42.22 |
| 2025-03-07 20:00:00 | -42.88% | -41.32% | -42.20 |
| 2025-03-08 00:00:00 | -27.22% | -26.62% | -26.69 |
| 2025-03-08 04:00:00 | -27.27% | -26.70% | -26.79 |
| 2025-03-08 08:00:00 | -27.32% | -26.14% | -26.81 |
| 2025-03-08 12:00:00 | -27.24% | -25.98% | -26.63 |
| 2025-03-08 16:00:00 | -27.25% | -25.96% | -26.67 |
| 2025-03-08 20:00:00 | -27.34% | -26.07% | -26.63 |
| 2025-04-12 12:00:00 | -45.12% | -44.37% | -44.80 |

*Figure 34: Historical Results for Bushing Capacitance Alerts*

The user can also view historical data on detected oil temperature anomalies (Figure 35) according to the data driven model and the methodology presented in D5.3.

🚨 Top Oil Temperature anomalies detected

| Timestamp | alarms | Deviation (Celsius) |
|---|---|---|
| 2025-02-03 19:00:00 | ✓ | 5.4116 |
| 2025-02-03 20:00:00 | ✓ | -4.1405 |
| 2025-04-24 11:00:00 | ✓ | 4.9662 |
| 2025-04-24 12:00:00 | ✓ | -5.012 |
| 2025-04-25 14:00:00 | ✓ | 5.2887 |
| 2025-04-25 15:00:00 | ✓ | -3.8934 |

*Figure 35: Historical Results for detected Top Oil Temperature anomalies*

#### 4.2.2.4 Real Time Data Dashboard

In the real time data dashboard, the user can view real-time information on assets (Figure 36). The user should initially select the asset they would like to view information for.

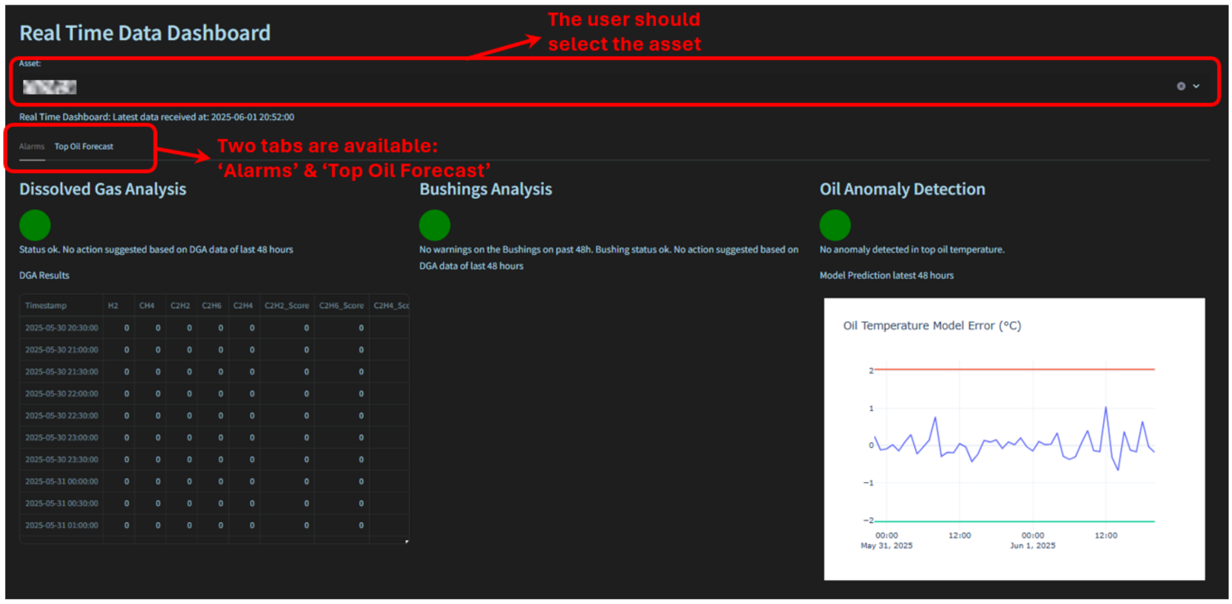



*Figure 36: Initial view of the 'Real Time Data' dashboard*

Two tabs are available, as depicted in Figure 36:

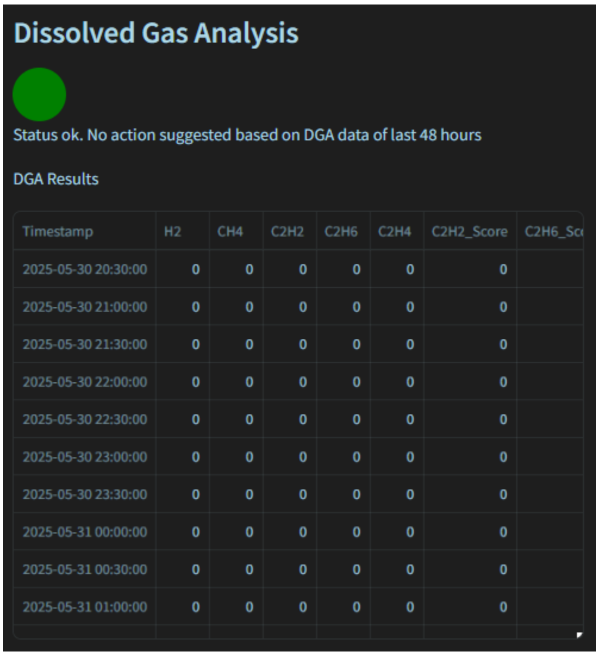
- Alarms
- Top Oil Forecast

In the **Alarms Tab**, the user can view real-time information on:

- Dissolved Gas Analysis (Figure 37-a): Information is available on the measurements of the gases, as well as the relevant score.
- Bushing Analysis (Figure 37-b): It is indicated whether there are warnings on the bushings during the past 48h. It is also indicated whether any action is suggested based on the bushing data of the last 48 hours.
- Oil Anomaly Detection (Figure 37-c): Information is presented on whether anomalies have been detected in the top oil temperature. A model prediction is also available. The fault threshold is defined by two control limits used to evaluate abnormal behaviors: Upper Control Limit (UCL) and Lower Control Limit (LCL) as described in D 5.3. Anomaly is defined if for the past three hours at least two values (with hourly resolution) are beyond the fault threshold/control limits.

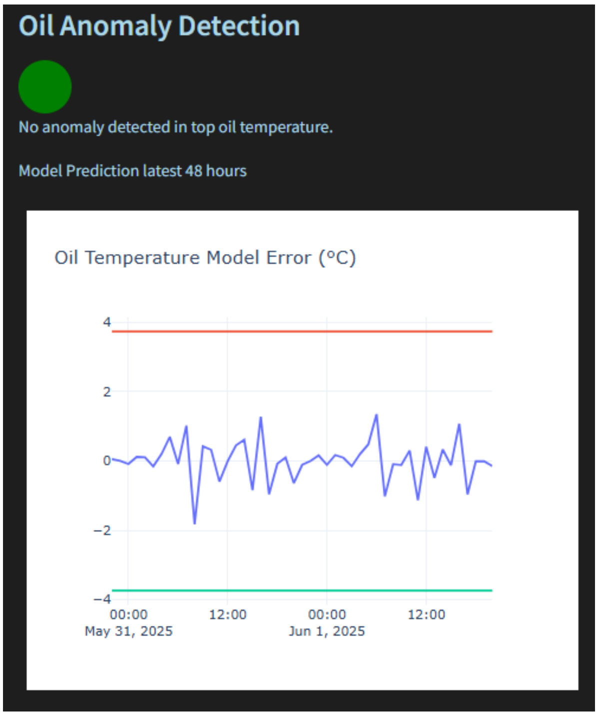
The color of the circle in each case indicates the status of the relevant analysis and changes to red if an alarm is raised.

Regarding the diagram presented in Figure 37-c, as well as the rest of the diagrams in the short-term asset management tool, additional options are presented when the user navigates on the top right side of the diagram, as depicted in Figure 38 (Download plot as a png, Zoom in/out, autoscale, etc.).

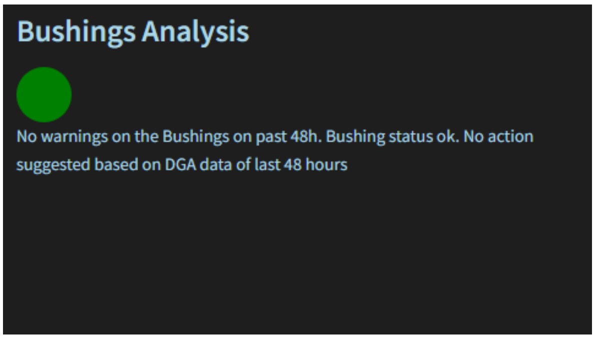



| Timestamp | H2 | CH4 | C2H2 | C2H6 | C2H4 | C2H2_Score | C2H6_Sc |
|---|---|---|---|---|---|---|---|
| 2025-05-30 20:30:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-30 21:00:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-30 21:30:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-30 22:00:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-30 22:30:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-30 23:00:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-30 23:30:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-31 00:00:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-31 00:30:00 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 2025-05-31 01:00:00 | 0 | 0 | 0 | 0 | 0 | 0 | |

*(a)*




*(c)*




*(b)*

*Figure 37: Real-Time information in the Alarm Tab: (a) Dissolved Gas Analysis, (b) Bushing Analysis, (c) Oil Anomaly Detection*

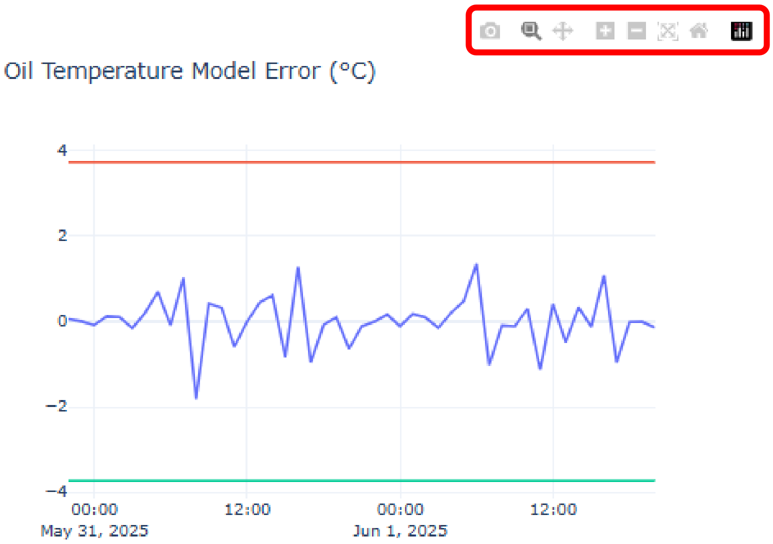



*Figure 38: Options for diagrams*

In the 'Top Oil Forecast' tab (Figure 39), the user can view the forecast of the oil temperature for the next 6 hours. In the diagram, the user can view forecast information regarding the $90^{th}$ quantile and $50^{th}$ quantile (or average value). The relevant threshold is also depicted.

At the top of the 'Top Oil Forecast' tab, the user can select the Limit for the Top Oil Temperature (Figure 39). The user can also view the failure probability at the bottom of the screen (Figure 39).

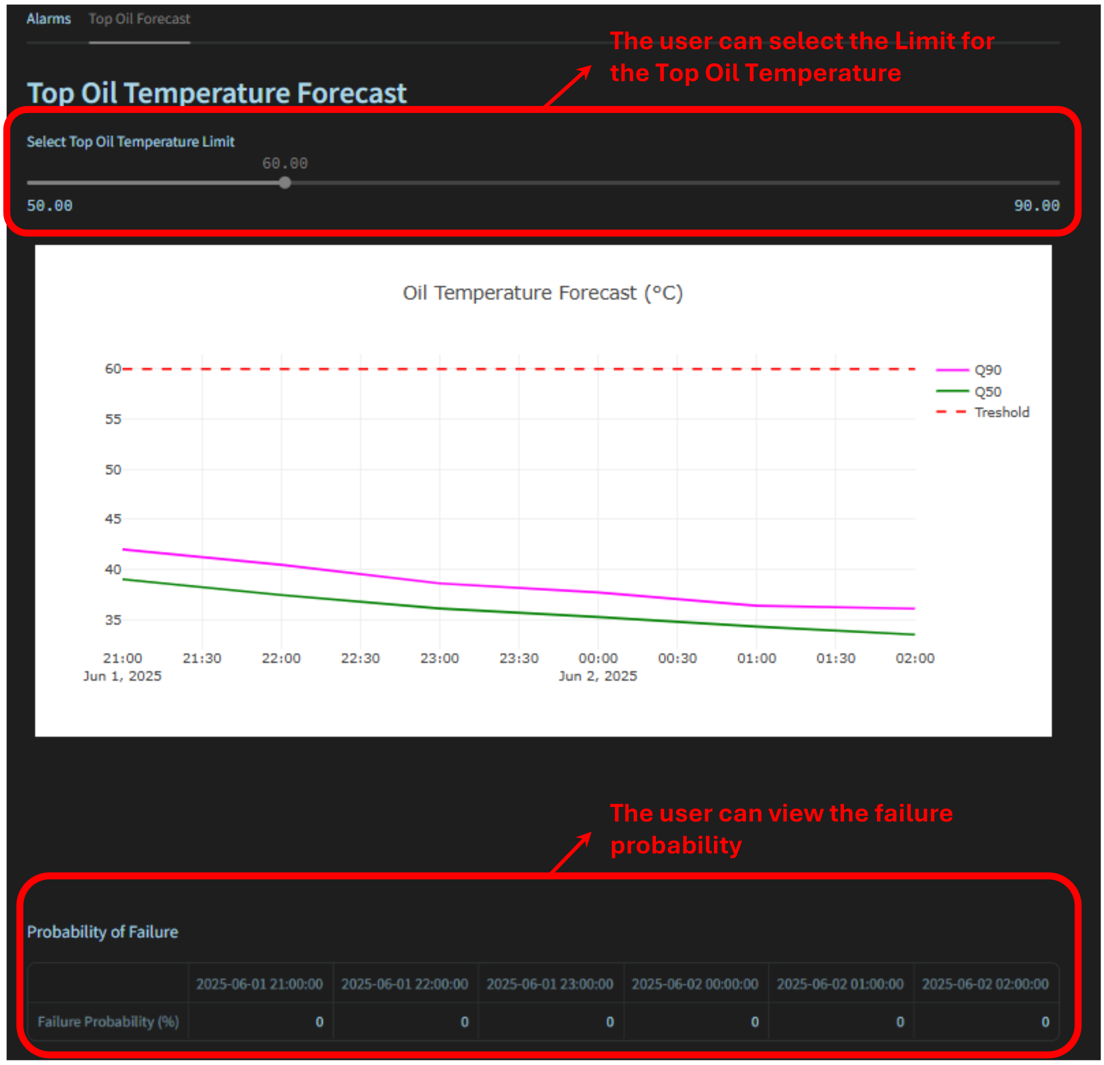



*Figure 39: View of the 'Top Oil Forecast' tab*

## 4.3 Non-Technical Losses detection

### 4.3.1 Description

Non-Technical Losses (NTL) refer to electrical energy that has been consumed but not invoiced and can, thus, be considered fraud or energy theft. Since they can impact the economic revenues of the energy actors, several solutions for detecting fraud in energy delivery exist in commercial products and in literature.

On the other hand, Technical Losses (TL) are inherent to the transmission and mainly consist of the dissipation of electricity in transportation (lines, shunts, etc.), transformation, distribution, and energy measurement. NTL is equal to the total energy injected in the network minus TL and the legal and measured consumptions.

$$NTL = P_{injected} - TL - \sum P_{consumer}$$

Many methods based on different machine learning techniques have been sketched to detect NTL, using SVM, KNN, decision trees, or other ML algorithms[2]. It should be noted that such methods can be classified as *data-oriented*, which utilize user-related data, mainly energy consumption. Due to the rise of ML and Big Data techniques, data-oriented techniques are the most promising to predict and classify whether a user has a fraudulent consumption. Among the different methods to detect NTL, *Network-Oriented* and *Hybrid methods* can be used to detect subsystems inside the network with potential energy thefts, either because of fraud consumption or unregistered connections. *Network-Oriented* methods are based on network analysis and the physical rules that describe such systems, while *Hybrid methods* refer to a combination of network and data-oriented methods.

As part of the ETER software, **ETRA has a model based on a mix of data and network-oriented techniques (hybrid methods).** Deep Neural Network and Power Flow Analysis are both used to detect fraudulent users and illegal unregistered connections. The hybrid method model has three main steps:

> Energy Balance: Initially, an aggregation of all the smart meter measurements that are fed from substations is done for each of them. With these aggregations we can compare them with the total injected energy during the period we have smart meters data.
>
> An energy balance is made for them, and different hourly features are extracted. Simple statistics like mean and hourly standard deviations, and z-scores.
>
> Suspicious Feeders: With the data extracted from the previous step, a machine learning algorithm is trained. With previously labelled data, we train a model that tells us the probability that a feeder has some possible NTL issue with previous knowledge.
>
> Expected and Real Power Flow Comparison: For those suspicious feeders, we run several power flows for each step. We use them to get the Technical Losses and also to compare the expected power flow with the real one.
>
> The expected power flow is the one computed with the measurements we got from the smart meters, all of them legal. On the other hand, with different temporal machine learning analysis we got a state estimator of the network, not using energy measurements but rather voltage and current data we got from line and buses. This data, joined with the real energy injected into the feeder, allows us to estimate the real steady state of the network. Now we can proceed to compute the differences amongst the network elements for these two scenarios, the real one and the expected one.
>
> That process is computed every time we have a new state estimator that can compare with the power flow from smart meters measurements. These differences allow us to detect lines and buses where the difference between the two scenarios is higher than a threshold. Because this computation is done regularly, when a line/bus has several issues during many hours/days, we can mark the line as suspicious, so the operators must visit to check if an illegal connection is made.

[2] More information on the classification of methods for detecting NTL is provided in D5.3.

### 4.3.2 User's Manual and Interface.

#### NTL Computation

The NTL computation is a transparent process for the user. When bus data is received, it is used to estimate the network's real state, through different processes that finally rely on power flow computation.

This result will be compared with power flow using smart meters data, and from this process, and applying hybrid approach, the system will detect lines where possible fraud is being committed.

So, in the NTL computation itself, the end user does not need to do anything. The results will be directly displayed on the ETER platform.

#### Suspicious NTL Summary

ETER platform has a portfolio route. On that, we can review the state of each specific element of the network. Clicking in the side navigation menu icon, we displayed network elements (Figure 40). Now we need to navigate to the bus that defines the sub-network where the line we want to inspect is located.

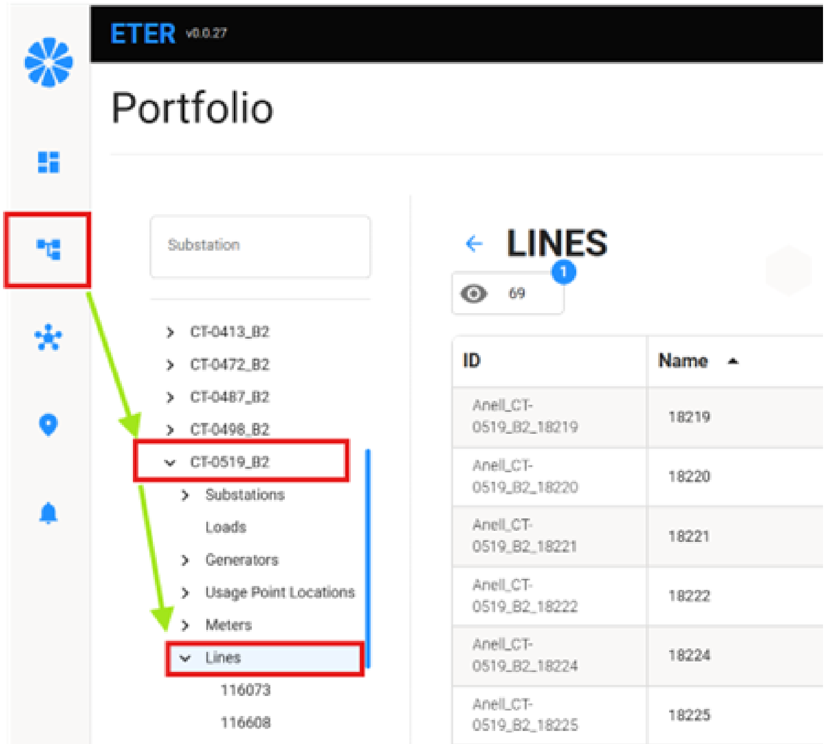



*Figure 40: Lines summary*

After clicking on the line's accordion header, the list of lines is displayed on the main page. There we can see the lines that the NTL process detected as suspicious of fraud (Figure 41).

On the table where frauds are shown, we can click on NTL column to sort the lines by number of issues detected.

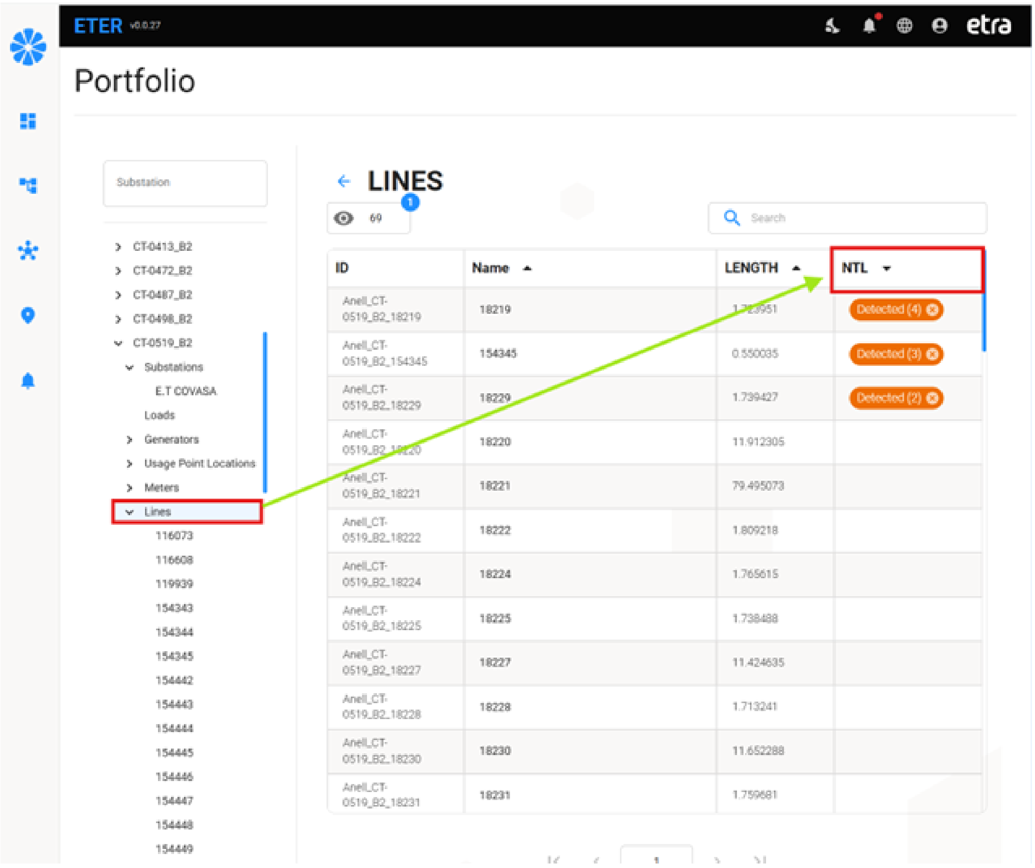



*Figure 41: Detected lines with potential frauds*

Clicking on the alarm chip, a dialog with the list of evidences is shown (Figure 42).

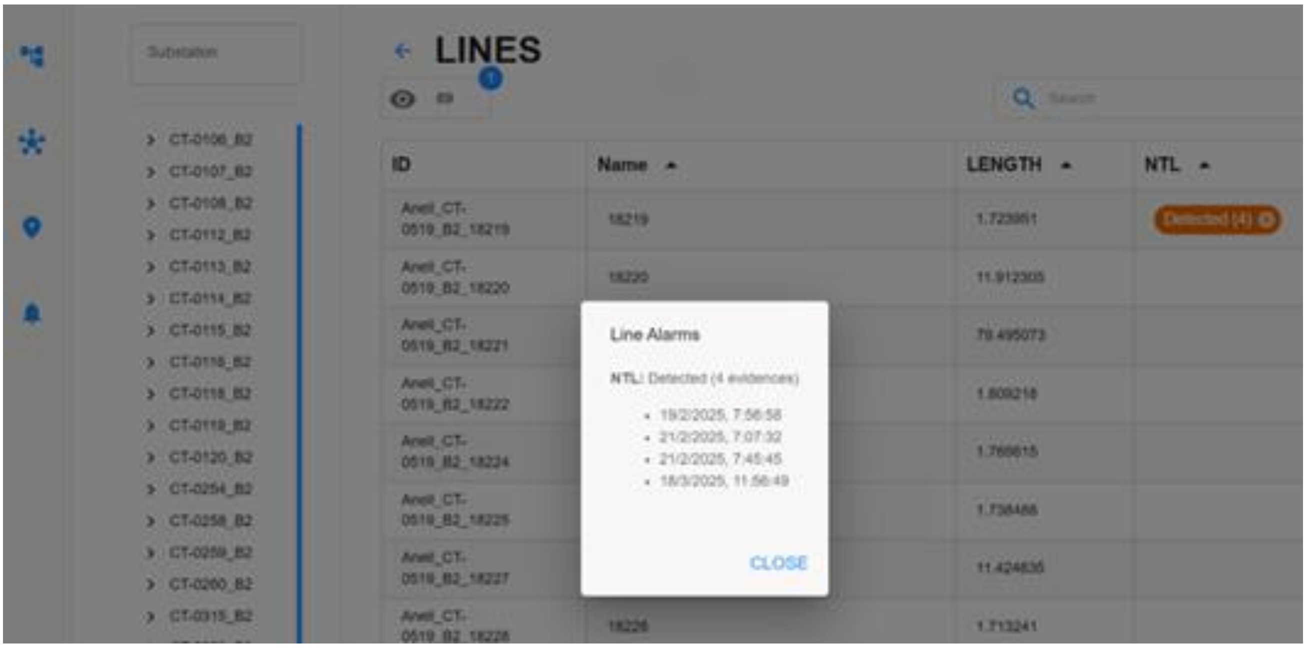



*Figure 42: List of evidences of fraud*

## Line Map

Also, the map shows the lines with alarm so the operator can know easily where the issues are being detected, hovering over the map (Figure 43).

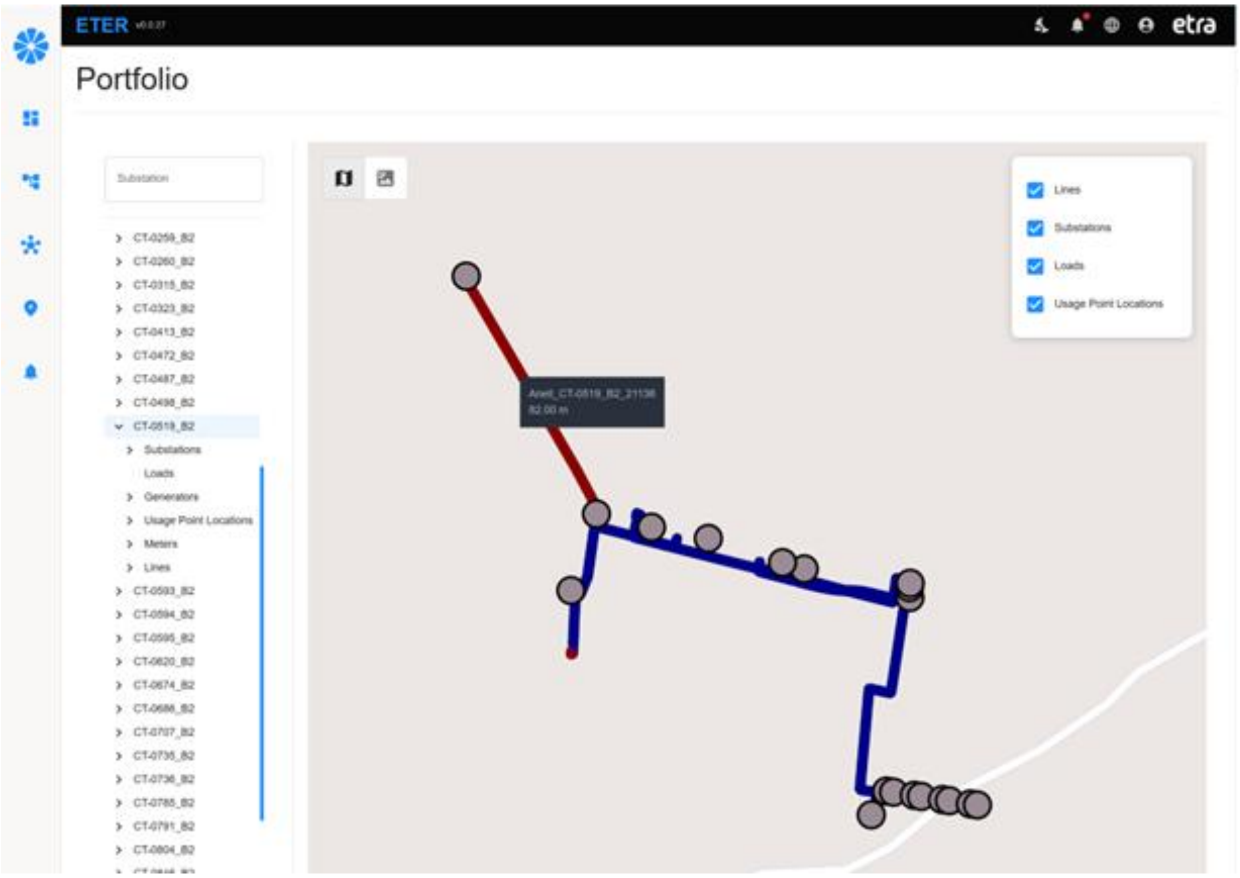



*Figure 43: Line Map*

## 4.4 Network Planning tool

### 4.4.1 Description

The Network Planning tool developed in OPENTUNITY aims to provide DSOs with an intelligent, flexible platform for long-term planning of electrical distribution networks. As the energy landscape shifts toward decarbonization, power distribution systems must evolve to support increasing electricity demand and the integration of RES. The traditional approach to network planning — focused largely on infrastructure reinforcement — must now account for the dynamic behavior of Distributed Energy Resources (DERs), such as solar panels, electric vehicles, energy storage systems, and demand response technologies. These changes call for more advanced planning methods capable of optimizing investments while ensuring reliability, cost-effectiveness, and sustainability.

In recent years, the role of consumers has evolved from passive energy users to active participants in the energy ecosystem. This shift has been facilitated by technologies and mechanisms like flexibility services, local energy markets, and prosumer models. As these players offer new sources of grid flexibility, planning tools must consider their behavior and the resulting market impacts. Local energy markets, in particular, are emerging as a mechanism to optimize RES integration and encourage local energy exchange, which directly influences how networks should be expanded or reconfigured. Despite growing literature on local markets and operations, their implications for distribution system planning remain underexplored, and OPENTUNITY's tool addresses this gap by integrating market considerations into the planning process.

The planning tool leverages advanced mathematical programming methods to model and solve the planning problem. It is formulated either as a single-year Mixed-Integer Linear Programming (MILP) model or a multi-year Mixed-Integer Second-Order Cone Programming (MISOCP) model, depending on the selected user objective — such as minimizing investment costs, deferring upgrades, or maximizing renewable integration. These models are solved using the GUROBI solver, which ensures computational efficiency and optimality. The single-stage optimization approach adopted in OPENTUNITY includes fixed flexibility pricing to reduce computational load and ensure results are delivered within minutes, making it practical for real-time scenario testing by DSOs. This allows planners to simulate different strategies and investment scenarios, enabling data-driven decision-making in a rapidly evolving grid environment.

Given the complexity of distribution systems and the increasing number of decision variables — such as where to place distributed generation units, energy storage systems, or EV charging stations — the tool is designed to handle both traditional grid upgrades and the deployment of flexibility resources. While mathematical models offer exact solutions, the tool's design also reflects an awareness of scalability limitations, balancing the need for accuracy with real-world usability. By incorporating DERs, flexibility sources, and user-defined planning objectives into a streamlined interface, the OPENTUNITY Network Planning tool offers a modern, actionable solution for shaping the future of distribution system infrastructure.

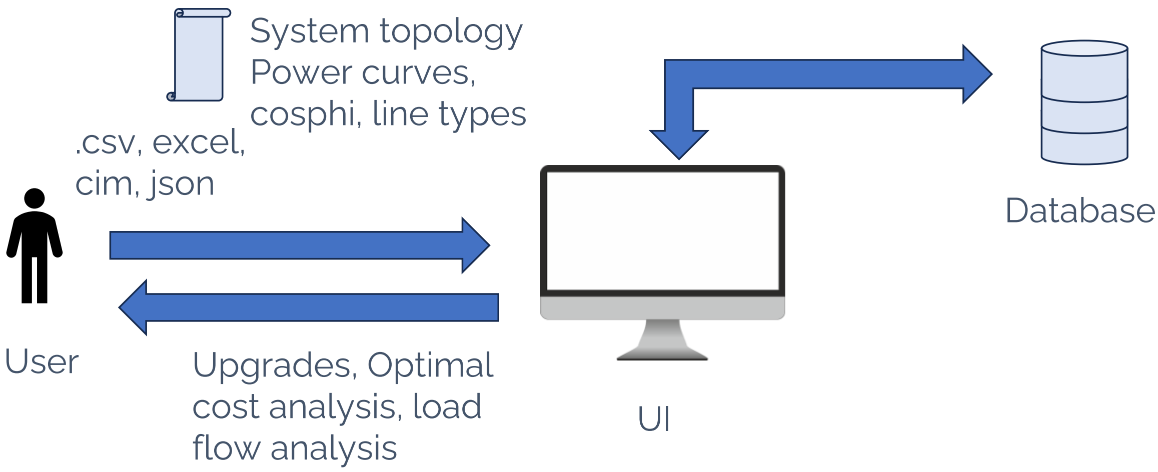



*Figure 44: Structure of the Network Planning tool*

The tool's structure is depicted in Figure 44. The user of the tool interacts with the UI by providing input data and getting results, like required upgrades, optimal cost analysis and load flow analysis results. Input data to the tool are provided via files with information on the system topology in various formats, power curves (i.e. the load of the system in each bus), power factor of loads and line types considered for upgrades. The format required for each input file (.csv, excel, cim, json, etc.) is described in section 4.4.2. The UI also interacts with a relevant database, where it stores and retrieves the required data.

### 4.4.2 User's Manual and Interface.

#### 4.4.2.1 General overview

The initial view of the planning tool is depicted in Figure 45. The user is instructed to Log-in by filling in their username and password. After the correct password and username have been used, the user should click on 'Log in'.

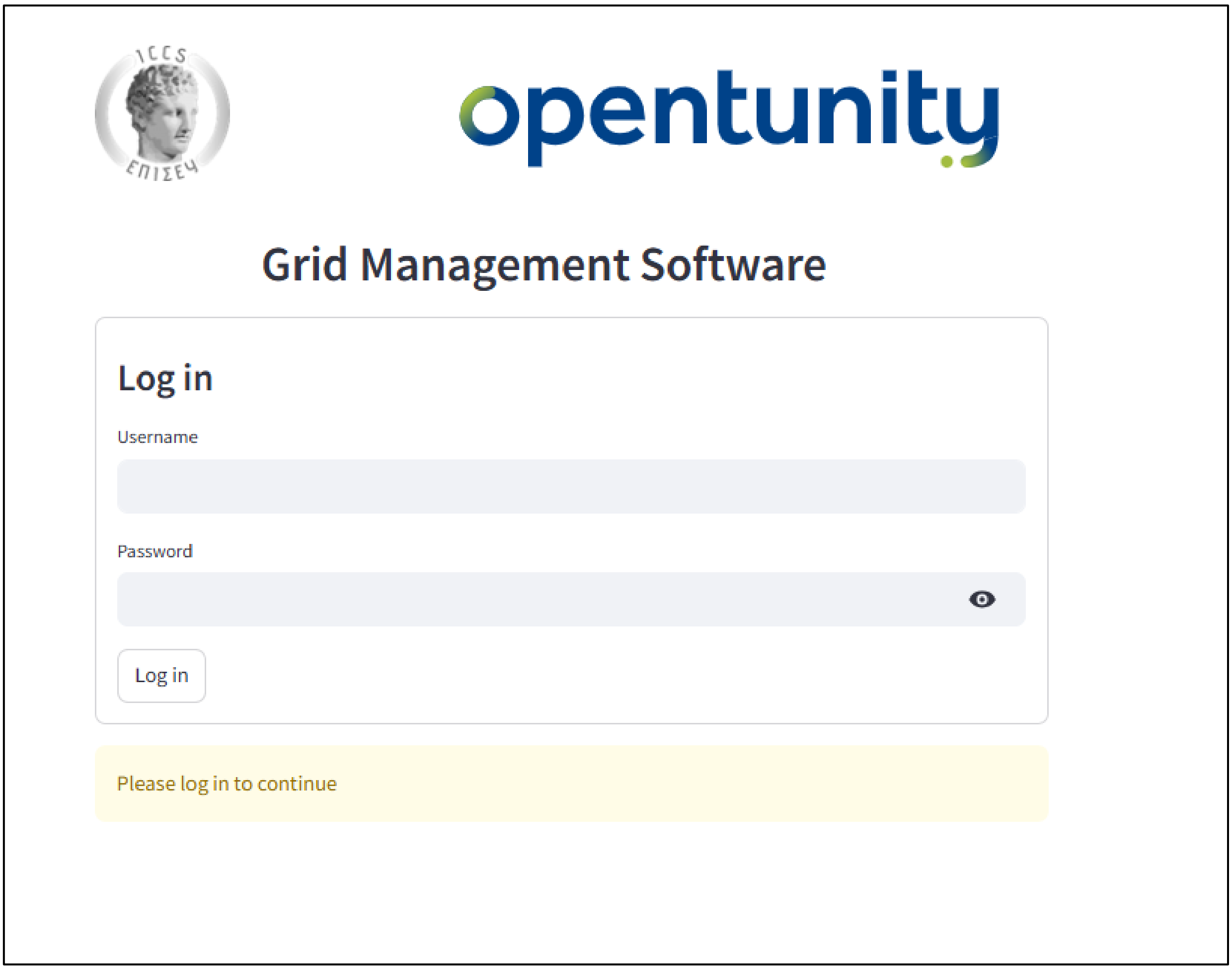



*Figure 45: Log-in screen of the Planning tool*

In case an incorrect username and/or password is provided, an 'Authentication failed' message appears (Figure 46).

When the user types the correct password and username the view in Figure 47 is presented. A short description of the planning tool is provided, alongside its capabilities, at the top of the screen. The user can log out by clicking on the relevant button at the upper left side of the screen (Figure 47).

The following two planning options are available:

- *New System Planning*: The user can start a new power-flow analysis (described in detail in Section 4.4.2.2), followed by an optimization objective for planning purposes (described in detail in Section 4.4.2.3)
- *Load System Planning*: The user has the option to load past results (described in detail in Section 4.4.2.4)

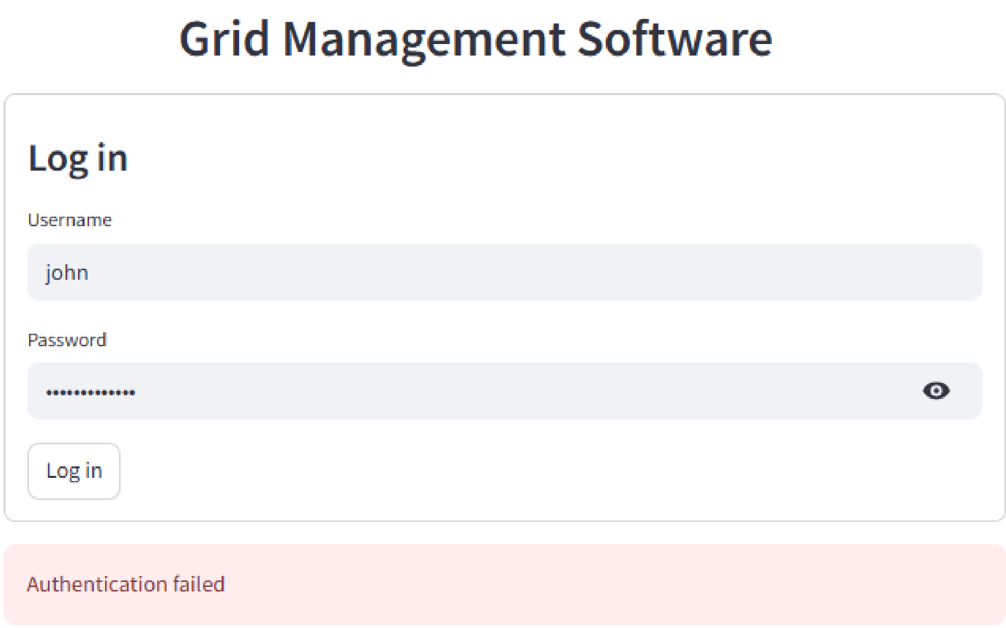



*Figure 46: 'Authentication failed' message in case of incorrect username and/or password*

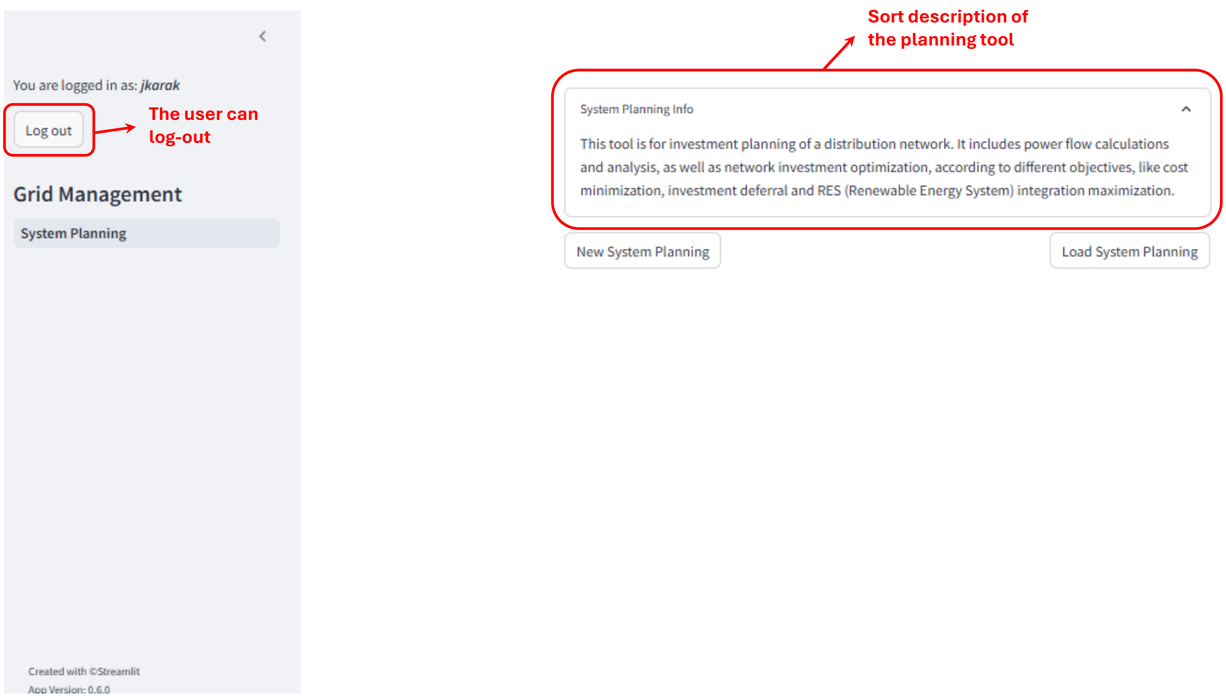



*Figure 47: Initial view of the Planning tool (after the user has logged in)*

#### 4.4.2.2 Power Flow

When the user clicks on 'New System Planning' (Figure 48) he is instructed to apply the necessary parameters for the Power Flow Analysis and upload the necessary files, as depicted in Figure 49.

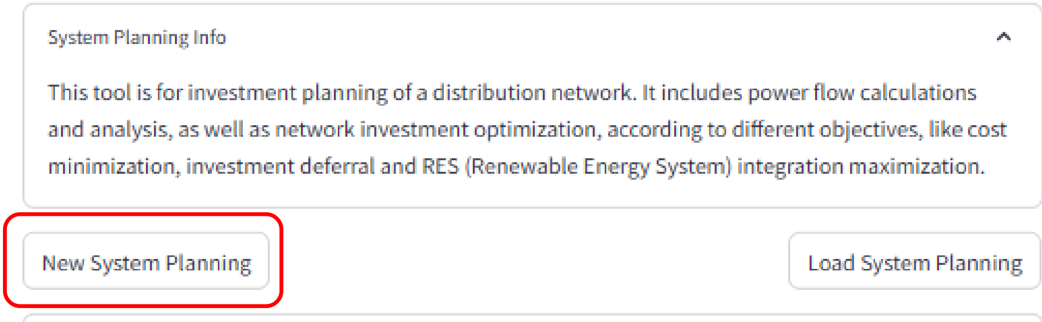



*Figure 48: 'New System Planning' icon at the upper left corner of the screen*

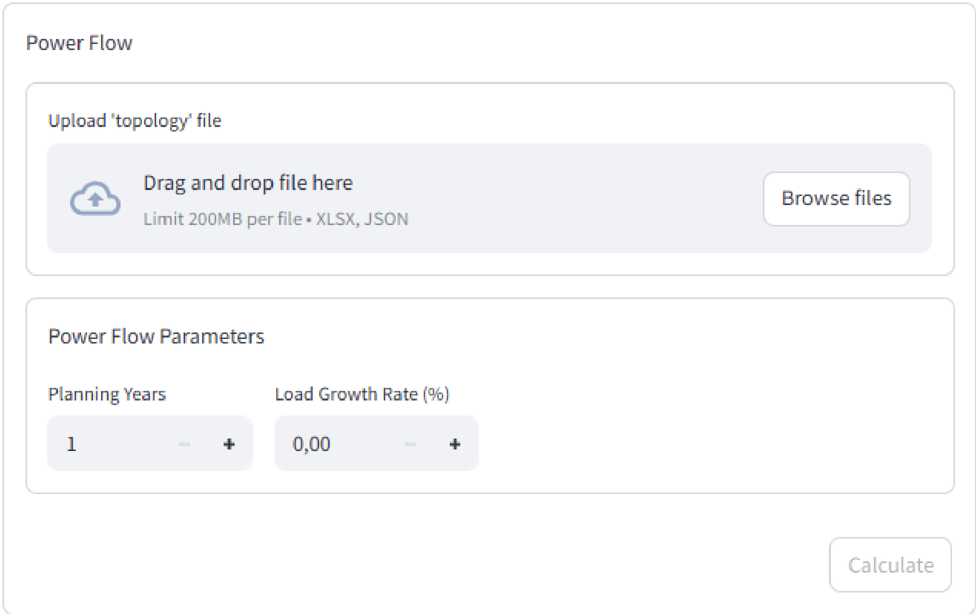



*Figure 49: View of the screen when the user clicks on 'New System Planning'.*

The user should initially upload the topology file (either xlsx, cim or pandapower json). In order to be informed of the structure of the required file, the user can download a template file by clicking on the relevant icon, as depicted in Figure 50. This option (downloading a template file) is also available for the .xlsx file format for the topology file.

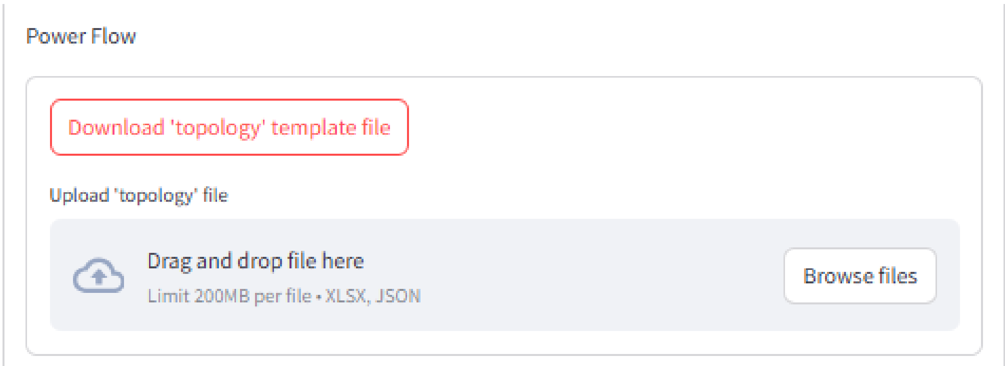



*Figure 50: The user can download a template file to be informed on the structure of the required file*

The JSON file should be in the pandapower format, while the cim must be provided in v16.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | name | vn_kv | substatio | latitude | longitude | sn_mva |
| 2 | [redacted] | 5.25 | TRUE | 41,6391 | 2,23799 | 0,4 |
| 3 | | 5.25 | TRUE | 41,6412 | 2,23126 | 0,63 |
| 4 | | 5.25 | TRUE | 41,6387 | 2,23291 | 0,4 |
| 5 | | 5.25 | TRUE | 41,6385 | 2,22891 | 0,4 |
| 6 | | 5.25 | TRUE | 41,6374 | 2,24161 | 0,1 |
| 7 | | 5.25 | TRUE | 41,6375 | 2,23003 | 0,1 |

*(a)*

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | name | from_bus | to_bus | length_km | r_ohm_per_km | x_ohm_per_km | c_nf_per_km | g_us_per_km | max_i_ka | type |
| 2 | [redacted] | [redacted] | [redacted] | 0,375524265 | 1.2 | 0.134 | 0.0 | 0.0 | 0.145 | OH |
| 3 | | | | 0,199001341 | 0,262 | 0,117 | 0.0 | 0.0 | 0.3 | UG |
| 4 | | | | 0,232625117 | 0,262 | 0,117 | 0.0 | 0.0 | 0.3 | UG |
| 5 | | | | 0,504089923 | 0.161 | 0,105 | 0.0 | 0.0 | 0.415 | OH |

*(b)*

| | A |
|---|---|
| 1 | bus |
| 2 | [redacted] |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |

*(c)*

| A | B | C |
|---|---|---|
| bus | name | p_max_mw |
| | | |
| | | |

*(d)*

*Figure 51: Excel topology data file format example: (a) Buses sheet (b) Lines sheet, (c) Substations sheet, (d) Generators sheet*

The input excel file for topology data should follow a specific format to successfully be accepted. It should include the following sheets depicted in Figure 51: Buses, Lines, Substations, Generators.

The *Buses sheet* should include the following columns:

- name (string): A unique identifier for each bus
- vn_kv (float): Nominal Voltage of Bus
- substation (Boolean): True or False. Indicates whether an MV/LV substation exists in the bus.
- latitude (float): geographic coordinates for the latitude of the substation, using the EPSG:4326 coordinate reference system
- longitude (float): geographic coordinates for the longitude of the substation, using the EPSG:4326 coordinate reference system
- sn_mva (float): if substation exists, the nominal MVA of the transformer

The *Lines sheet* should include the following columns:

- name (string): A unique identifier for each line
- from_bus (string): starting point (bus) of the line
- to_bus (string): ending point (bus) of the line
- length_km (float): length of the line in km
- r_ohm_per_km (float): Electrical resistance per kilometer in ohms
- x_ohm_per_km (float): Electrical reactance per kilometer in ohms
- c_nf_per_km (float): line capacitance (line-to-earth) in nano Farad per km
- g_us_per_km (float): dielectric conductance in micro Siemens per km
- max_i_ka (float): Maximum current for the line in kA

- type (string): Indicates the type of installation. Accepted values are OH (Overhead) or UG (Underground).

The *Substations sheet* should only include the column bus, indicating in which bus an HV/MV substation is present. The *Generators sheet* indicates the generators within the examined topology (if any) and should include the columns: bus (string), name (string), p_max_mw (float).

The user can either drag and drop the file on the relevant field or click on 'Browse files'. In case a file with a format different than the expected one is uploaded, a message '*No network loaded. Please upload a topology file.*' appears to inform the user accordingly, as depicted in Figure 52.

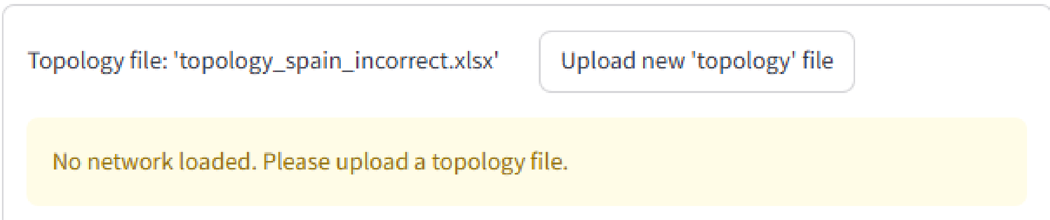



*Figure 52: Message that appears when the user uploads incorrect files for the network topology.*

As soon as the user uploads the file with the correct format, they can proceed to the next step. If the distribution network contains loops, the user is instructed to remove them before proceeding with the power flow calculation (Figure 53). The radial structure is needed both in fast power flow calculation and allows the use of optimization for the grid upgrade problem. Furthermore, it highlights a worst case condition which is typical in grid planning studies. Loops in the network can be removed by de-energizing lines. The user can select the line to de-energize, in the drop-down list that appears when clicking on the field 'Select a line to de-energize' (Figure 53).

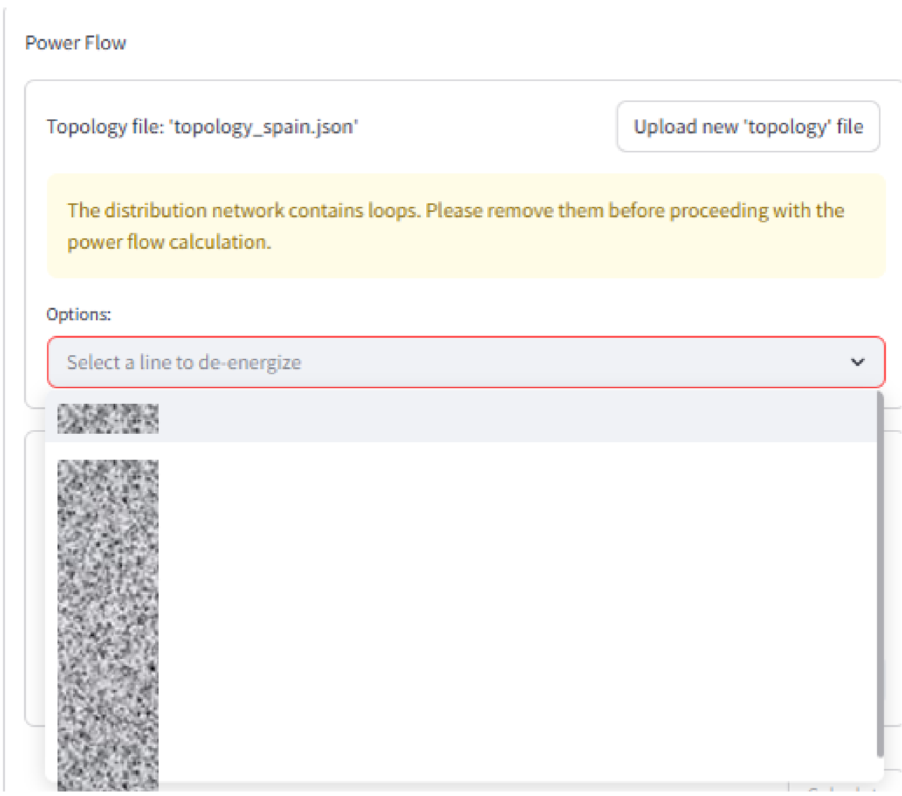



*Figure 53: The user is instructed to remove the loops by de-energizing lines.*

After the user has selected the line to de-energize, a message appears to inform them: '*The following lines are de-energized*: …', as depicted in Figure 54. The user can click on 'view' in order to view the de-energized line in a map (Figure 54), which appears a dashed line.

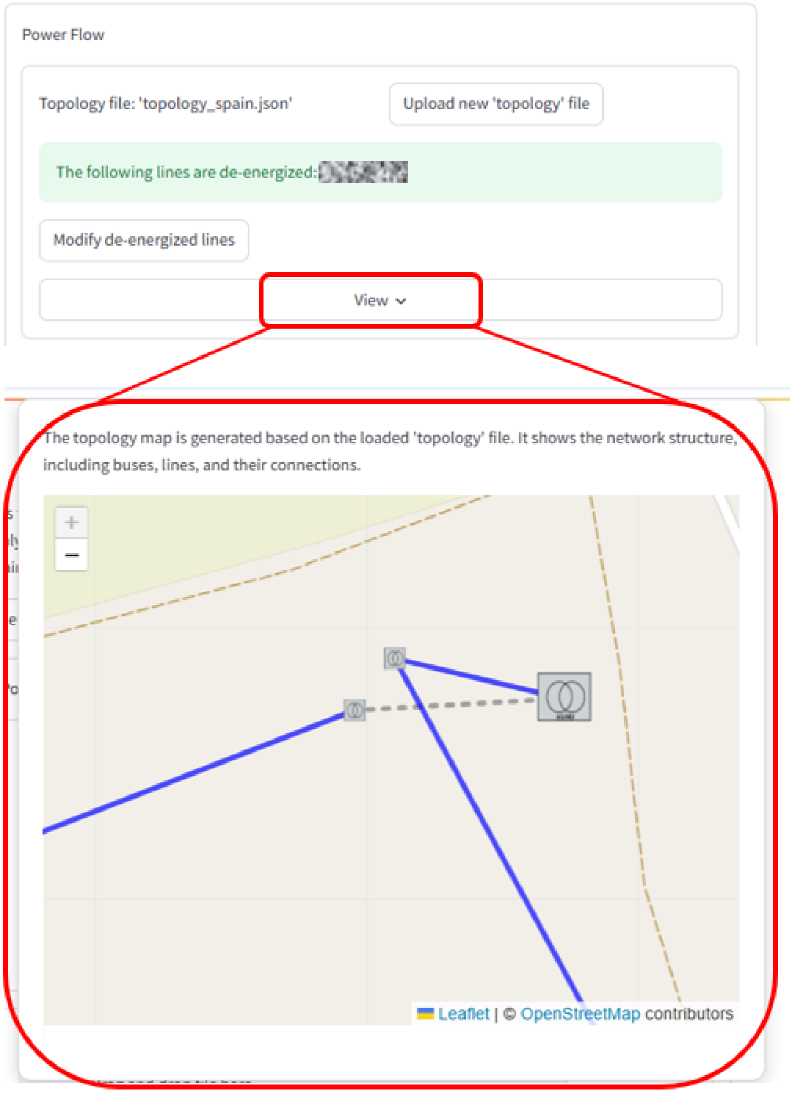



*Figure 54: The user can view, on a map, the de-energized line*

The user can also view the topology map (Figure 55), which is generated based on the loaded 'topology' file. This map shows the network structure, including buses, lines, and their connections. The user has the option to navigate in the map with options for zoom-in, zoom-out, etc.

At the next step, the user should upload the file containing information on the system's load characteristics (i.e. the 'power curves' file), and the file with information on the substations' angle (i.e. the 'cosphi' file), as depicted in Figure 56. The user can either drag and drop the file on the relevant field or click on 'Browse files'. For both files, a .csv file should be uploaded, with a limit of 200MB per file.


*Figure 55: The user can view the topology map*

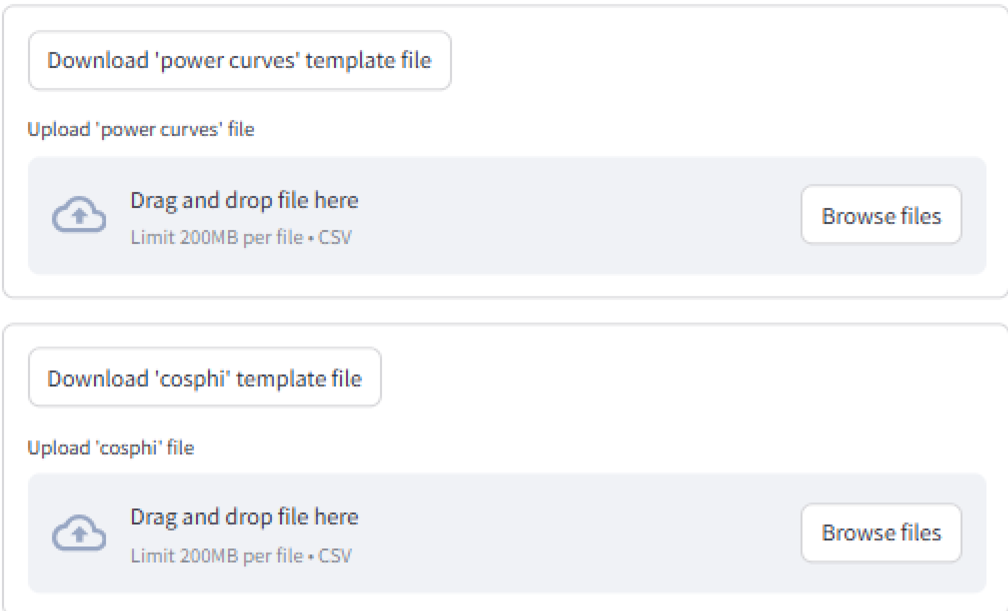



*Figure 56: The user should upload the 'power curves' file and the 'cosphi' file.*

The power curves file and the cosphi files must be provided in CSV format with UTF-8 encoding (Figure 57). The power curves file should include information of a year scenario for the active power of the system's MV/LV substations. The first column 'Hour' (integer) indicates the hours within a year (0 … 8759). The next columns should include the name of the buses (string) that have substations. Each line should indicate the active power in each bus (float) with substation.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Hour | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | 0 | 0.05396 | 0.08926 | 0.06262 | 0.04905 | 0.01058 | 0.00457 | 0.0405 | 0.02905 | 0.02452 | 0.05991 | 0.01067 |
| 3 | 1 | 0.04964 | 0.08083 | 0.05743 | 0.051 | 0.01025 | 0.00433 | 0.03599 | 0.02722 | 0.02482 | 0.05884 | 0.01292 |
| 4 | 2 | 0.04449 | 0.0763 | 0.04993 | 0.04655 | 0.00992 | 0.00595 | 0.04185 | 0.02643 | 0.02215 | 0.06301 | 0.01289 |
| 5 | 3 | 0.03873 | 0.06924 | 0.04657 | 0.04596 | 0.00997 | 0.00671 | 0.04476 | 0.01915 | 0.02248 | 0.05732 | 0.01163 |
| 6 | 4 | 0.03371 | 0.06787 | 0.04566 | 0.04203 | 0.01158 | 0.00666 | 0.0468 | 0.01496 | 0.01732 | 0.05 | 0.02548 |
| 7 | 5 | 0.03311 | 0.06693 | 0.04229 | 0.03505 | 0.01157 | 0.0068 | 0.04899 | 0.01944 | 0.01731 | 0.04394 | 0.02048 |
| 8 | 6 | 0.03211 | 0.06172 | 0.04035 | 0.03442 | 0.00997 | 0.00455 | 0.03555 | 0.01508 | 0.01541 | 0.04491 | 0.02025 |
| 9 | 7 | 0.02993 | 0.05954 | 0.04354 | 0.03276 | 0.00959 | 0.00412 | 0.03403 | 0.0207 | 0.01372 | 0.04831 | 0.03804 |
| 10 | 8 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

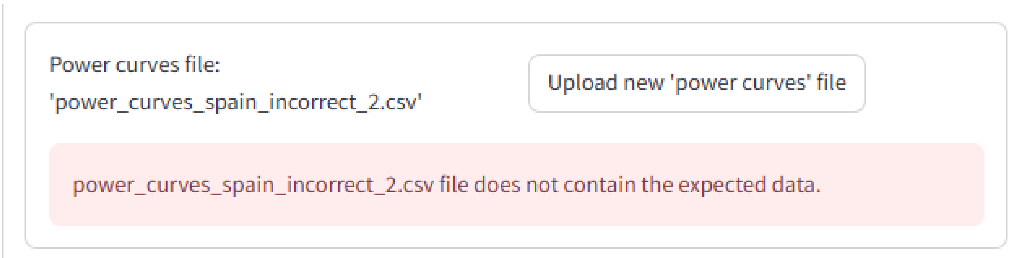
*Figure 57: power curves csv file format*

The coshpi file should include the columns depicted in Figure 58: Substation (string), with the name of the substation's bus, and 'Coshpi' (float) indicating the angle of the respective substation.

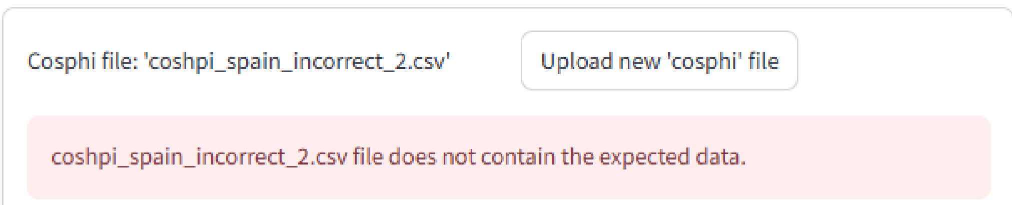
| | A | B |
|---|---|---|
| 1 | Substation | Cosphi |
| 2 | [illegible] | 0.989108623 |
| 3 | [illegible] | 0.995363157 |
| 4 | [illegible] | 0.980867161 |
| 5 | [illegible] | 0.998216192 |
| 6 | [illegible] | 0.976165439 |
| 7 | [illegible] | 0.981994669 |
| 8 | [illegible] | 0.999825903 |
| 9 | [illegible] | [illegible] |

*Figure 58: cosphi csv file format*

In case files with a different format than the expected one are uploaded, a message appears to inform the user accordingly (Figure 59).



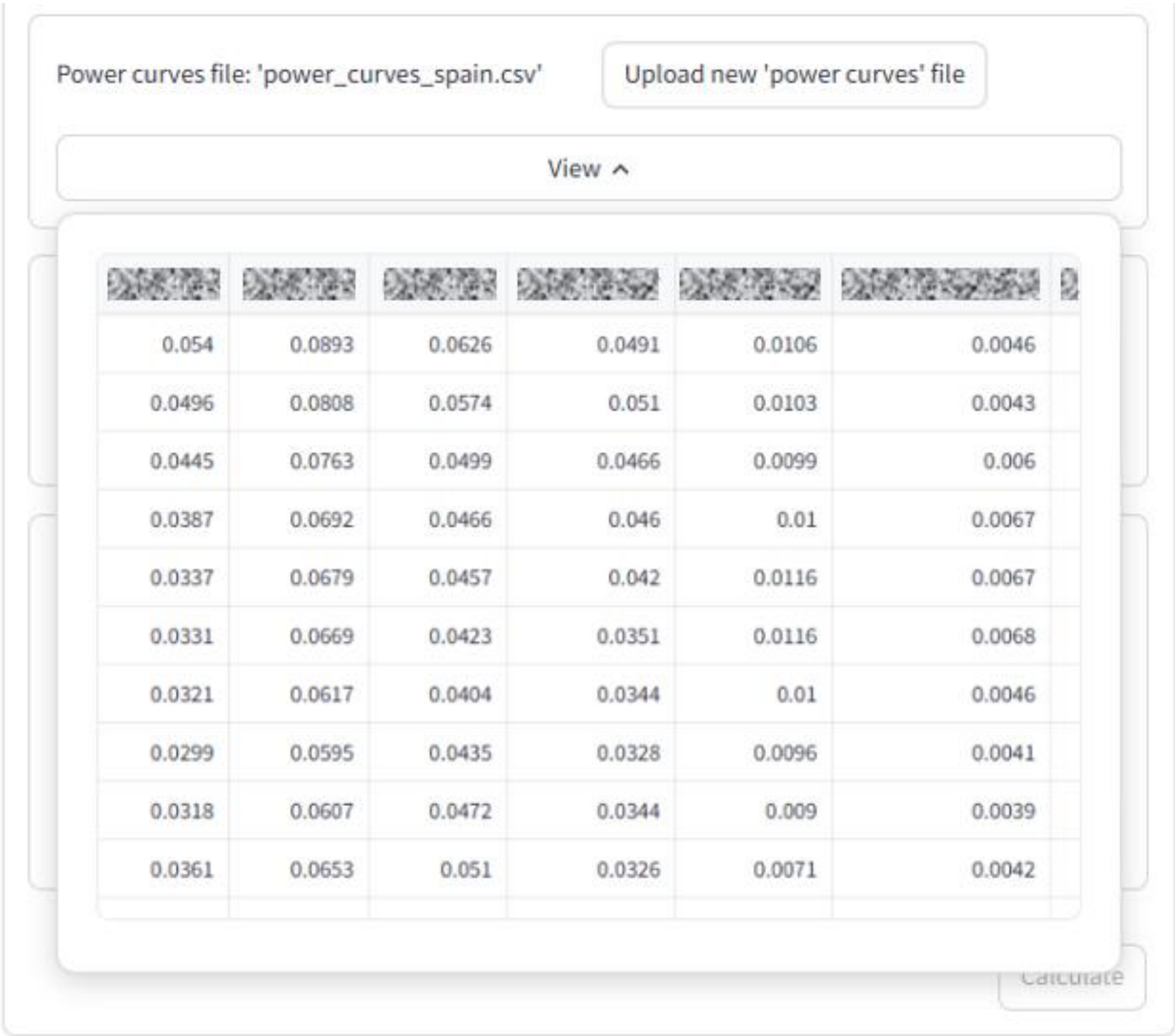

*(a)*




*(b)*

*Figure 59: Message that appears when the user uploads incorrect files for (a) the power-curves, and (b) the cosphi.*

When the user uploads the correct file for the loads of the system (i.e. the 'power curves' file), they can view the relevant information by clicking on the 'View' icon (Figure 60). The user can view the table with information about the load of each bus for each hour of the year.

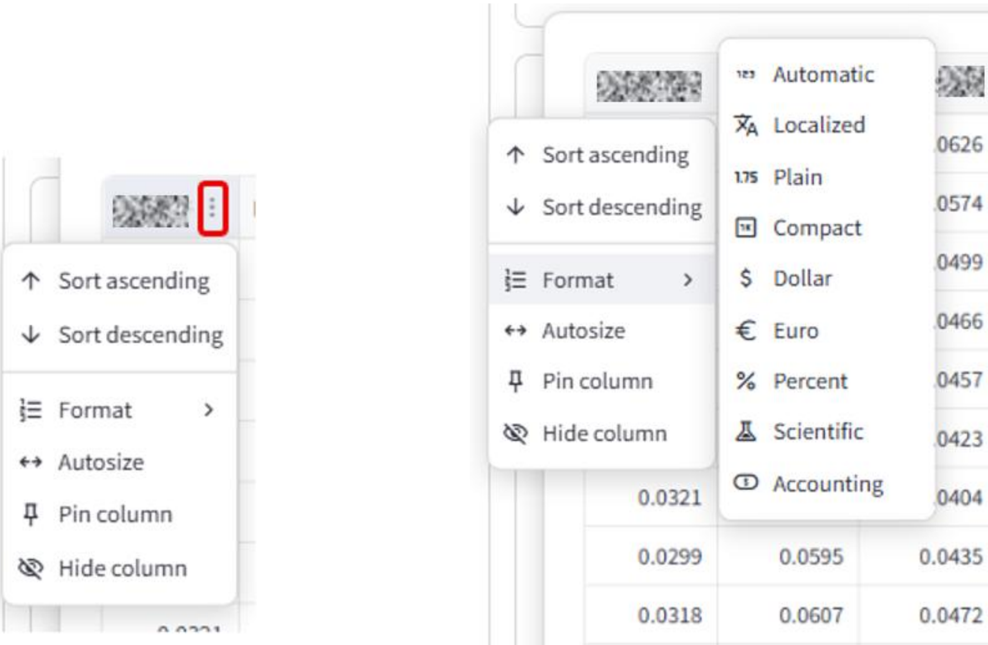



| | | | | | |
|---|---|---|---|---|---|
| 0.054 | 0.0893 | 0.0626 | 0.0491 | 0.0106 | 0.0046 |
| 0.0496 | 0.0808 | 0.0574 | 0.051 | 0.0103 | 0.0043 |
| 0.0445 | 0.0763 | 0.0499 | 0.0466 | 0.0099 | 0.006 |
| 0.0387 | 0.0692 | 0.0466 | 0.046 | 0.01 | 0.0067 |
| 0.0337 | 0.0679 | 0.0457 | 0.042 | 0.0116 | 0.0067 |
| 0.0331 | 0.0669 | 0.0423 | 0.0351 | 0.0116 | 0.0068 |
| 0.0321 | 0.0617 | 0.0404 | 0.0344 | 0.01 | 0.0046 |
| 0.0299 | 0.0595 | 0.0435 | 0.0328 | 0.0096 | 0.0041 |
| 0.0318 | 0.0607 | 0.0472 | 0.0344 | 0.009 | 0.0039 |
| 0.0361 | 0.0653 | 0.051 | 0.0326 | 0.0071 | 0.0042 |

*Figure 60: When the user uploads the 'power curves' file, they can view the relevant information by clicking on the 'View' icon.*

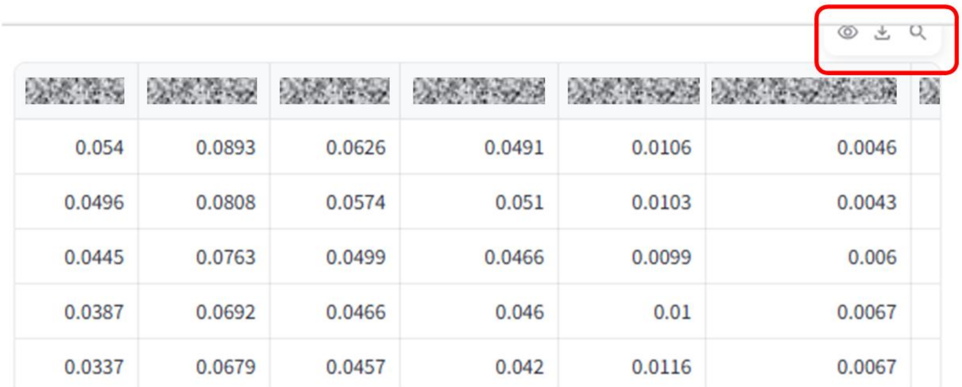
Additional options are available when the user clicks on the three dots next to the name of each column as depicted in Figure 61-a (Sort in Ascending/Descending order, Autosize, etc.). In case of numerical values additional 'format' options are available, as depicted in Figure 61-b (Automatic, Scientific, Percent, etc.). Moreover, options for the whole table are available when the user clicks on the relevant icons at the top right side off the tables (Figure 62), like show/hide columns, download the whole table as .csv file, search.

The options in Figure 61 and Figure 62 are available for all tables within the network planning tool.




(a) (b)

*Figure 61: (a) Options when the user clicks on the three dots next to the name of each column, (b) format options for numerical values*



| | | | | | |
|---|---|---|---|---|---|
| 0.054 | 0.0893 | 0.0626 | 0.0491 | 0.0106 | 0.0046 |
| 0.0496 | 0.0808 | 0.0574 | 0.051 | 0.0103 | 0.0043 |
| 0.0445 | 0.0763 | 0.0499 | 0.0466 | 0.0099 | 0.006 |
| 0.0387 | 0.0692 | 0.0466 | 0.046 | 0.01 | 0.0067 |
| 0.0337 | 0.0679 | 0.0457 | 0.042 | 0.0116 | 0.0067 |

*Figure 62: Options for showing/hiding columns, downloading as .csv, and searching are available when clicking on the relevant icons at the top right side if the tables.*

When the user uploads the correct file for the angles in the substations of the system (i.e. 'cosphi' file), they can view the relevant information by clicking on the 'View' icon (Figure 63).

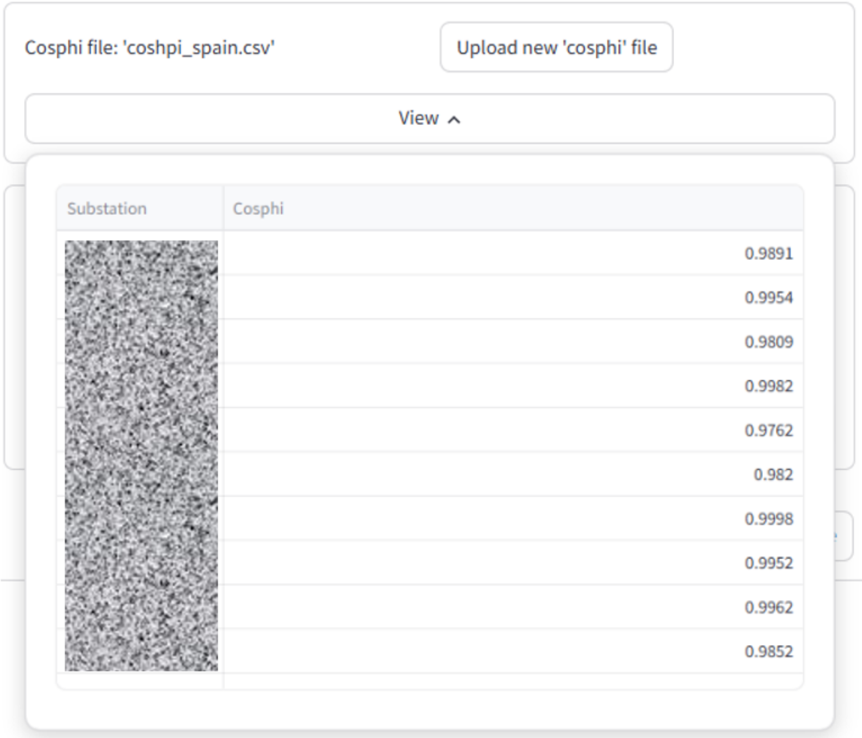



*Figure 63: When the user uploads the 'cosphi' file, they can view the relevant information by clicking on the 'View' icon.*

Next, the user should select the power flow parameters (Figure 64):

- Planning Years: The number of years to be considered for planning
- Load Growth Rate (%): The growth rate (percentage) for the load, that is expected each year.

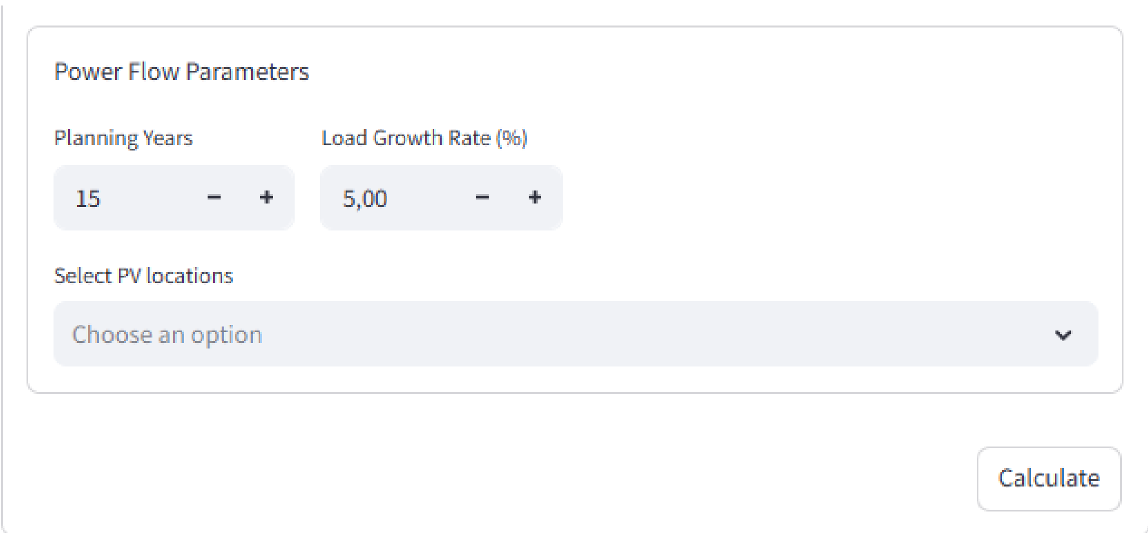



*Figure 64: The user should select the power flow parameters.*

The user also has the option to select whether PVs will be installed within the planning period. In this case, the user should select the PV Power for each location, as well as the year (i.e. 'PV Installation Years') when the PVs will be installed in each location (Figure 65).

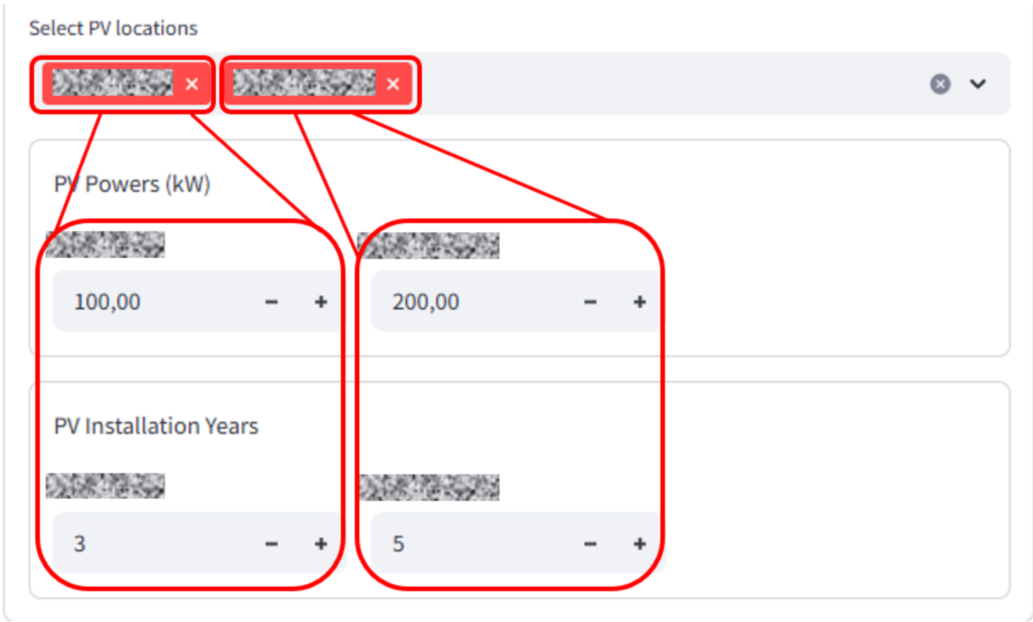



*Figure 65: The user has the option to select the parameters for PV installation.*

Finally, the user should click on 'Calculate' at the bottom of the screen (Figure 66). A status bar appears to inform the user on the process of calculating the Power Flow results (Figure 67)

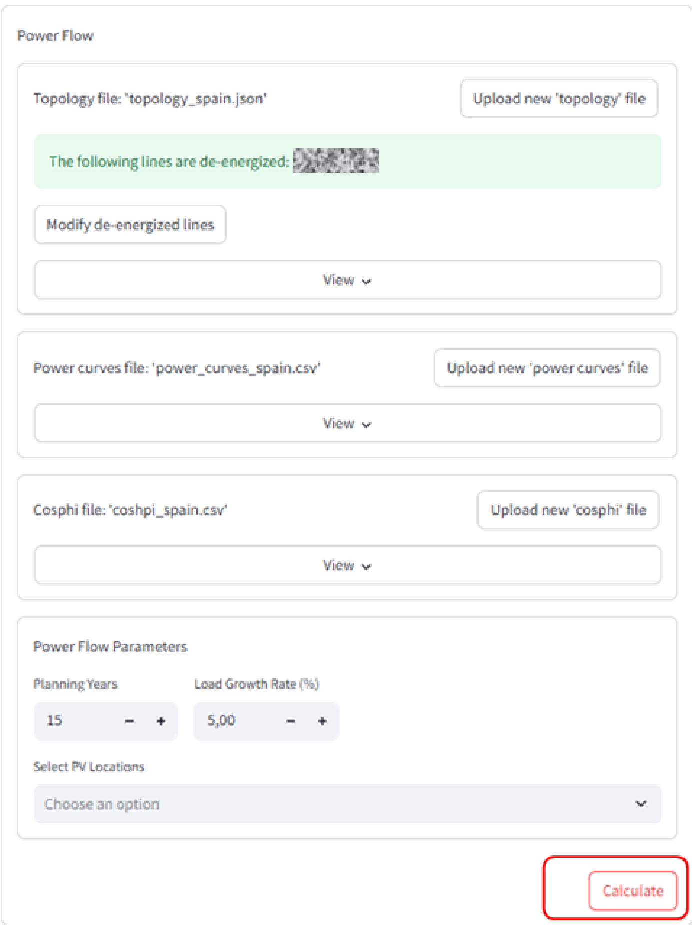



*Figure 66: The user should click on 'Calculate' at the bottom of the screen to start the Power Flow analysis.*

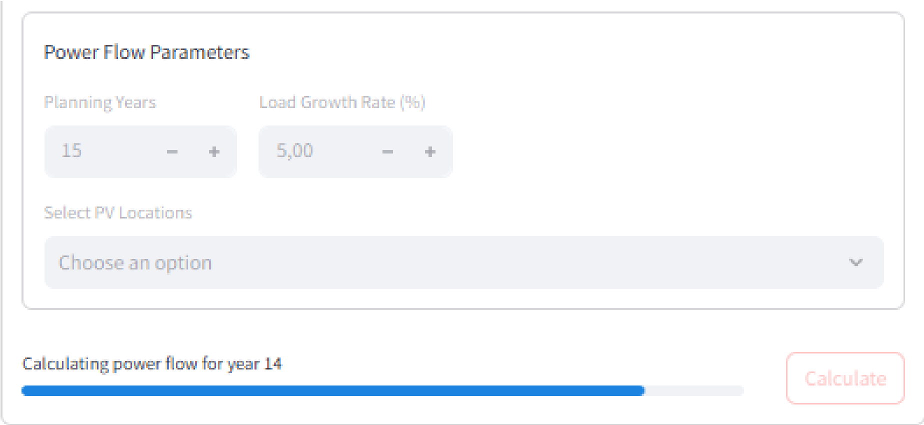



*Figure 67: Status bar for the process calculating the Power Flow results.*

After the relevant calculations take place, the user can click on 'Power Flow Results' (Figure 68) to view the relevant results. The following tabs are available:

- Analysis
- Graphs
- Map

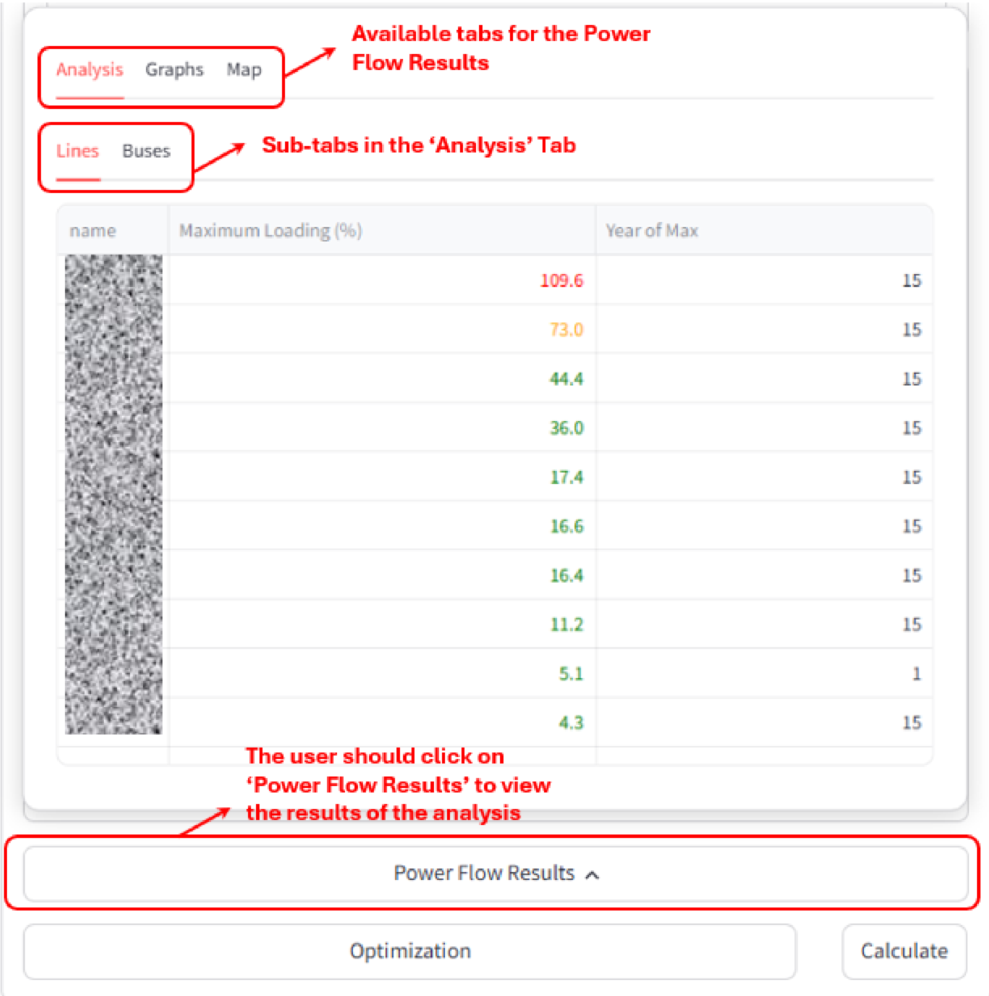



*Figure 68: The user should click on 'Power Flow Results' to view the relevant results*

In the 'Analysis' tab, in the 'Lines' sub-tab, the user can view results on the expected maximum loading of lines and the relevant year (Figure 68) it takes place.

Information is also available for the system's buses, as depicted in Figure 69, within the 'Buses' sub-tab. In this case the user can view:

- Maximum Voltage, and the year it takes place (column 'Year of Max'),
- Minimum Voltage, and the year it takes place (column 'Year of Min'),

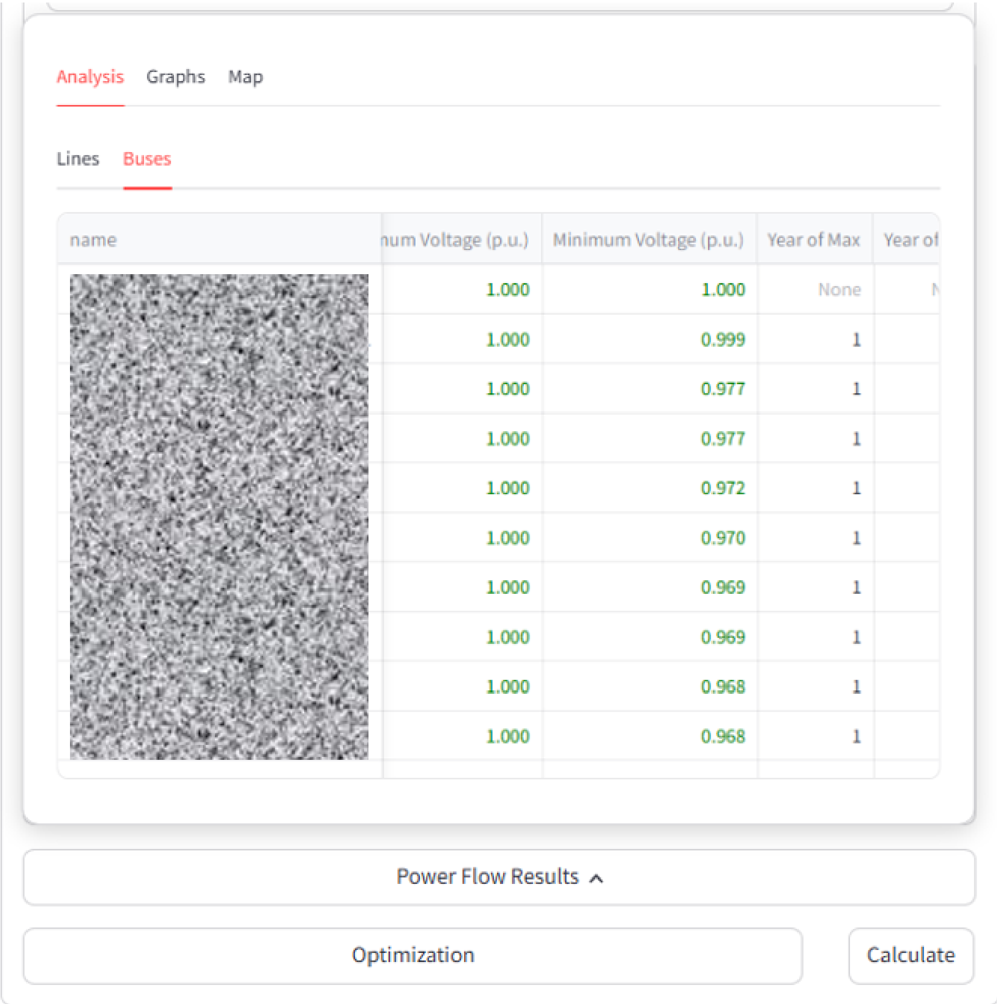
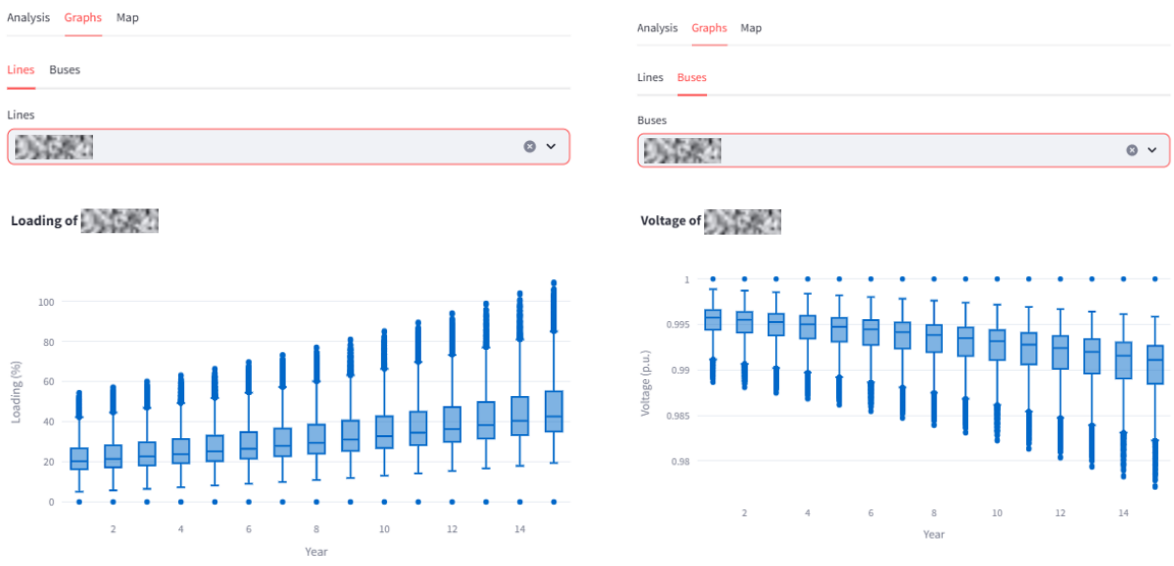



*Figure 69: Information on buses in the 'Analysis' tab.*

Different coloring in the values for the lines/voltages indicates their loading status:

- Green: No issue is expected in the line
- Yellow: The loading of the line is increased, but no issue is noted
- Red: The loading of the line is critical
- Dark red: The loading of the line has exceeded the nominal one (greater than 100%)

The user can view the relevant information for the system's lines and buses in the form of diagrams in the 'Graphs' tab (Figure 70). After the user selects the required line or bus they can view the relevant boxplots, indicating information on the maximum, minimum, etc. voltage/loading (for selected lines/buses).




(a) (b)

*Figure 70: 'Graphs' tab with information on (a) lines and (b) buses.*

The user can further interact with the diagrams, by hovering over the boxplots, as depicted in Figure 71. They can view the max/min value, the upper/lower fence, q1/q3/median values, for each examined planning year. By clicking on the icons at the top right corner of the diagram (Figure 71) additional options are available, like 'Download plot as png', Zoom in/out, Autoscale, etc.

The above-mentioned options, visible at the top right corner of diagrams, are available for all diagrams that are presented within the network planning tool.

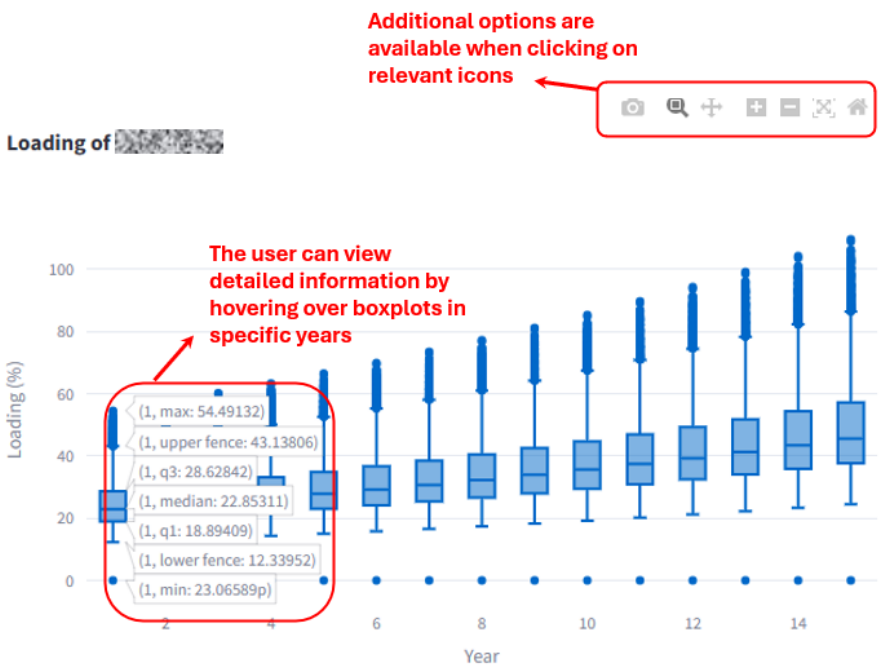



*Figure 71: 'Indicative boxplot in the graphs tab.*

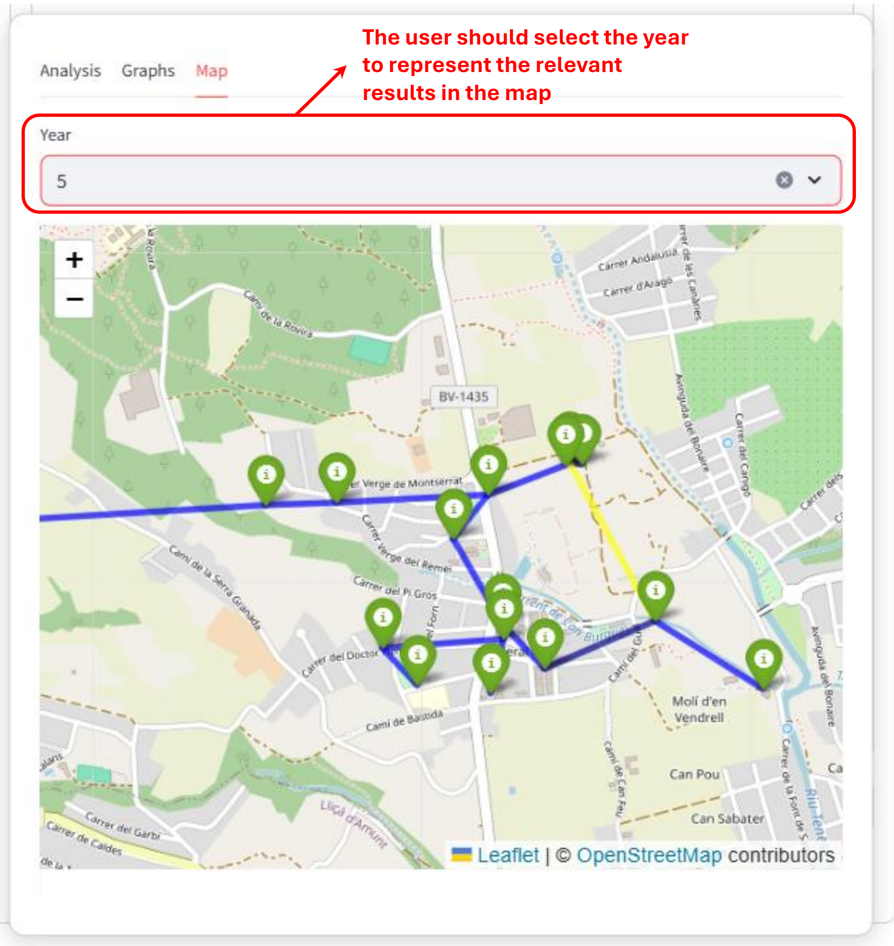
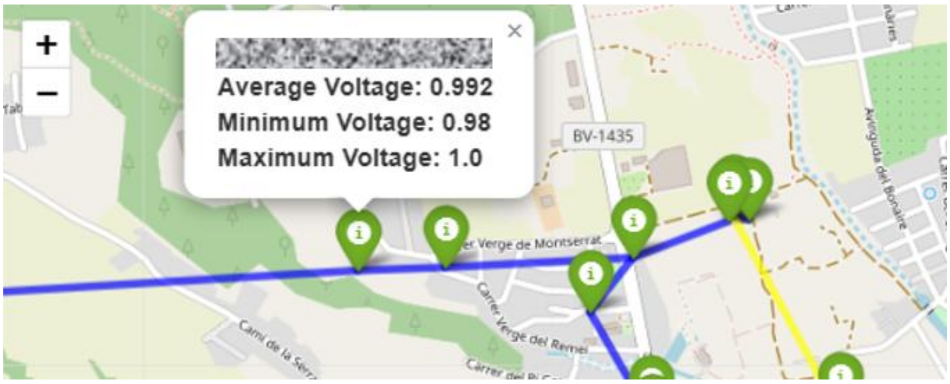



*Figure 72: 'Maps' tab*

The user can also view the results represented in a map, as depicted in the 'Maps' tab in Figure 72. In this case, the user should select the specific year to view results for. The user can then click on a specific bus or line to view detailed results on the values of the voltages and the loading of the lines respectively (Figure 73).




*(a)*


*(b)*

*Figure 73: In the 'Maps' tab the user can click on specific (a) buses or (b) lines, to view the relevant information regarding a specific year.*

A different coloring in the lines indicates their loading (Figure 74):

- Blue: The loading is lower than 25%
- Dark Blue: the loading is between 25% and 50%
- Yellow: The loading is between 50% and 75%
- Red: The loading is greater than 75% but lower than 100%
- Dark red: The loading is greater than 100%

A different coloring also indicates the voltage value in the buses:

- Green: the average voltage is greater than 0.96 p.u. and lower than 1.04 p.u.
- Orange: the average voltage is between 1.04 and 1.08 p.u.
- Red: the average voltage is greater than 1.08 p.u.
- Light Blue: The average voltage is between 0.92 and 0.96 p.u.
- Blue: The average voltage is lower than 0.92 p.u.

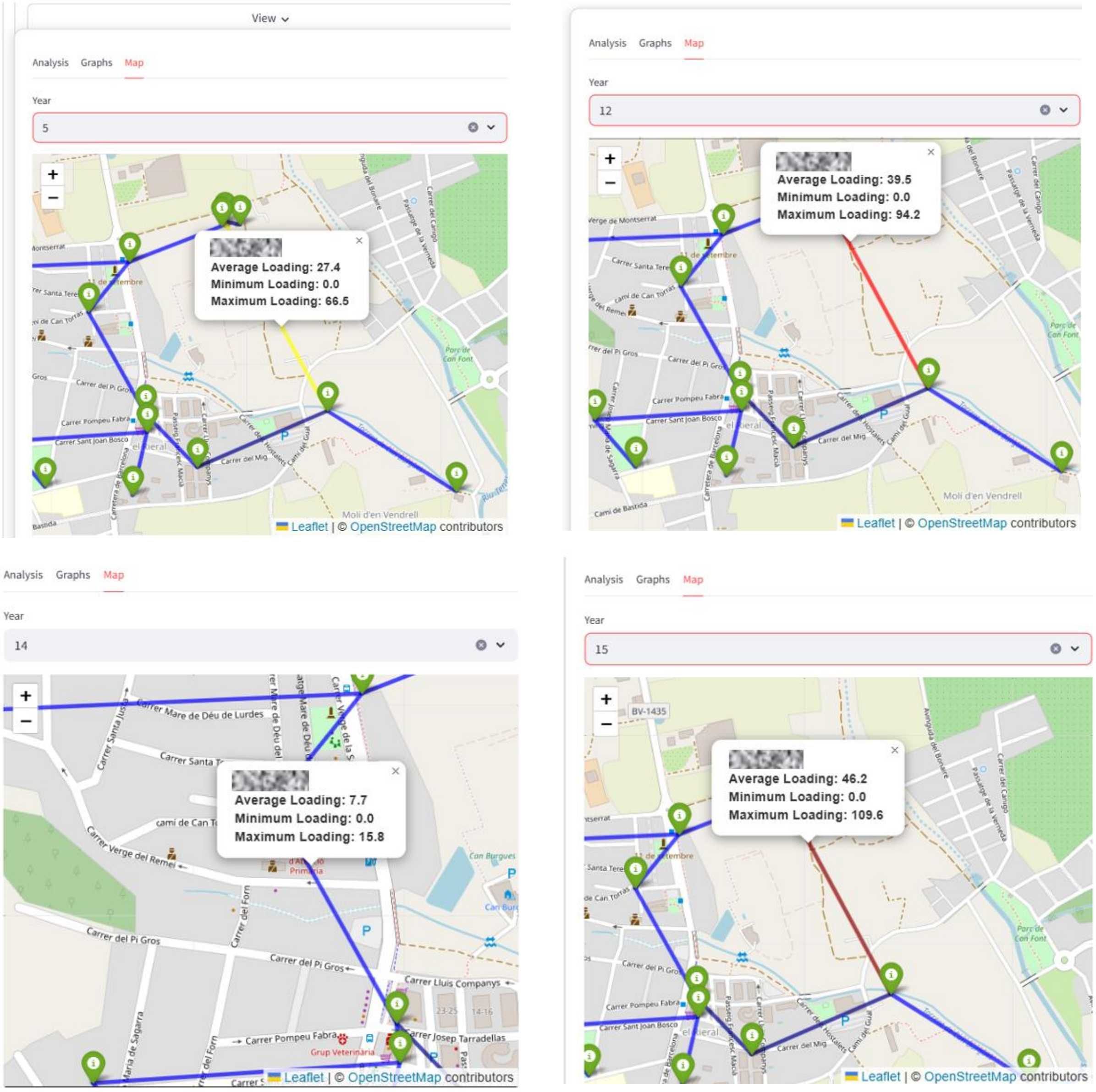



*Figure 74: The coloring of the lines indicates their loading status*

#### 4.4.2.3 Optimization

After the calculation of the power flow results, the user can proceed with the optimization for planning. The user should click on the 'Optimization' button at the bottom of the screen as depicted in Figure 75.

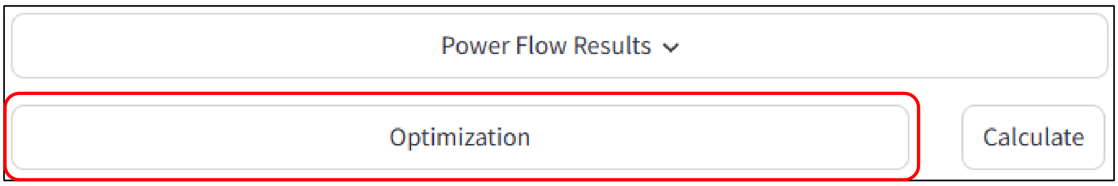



*Figure 75: The user should click on the 'Optimization' button at the bottom of the screen, to proceed with the optimization for planning*

The general view of the 'Optimization' screen is presented in Figure 76. Initially the user should upload the 'line types' file with information on the lines of the system. The user can upload the relevant file, either by clicking on 'Browse files' or by dragging and dropping the file in the relevant field. In case a file with the incorrect format is uploaded, the user is notified accordingly (Figure 77).

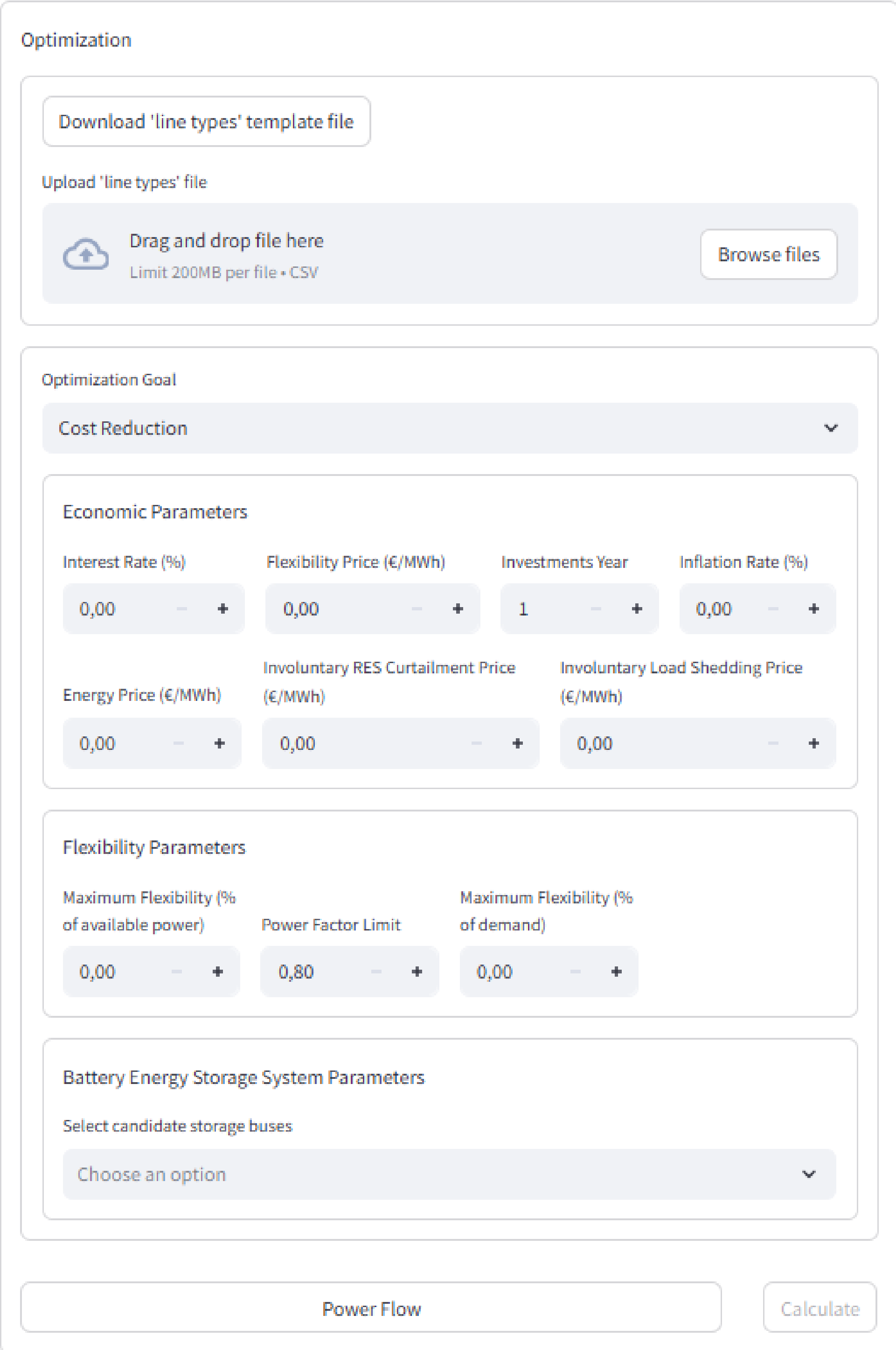



*Figure 76: General view for 'Optimization'*

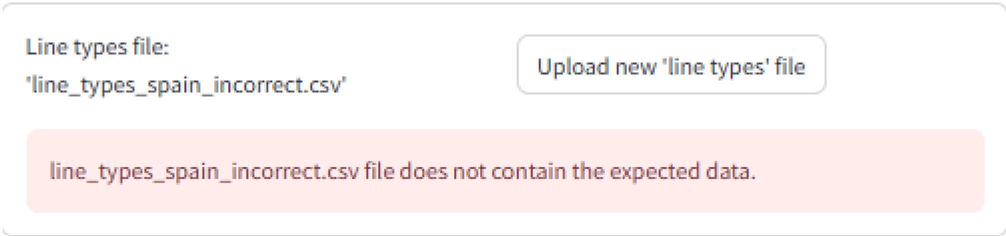



*Figure 77: In case a Line types file with the incorrect format is uploaded, the user is notified accordingly*

The line types file must be provided in CSV format with UTF-8 encoding. Each row in the file should include the following fields in the specified order:

- Name (string): The unique identifier for the line.
- r_ohm_per_km (float): Electrical resistance per kilometer in ohms.
- x_ohm_per_km (float): Electrical reactance per kilometer in ohms
- max_i_ka (float): Maximum current for the line in kA
- cost_per_km_€: (float): The cost for upgrading the line in €/km
- type (string): Indicates the type of installation. Accepted values are OH (Overhead) or UG (Underground).

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Name | r_ohm_per_km | x_ohm_per_km | max_i_ka | cost_per_km_€ | type |
| 2 | [illegible] | 0.614 | 0.374 | 0.2 | 46814.00 | OH |
| 3 | [illegible] | 0.262 | 0.102 | 0.3 | 57217.00 | OH |
| 4 | [illegible] | 0.403 | 0.12 | 0.25 | 94570.00 | UG |
| 5 | [illegible] | 0.262 | 0.117 | 0.315 | 105078.00 | UG |
| 6 | [illegible] | 0.161 | 0.105 | 0.415 | 115585.00 | OH |
| 7 | | | | | | |

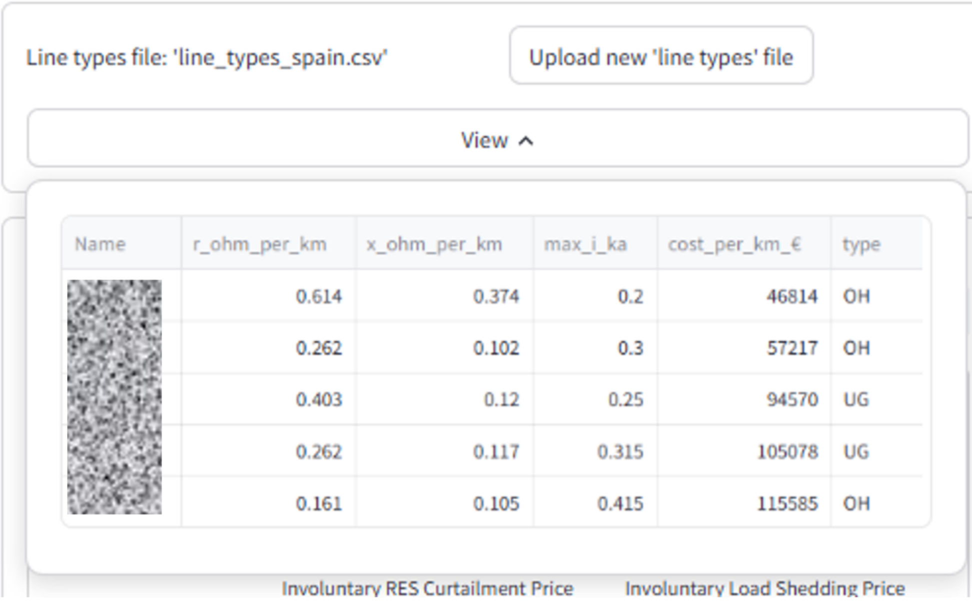
*Figure 78: line types csv file format*

When the user uploads the Line types file with the expected format, they can view the relevant information as a table, by clicking on the 'View' button (Figure 79).

At the next step, the user should select the Optimization goal in the drop-down list that appears in Figure 80:

- Cost Reduction
- Investment Deferral
- Optimal Investment for RES Maximization

Information on the optimization model that is used for each goal is provided in D5.3.




| Name | r_ohm_per_km | x_ohm_per_km | max_i_ka | cost_per_km_€ | type |
|---|---|---|---|---|---|
| [illegible] | 0.614 | 0.374 | 0.2 | 46814 | OH |
| [illegible] | 0.262 | 0.102 | 0.3 | 57217 | OH |
| [illegible] | 0.403 | 0.12 | 0.25 | 94570 | UG |
| [illegible] | 0.262 | 0.117 | 0.315 | 105078 | UG |
| [illegible] | 0.161 | 0.105 | 0.415 | 115585 | OH |

*Figure 79: The user can view the information included in the Line types file represented in a table, by clicking on the View button*

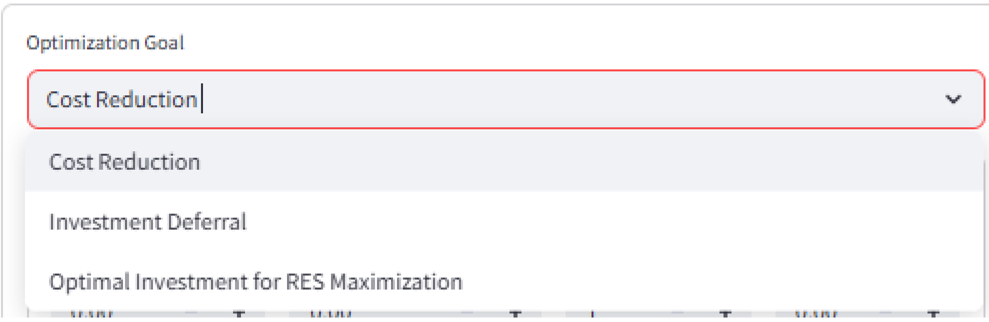



*Figure 80: The user should select the Optimization goal.*

For the 'Investment deferral' and 'Cost reduction' goals the user should set the following parameters for the optimization:

1. Economic Parameters
2. Flexibility Parameters
3. Battery Energy Storage Parameters

In the E*conomic parameters* the user should fill in the following fields:

- ✓ Interest rate: The interest rate considered for the investment evaluation
- ✓ Inflation rate: The inflation rate considered for the investment evaluation.
- ✓ Flexibility Price (€/MWh)
- ✓ Investments Year: Investments are only allowed after this specific year.
- ✓ Involuntary RES Curtailment Price (€/MWh): The cost (in €/MWh) for curtailing RES production
- ✓ Involuntary Load Shedding Price (€/MWh): The cost (in €/MWh) for curtailing part of the system's load.

In the *Flexibility parameters* the user should fill in the following fields:

- ✓ Maximum Flexibility (% of available power): The flexibility that can be offered by RES

- ✓ Power Factor Limit: The limit in the power factor in relation to RES
- ✓ Maximum Flexibility (% of demand): The flexibility that can be offered by the system's demand

In the *Battery Energy Storage System Parameters* the user should initially select the buses where storage will be installed (Figure 81). Then the user should fill in the following fields:

- ✓ Power Capacity Price (€/MW)
- ✓ Energy Capacity Price (€/MWh)
- ✓ Min Capacity (MW)
- ✓ Max Capacity (MW)
- ✓ Efficiency (%)
- ✓ Power Factor Limit
- ✓ Initial SoC (%)
- ✓ Min SoC (%)
- ✓ Max SoC (%)

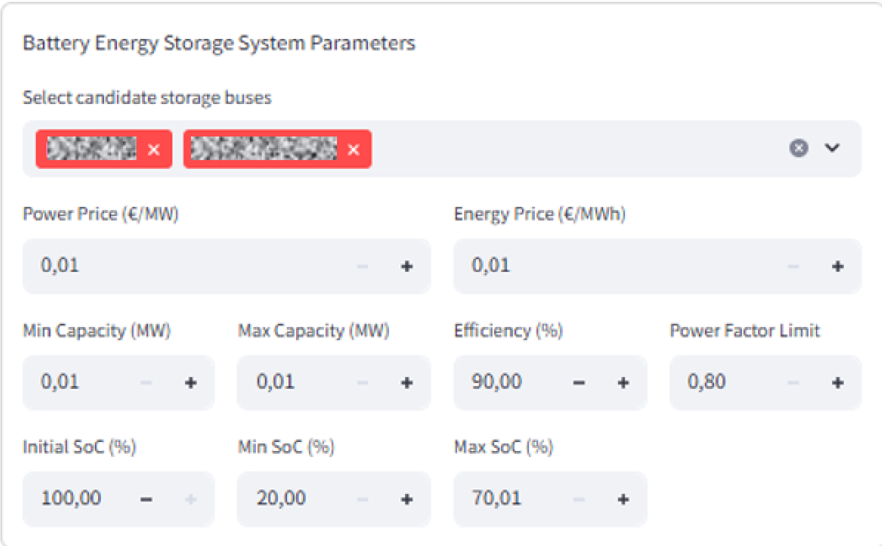



*Figure 81: Battery Energy Storage System Parameters*

After providing all the required parameters, the user should click on 'Calculate' at the bottom right corner of the screen to start the optimization process (Figure 82). A status bar appears to inform the user on the process of the optimization analysis (Figure 83).

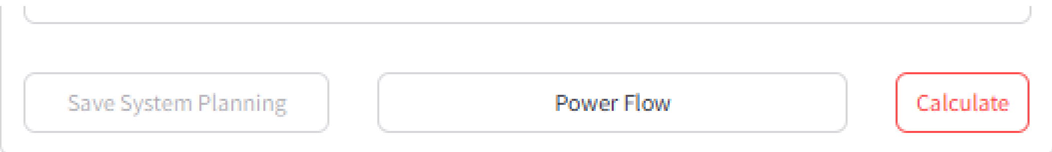



*Figure 82: The user should click on 'Calculate' at the bottom right corner of the screen to start the optimization process*

After the optimization process has finished the user can view the optimization results by clicking on 'Optimization Results' (Figure 84). Two tabs are available in the Optimization Results: 'Costs' and 'Upgrades'. In the Costs Tab the user can view information on the system's cost for each examined year (Figure 84).

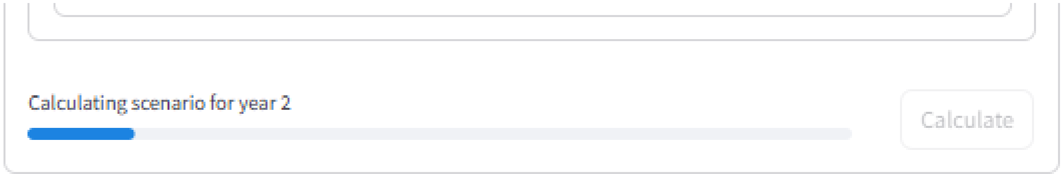



*Figure 83: Status bar to inform the user on the process of the optimization analysis*

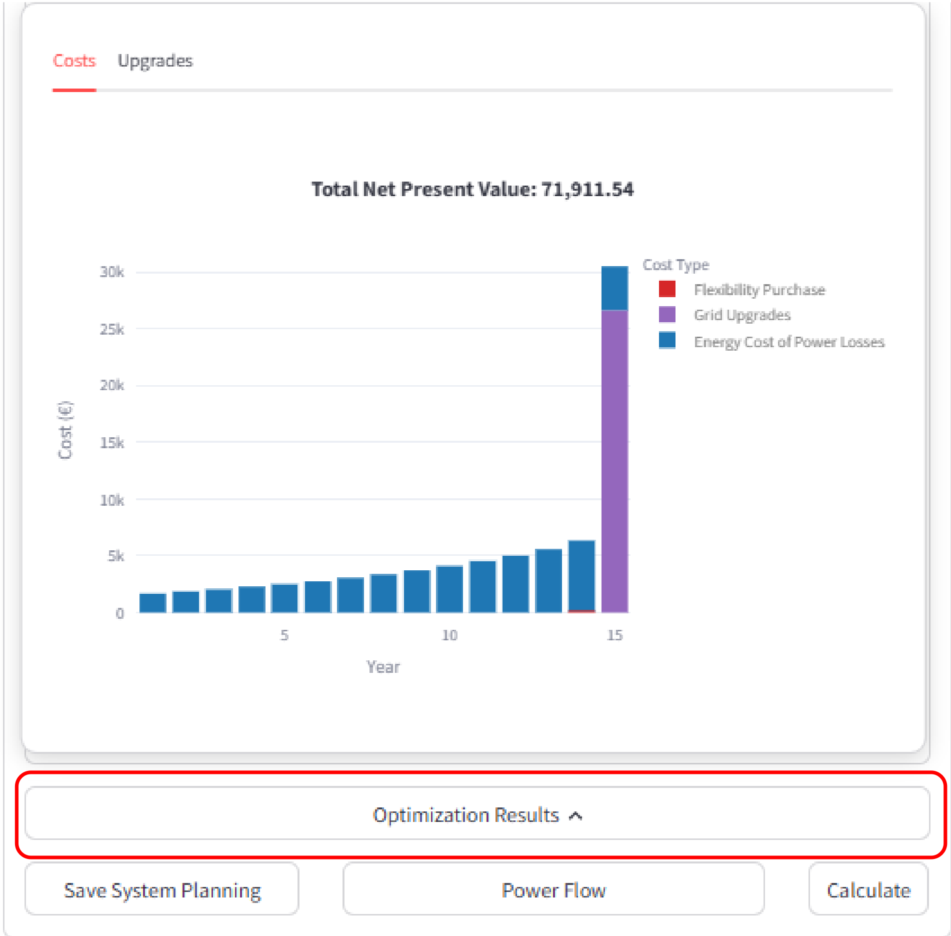
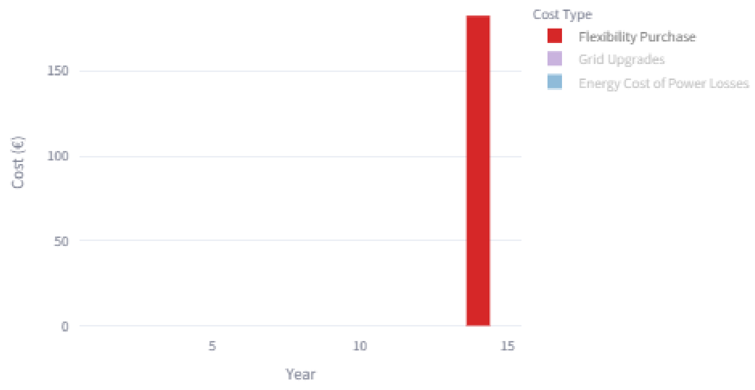
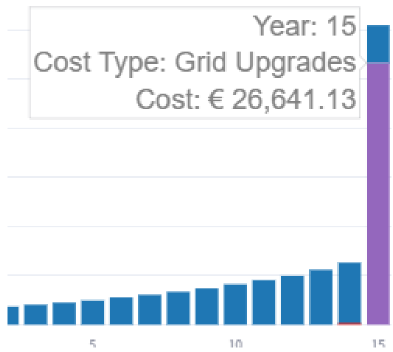



*Figure 84: The user can view the optimization results by clicking on 'Optimization Results'. In the Costs Tab the user can view information on the system's cost for each examined year.*

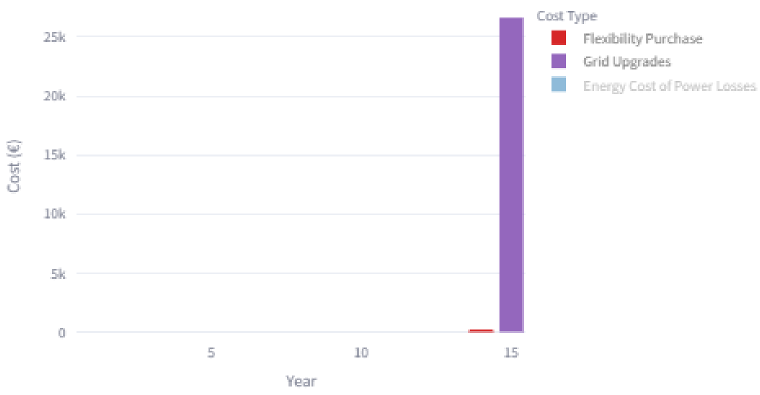
When the user hovers the pointer above a specific bar for a specific year, detailed information appears for the costs, as depicted in Figure 85-c. The user can also interact with the diagram to view specific costs. Double clicking on a specific cost results in the display of just the relevant cost in the diagram (Figure 85-a). When the user (single) clicks on a specific cost in the legend, this cost is removed from the diagram (Figure 85-b).




(a)

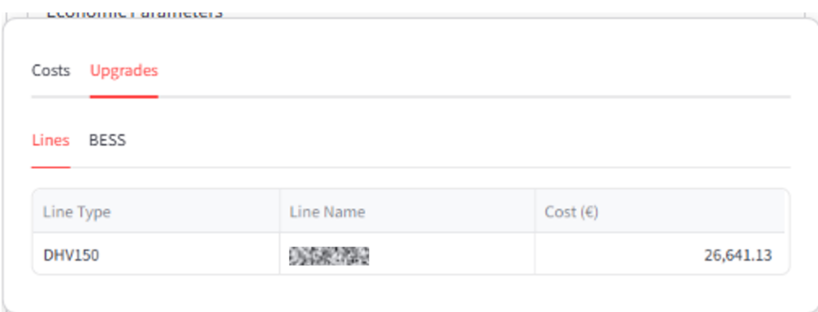



(c)

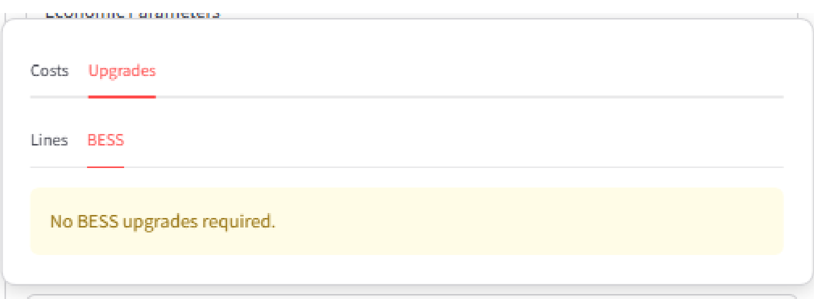



(b)

*Figure 85: The user can interact with the diagram in the 'Costs' Tab: (a) The user double clicks on 'Flexibility Purchase' in the legend to view the relevant cost results, (b) the user (single) clicks on 'Energy Costs of Power Losses' in the legend to remove the relevant costs from the diagram, (c) The user hovers the pointer over the bar for year-15 to view detailed information for this specific year,*




(a)




(b)

*Figure 86: In the 'Upgrades' tab of the 'Optimization Results', the user can view information on the upgrades related to: (a) the lines of the system and (b) the BESS.*

In the 'Upgrades' tab of the 'Optimization Results', the user can view information on the upgrades related to the lines of the system and the BESS. The 'Lines' sub-tab displays information on the name of the line that needs to be upgraded, the relevant cost, and the relevant line type (Figure 86-a). Information for the upgrades related to the BESS is provided in the 'BESS' tab (Figure 86-b).

Regarding the optimization goal of 'Optimal Investment for RES Maximization' (Figure 87), the user should fill in the Economic and Flexibility Parameters.

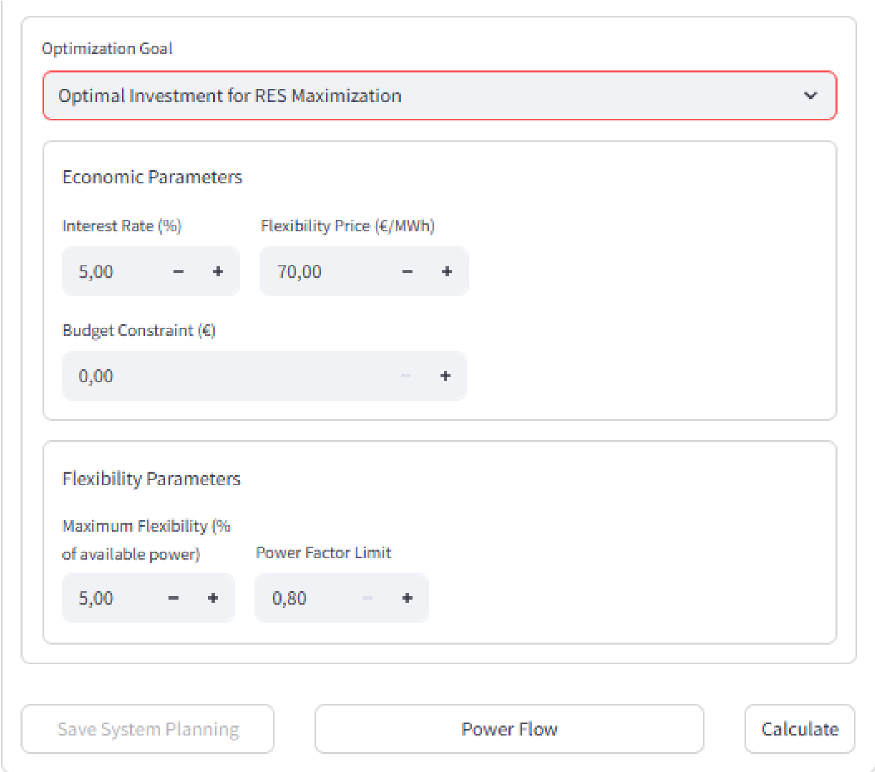



*Figure 87: In the 'Optimal Investment for RES Maximization' goal, the user should fill in the Economic and Flexibility Parameters.*

In the *Economic parameters* the user should fill in the following fields:

- ✓ Interest rate: The interest rate considered for the investment evaluation
- ✓ Flexibility Price (€/MWh)
- ✓ Budget Constraint (€): The budget limit (in €) that is set for the required upgrades

In the *Flexibility parameters* the user should fill in the following fields:

- ✓ Maximum Flexibility (% of available power): The flexibility that can be offered by RES
- ✓ Power Factor Limit: The limit in the power factor in relation to RES

After filling the required fields, the user should click on 'Calculate' at the bottom right corner of the screen. When the optimization calculations are performed, the user can click on 'Optimization Results' to view the relevant results (Figure 88). Two tabs are available: 'Upgrades' and 'Hosting Capacity'. In the 'Upgrades' tab, the user can view the required upgrades to maximize the RES penetration in the distribution grid. In particular, the user can view the name of the line that needs to be upgraded, the relevant line type, as well as the relevant upgrade cost (Figure 88).

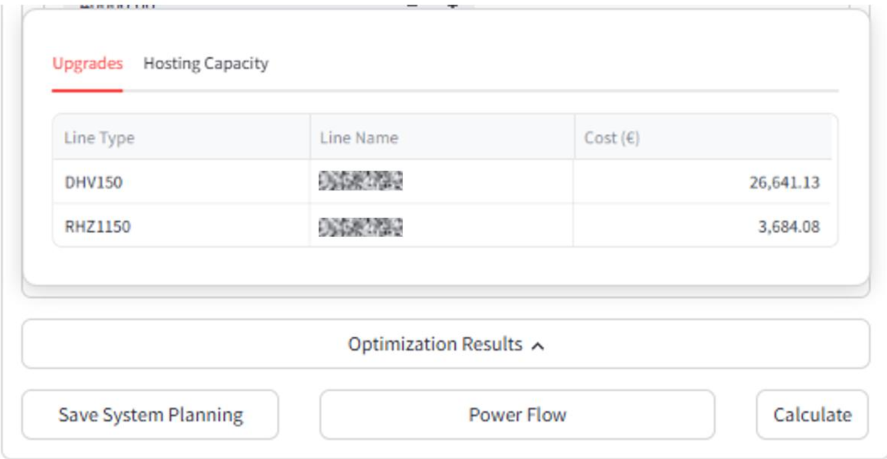



*Figure 88: The user can view the optimization results by clicking on 'Optimization Results'. In the 'Upgrades' tab, the user can view the required upgrades to maximize the RES penetration.*

In the 'Hosting Capacity' tab, the user can view the total RES hosting capacity (at the top line of the table), as well as the RES hosting capacity in each bus (Figure 89).


*Figure 89: In the 'Hosting Capacity' tab, the user can view the RES hosting capacity (total and in each bus).*

#### 4.4.2.4 Saving and Loading Results

After the calculation of the Optimization Results, the user has the option of saving the relevant results. In this case, the user should click on the 'Save System Planning' icon at the bottom of the screen, as depicted in Figure 90.

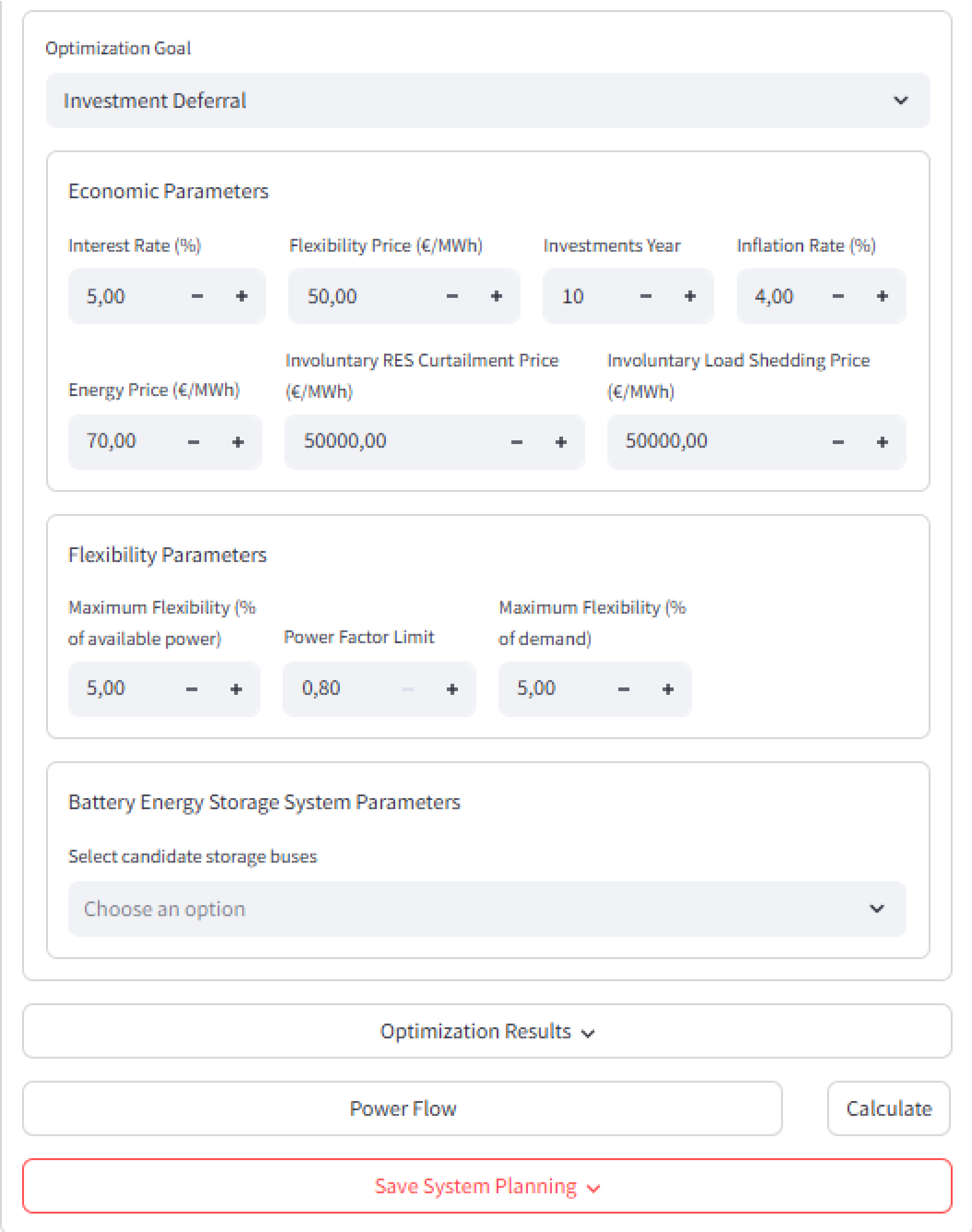



*Figure 90: The user can save the optimization results*

The user should provide a name for the relevant optimization results, as well as an indicative description (Figure 91). Finally, the user should click on the 'Save' icon (Figure 91). A processing icon appears to inform the user that the tool is saving the results, as depicted in Figure 92. Afterwards, a notification message appears to inform the user that the Optimization Results are successfully saved (Figure 93).

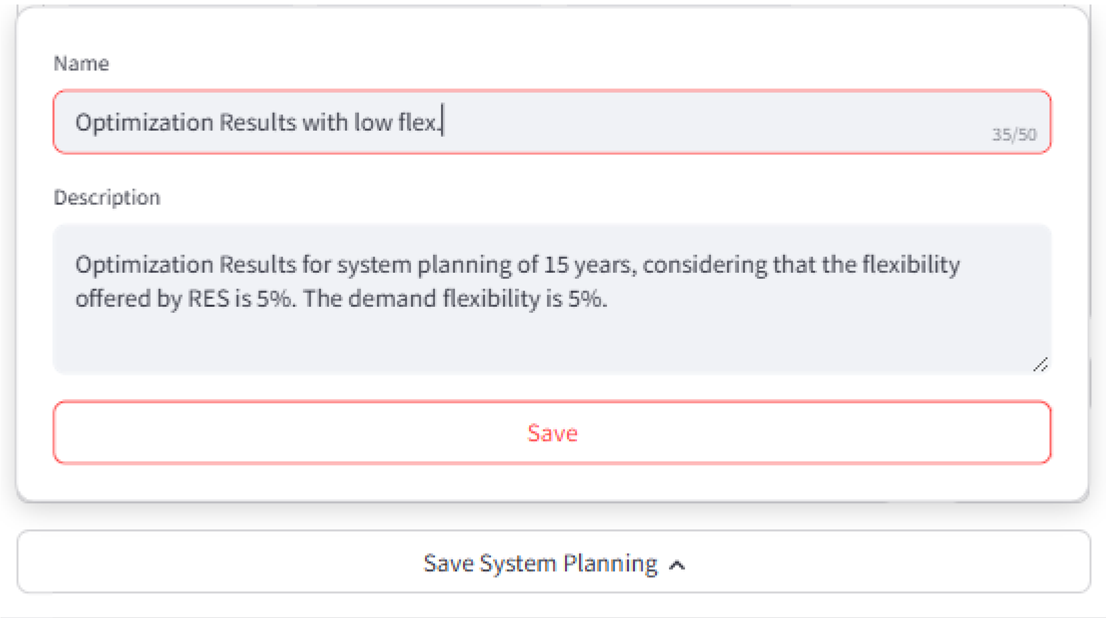



*Figure 91: The user provides a name and a description, before saving on the optimization results.*

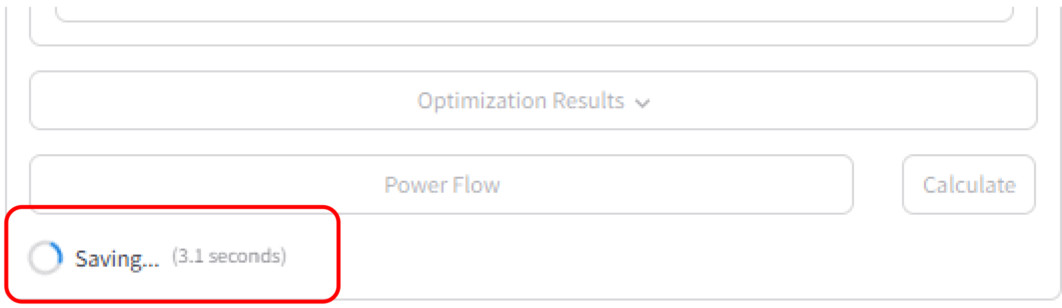



*Figure 92: The tool is saving the Optimization Results*

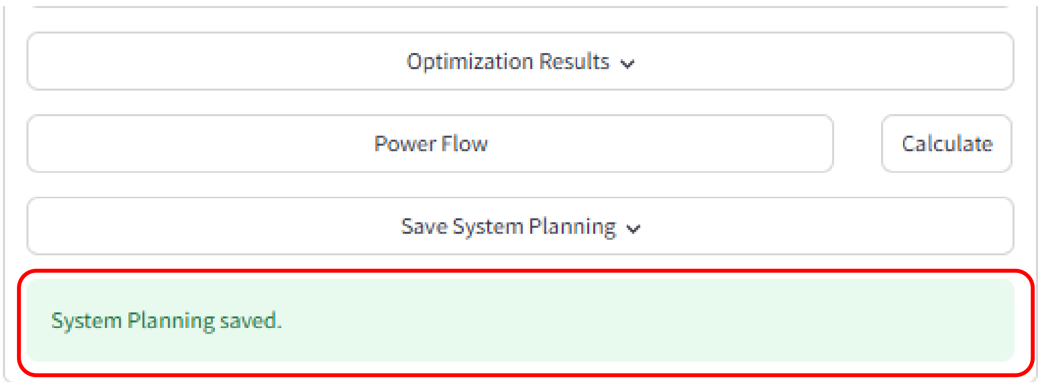



*Figure 93: The Optimization Results are saved successfully*

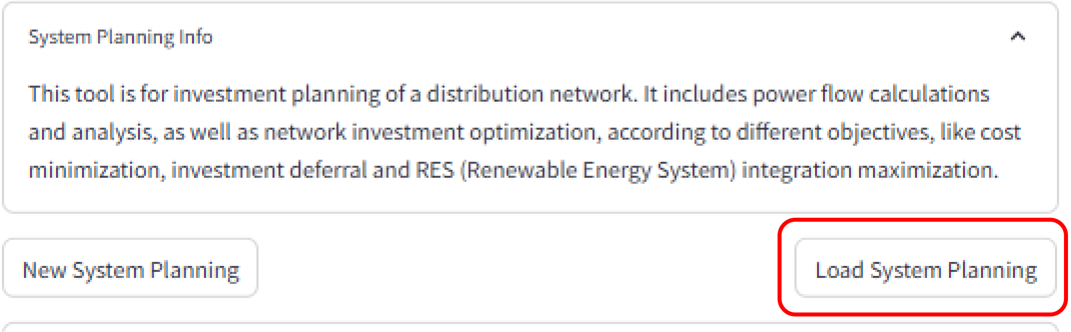



*Figure 94: Load System Planning icon at the up right corner of the screen.*

In order to load the relevant results, the user can click on the 'Load System Planning' icon at the up right corner of the screen (Figure 94). Afterwards, a drop-down list with the names of the relevant saved results appears (Figure 95). After the user has selected the relevant results, information on the date that they were created, as well as the relevant description that the user has provided is presented (Figure 96). The user should click on the icon 'Load System Planning' to proceed with viewing the relevant optimization results (Figure 96).

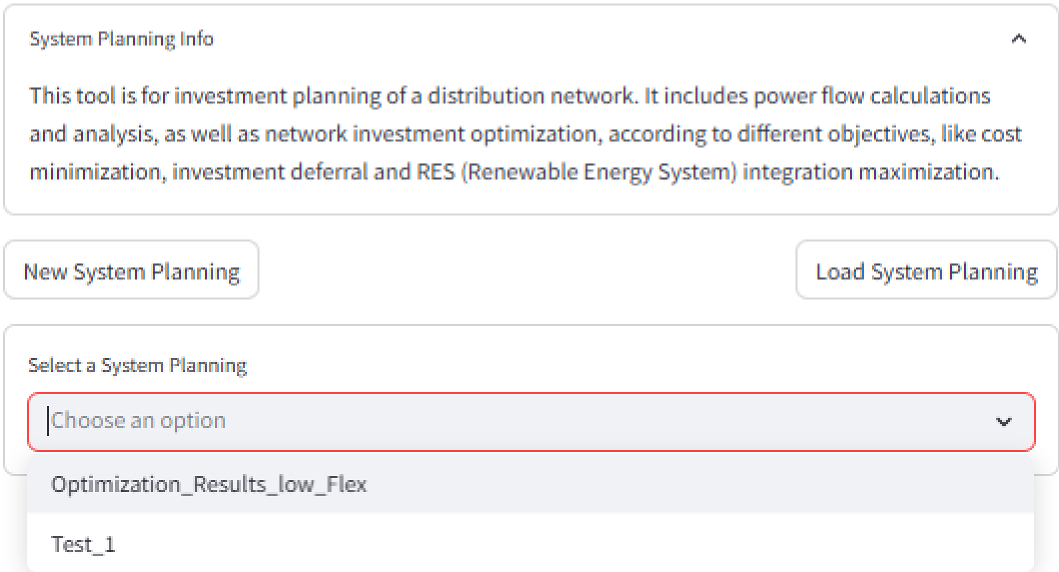



*Figure 95: Drop-down list with the names of the relevant saved results.*

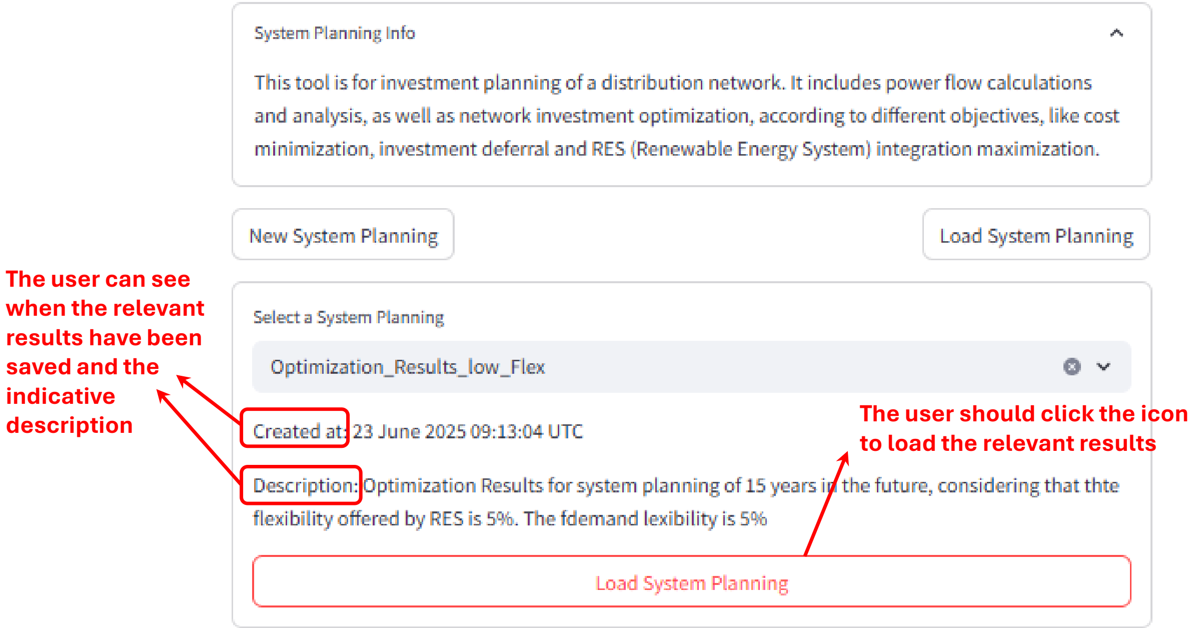



*Figure 96: Information on when the selected optimization results have been saved and the indicative description. The user should click on the icon 'Load System Planning'.*

Once the user clicks on the 'Load System Planning' icon, a loading icon appears, informing the user that System Planning results are loading, as depicted in Figure 97. When the results are loaded, the parameters selected by the user when they saved the results can be viewed, as depicted in Figure 98.

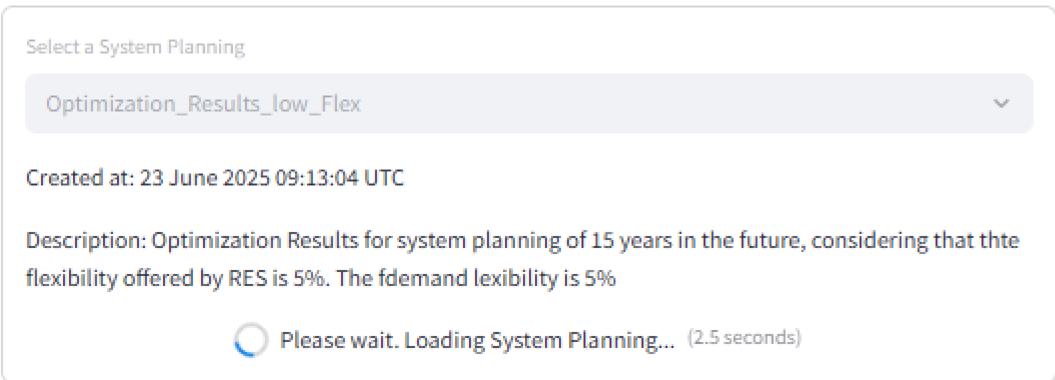



*Figure 97: Loading icon to inform the user that System Planning results are loading.*

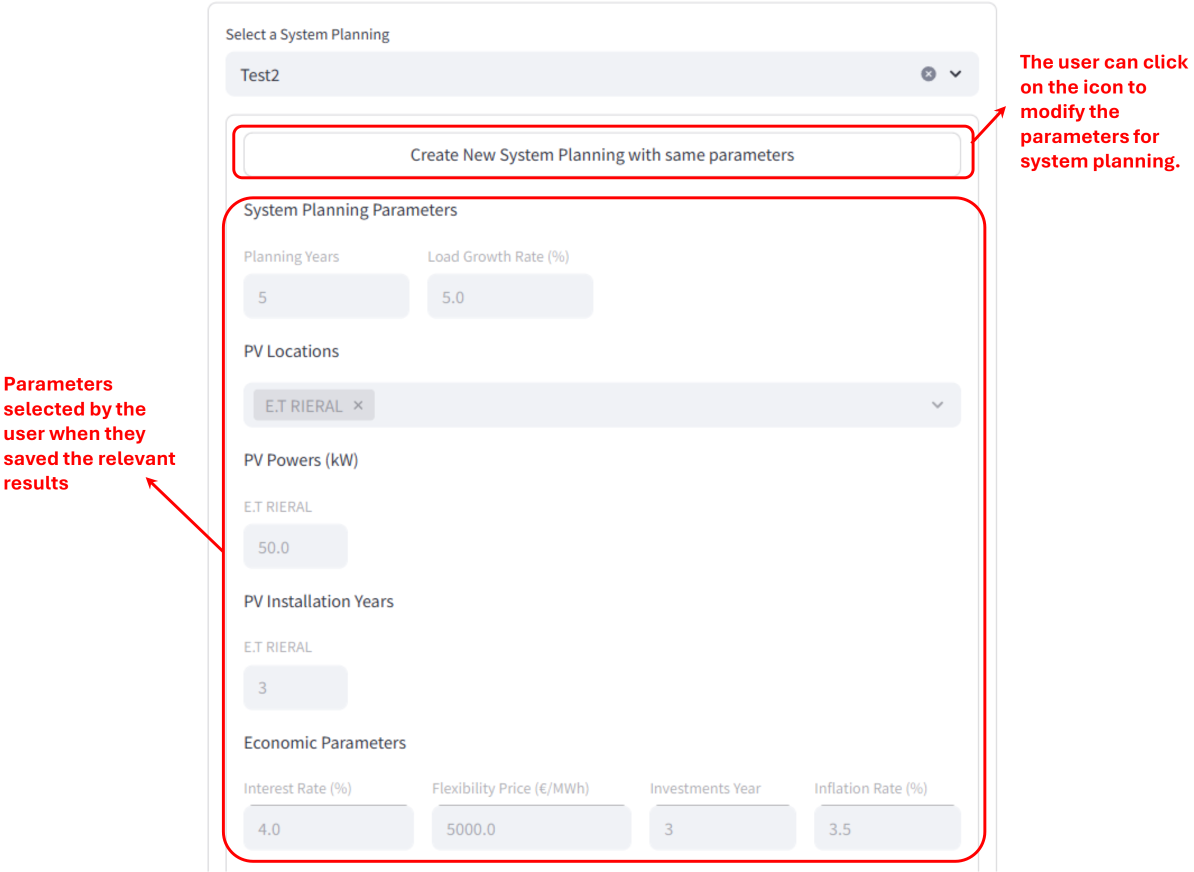



*Figure 98: When loading System Planning results, the user can view the relevant parameters. The user can also modify the parameters by clicking on the relevant icon.*

Below the relevant parameters, when clicking on the 'View' icon (Figure 99), the user can view:

- *Optimization Data*: Optimization results linked to the objective/goal that has been set by the user. Results are presented as described in Section 4.4.2.3:
  - ✓ *Investment Deferral*: The user can view the optimization results by clicking on the 'View' icon. In the 'Costs' Tab, the user can view information on the system's cost for each examined year (Figure 84). In the 'Upgrades' tab, the user can view information on the upgrades related to the lines of the system and the BESS, as depicted in Figure 86.
  - ✓ *Cost Reduction*: The results presented are similar to the 'Investment Deferral' goal
  - ✓ *Optimal Investment for RES Optimization*: The user can view the optimization results by clicking on the 'View' icon. In the 'Upgrades' tab, the user can view the required upgrades to maximize the RES penetration (Figure 88). In the 'Hosting Capacity' tab, the user can view the total RES hosting capacity, as well as the RES hosting capacity in each bus (Figure 89).
- *Power Flow Data*: Data regarding the power flow analysis, as performed when the user saved the relevant results. By clicking on the 'View' icon the user can view the power flow results as described in Section 4.4.2.2. The initial view of the results is similar to the one presented in Figure 68, with information on the system's lines (Figure 68), system's buses (Figure 69), Graphs' tab with information on lines and buses (Figure 70), and results in the map, as depicted in the 'Maps' tab (Figure 72):
- *Topology map*: Map of the provided topology as presented in Figure 55

- *Power Curves Data*: Information on the load of the system in each bus according to the input data provided by the user (Figure 60)
- *Cosphi Data*: Information for the angles of the system's substations according to the input data provided by the user (Figure 63)
- *Line Types Data*: Information on the lines of the system, according to the input data provided by the user (Figure 79).

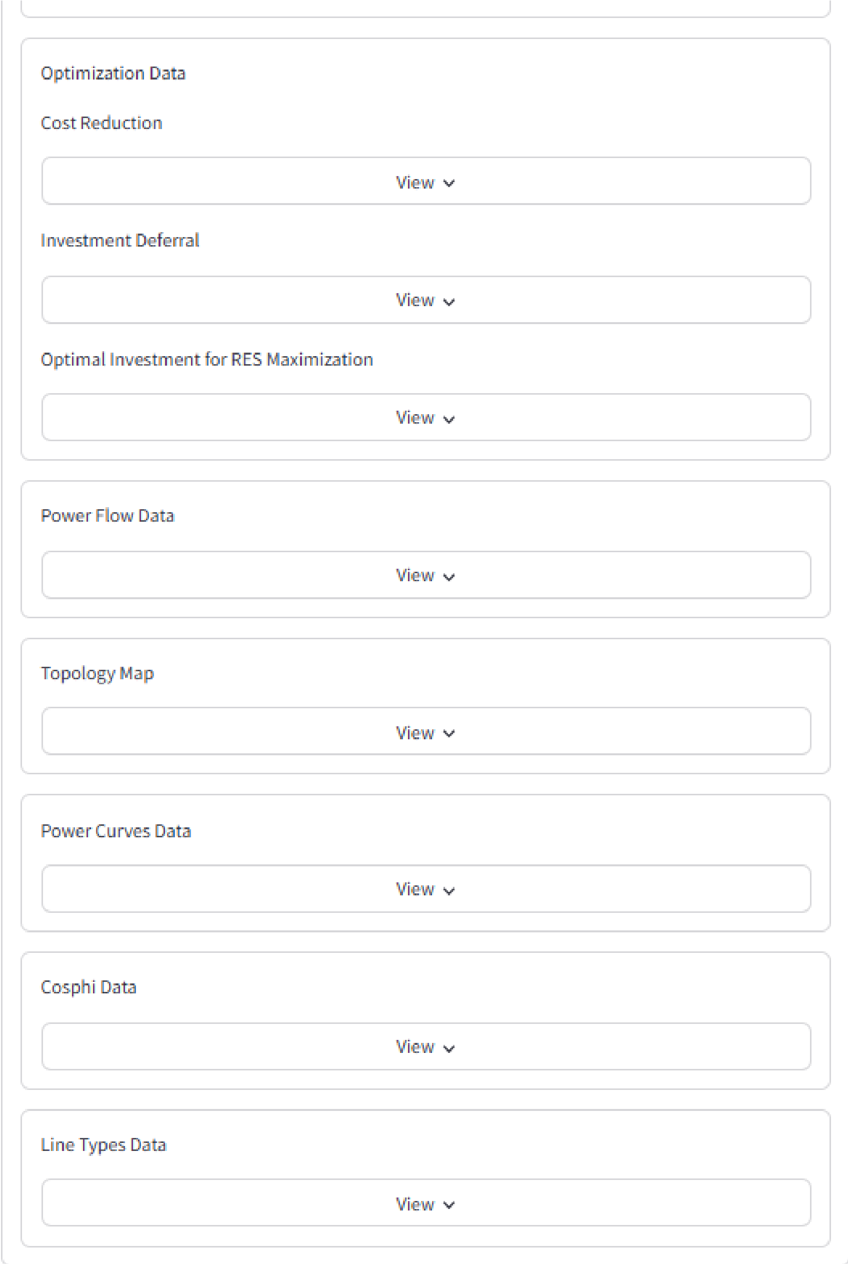



*Figure 99: When loading the optimization results, the user has the option to view data related to optimization calculations, Power flow analysis, and input data (topology map, power curves, cosphi and line types).*

In case the user would like to modify the initial parameters for the System Planning, they can click on the icon 'Create New System Planning with same parameters', as presented in Figure 98. Once the user clicks this button, they will be directed to the New System Planning screen with the parameters pre-filled (Figure 64). The user can follow the same workflow as when creating a new System Planning and as described in Section 4.4.2.2. Since the results will be preloaded, the 'Power Flow' button will be available at any time to proceed to the 'Optimization' screen. The parameters in the 'Optimization' screen (Figure 76) will also be pre-filled, and in case the user would like to modify the parameters to receive new optimization results they can do so by following the workflow described in Section 4.4.2.3.

# 5 CONCLUSIONS

This deliverable presents the final developments of the OPENTUNITY modules that have been developed to offer capabilities for advanced asset management and intelligent distribution system planning. The developed modules offer a wide-ranging digital suite that supports grid resilience, improves decision-making, and facilitates the transition to a smarter, more sustainable energy system.

The deliverable focuses on the user interfaces for each module, which have been developed to ensure accessibility and usability in their application. Detailed user manuals were included to facilitate the adoption of the modules by system operators across pilot sites.

The Long-Term Asset Management module allows predictive maintenance for smart meters by estimating failure probabilities and generating end-of-life curves based on operational data and historical failure logs. The proposed method allows proactive replacement strategies and enhances the overall reliability of the grid. The developed UI allows users to upload smart meter data, generate and visualize end-of-life curves, identify high-risk meters (based on machine learning methods), and provides a map-based representation of critical meters.

The Short-Term Asset Management module offers near real-time monitoring of transformers through anomaly detection and short-term top-oil temperature forecasting, improving the capabilities for reaction and awareness of operators and minimizing service disruptions. The developed UI for this module provides dashboards for uploading historical logs, analyzing real-time asset health indicators (DGA, bushing alerts, top-oil anomalies), and forecasting transformer oil temperature.

The Non-Technical Losses Detection module introduces a hybrid machine learning methodology that combines a mix of data-oriented and network-oriented techniques to detect energy that has been consumed but not invoiced and can, thus, be considered fraud or energy theft. The relevant UI displays lines and network elements flagged for suspicious behavior, presents fraud evidence summaries, and highlights noteworthy lines on an interactive map.

The Network Planning Tool provides DSOs an intelligent platform for long-term planning of electrical distribution networks. The tool is designed to handle both traditional grid upgrades and the deployment of flexibility resources. It utilizes advanced mathematical programming methods offering different options for selected user objectives. The applied methodologies ensure results are delivered within minutes, making it practical for real-time scenario testing by DSOs. The UI for the planning tool allows users to configure planning parameters and execute power flow and multi-year optimization analyses based on selected objectives such as cost reduction, investment deferral, or RES maximization. It offers interactive visualizations, comprising maps, charts, and detailed tables, to display results related to power-flow (voltage levels, line loading, etc.) and planning (investment needs, RES hosting capacity, etc.). Finally, it allows users to save, reload, and modify planning scenarios through a user-friendly web-based interface.

# 6 ACRONYMS

| Acronym | Explanation |
|---|---|
| **AMI** | Advanced Metering Infrastructure |
| **ANN** | Artificial Neural Network |
| **BESS** | Battery Energy Storage System |
| **CNN** | Convolutional Neural Network |
| **DER** | Distributed Energy Resource |
| **DGA** | Dissolved Gas Analysis |
| **DMS** | Distribution Management System |
| **DSO** | Distribution System Operator |
| **EoL** | End-of-Life |
| **EPSG** | European Petroleum Survey Group (coordinate reference system, e.g., EPSG:4326) |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **IPTO** | Independent Power Transmission Operator (Greek TSO) |
| **KPI** | Key Performance Indicator |
| **LCL** | Lower Control Limit |
| **MILP** | Mixed-Integer Linear Programming |
| **MISOCP** | Mixed-Integer Second-Order Cone Programming |
| **ML** | Machine Learning |
| **MV** | Medium Voltage |
| **NTL** | Non-Technical Losses |
| **OH** | Overhead (line type) |
| **OLMS** | On-Line Monitoring System |
| **RES** | Renewable Energy Sources |
| **SFTP** | Secure File Transfer Protocol |
| **SCADA** | Supervisory Control and Data Acquisition |
| **SoC** | State of Charge |
| **TL** | Technical Losses |
| **TSO** | Transmission System Operator |

| | |
|---|---|
| **UCL** | Upper Control Limit |
| **UI** | User Interface |
| **UG** | Underground (line type) |
| **UHV** | Ultra High Voltage |
| **WP** | Work Package |