D5.2 – Final DSF Hybrid Simulation Engine

Deliverable ID	**D5.2**
Deliverable Title	**Final DSF Hybrid Simulation Engine**
Work Package	**WP5**
Dissemination Level	**PUBLIC**
Version	**1.0**
Date	**23/09/2019**
Status	**final**
Type	**Prototype**
Lead Editor	**FIT**
Main Contributors	**FIT, LINKS**

Published by the Storage4Grid Consortium

Document History

Version	Date	Author(s)	Description
0.1		FIT	First TOC draft
0.2	2019-07-11	FIT	DSF-SE text added
0.3	2019-07-15	LINKS	Frist draft of DSF-EE
0.4	2019-07-22	LINKS	Described DSF-SE Plug-in for Hybrid simulation
0.5	2019-08-05	LINKS	Final version of DSF-EE
0.7	2019-08-21	FIT	Figures updated, appendix added, formatting
0.8	2019-08-29	FIT	LINKS contribution updated, tables and references updated
0.9	2019-09-05	FIT	Updates from FIT after UPB's review
0.95	2019-09-06	FIT	Further updates from LINKS after UPB's review, updates from ALPERIA/EDYNA's review
1.0	2019-09-11	FIT	Final, approved version

Internal Review History

Review Date	Reviewer	Summary of Comments
2019-09-11	UPB	Approved with corrections
2019-09-06	Elia Kinigadner ALPERIA/EDYNA	Approved Minor Corrections

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Executive Summary

This deliverable presents the final prototype of the S4G Simulation Engine (SE) and its plug-in for hybrid simulation. They are both part of the Decision Support Framework (DSF). The DSF-SE is a key component of S4G which enables power flow simulations on custom grid topology definitions and allows the investigation of sizing, distribution and impact of ESS and EVs in future grids as well as to draw conclusions on for example technical feasibility, RES exploitation and grid stability. It makes possible therefore the implementation of all S4G use cases which involve simulation.
The simulation engine can be used through the DSF-SE API which has two endpoints: *simulation* and *commands*. A client can insert, change, delete, and get information about a grid topology through the simulation endpoint. The commands endpoint allows the client to control the start of the simulation defining some parameters like simulation time, the grid currents (I) and node voltage thresholds. The client can also stop the simulation or get its status as well as its results through the commands endpoint.
DSF-SE has been integrated with other S4G components, namely PROFESS, DSF connectors, and GESSCon. DSF-SE makes use of the PROFESS and PROFEV API for generating set points that are used for controlling of ESS and charging stations defined in the grid topology. Load profiles, PV generation profiles and price profiles can be obtained through the DSF connectors. ESS schedules for the next day, taking into consideration a global vision of the grid, can be obtained through the integration with GESSCon. Simulation results comprehend three values: voltage at grid node level, currents in the lines, and power losses at line level.

The DSF-SE plug-in for hybrid simulation features Hardware-in-the-Loop (HIL) which allows the verification of innovative components such as the Energy Router (ER) prototype. Its safe operation and response within specified scenarios can be verified this way. The hybrid simulation plug-in can accommodate one or many physical systems into the simulation. To test and verify the correct function of developed connectors in the context of the S4G project, the plug-in Hybrid Simulation has been tested with the single-phase ER deployed in Bucharest test site.

The DSF provides technical as well as economic simulation results for the user to take informed decisions. As already said, The DSF-SE provides technical results of the simulation. On the other hand, the DSF-Economic Engine (DSF-EE) provides economic insights of scenarios with distributed storage systems at substation and prosumer level. The DSF-EE has been built taking into consideration for example the identification of stakeholders, the selection of four scenarios, the scenarios' geographical areas, variables to be considered, etc. Variables can be for example the time horizon for investment, the PV penetration and the CapEx for grid strengthening. All these considerations go into the functional forms or algorithms used in the DSF-EE. They are based on the final computation of a total cost of ownership (TCO) function for each scenario, both from the DSO and prosumer point of view. The DSF-EE is integrated with the DSF-SE and with the Professional GUI in the sense that it gets inputs from both components. Conclusions based on the economic model are presented under section 4.4.3. One conclusion to be highlighted is that for the scenarios analysed involved the two DSOs in the project, energy storage solutions do not seem yet to be attractive from an economic point of view in comparison with network reinforcement.

1 Introduction

The deliverable 5.2 Final DSF Hybrid Simulation Engine documents the results of T5.1 whose main goal is to provide a tool able to analyse different scenarios featuring combinations of loads, energy storage systems and renewables in an existing grid. This deliverable is a final update of D5.1 Initial DSF Hybrid Simulation Engine.
Chapter 2 presents the structure of DSF-SE, it describes its components and presents examples of its use. Chapter 3 describes the DSF-SE plug-in for hybrid simulation. The DSF Economic Engine (DSF-EE) is presented in chapter 4. Chapter 5 contains the deployment instructions, whereas chapter 6 shows software dependencies and requirements. Chapter 7 discusses the conclusions.

1.1 Scope

The goal of WP5 is the development of the S4G Decision Support Framework to support analysis, planning, forecast and optimization of storage system behaviour. Core of this development is the DSF-Simulation Engine, which allows the power flow analysis of the grid in different conditions. The present deliverable consists of further development of the first prototype presented in D5.1 Initial DSF Hybrid Simulation Engine. It takes into consideration developments made in T5.2 - DSF Interoperability with 3rd party and DSO systems – as well as in T5.3 - DSF Hybrid Simulation Support.

1.2 Related documents

ID	Title	Version	Date
D2.2	Final Storage Scenarios and Use Cases	1.0	2018-07-31
D2.4	Final S4G Business Models	1.0	2019-08-01
D3.3	Final S4G Components, Interfaces and Architecture Specification	1.0	2019-08-31
D4.10	Final USM extensions for Storage Systems	1.0	2019-08-31
D5.1	Initial DSF Hybrid Simulation Engine	1.0	2017-02-22
D5.5	Final DSF Connectors for external systems and services	1.0	2019-08-31
D6.3	Phase 3 Test Site Plans	1.0	2019-08-31
D6.9	Final Interfaces for Professional and Residential Users	1.0	2019-08-31

2 DSF Simulation Engine (DSF-SE)

The DSF-SE is a cloud service that embeds the open source simulator OpenDSS for conducting power flow simulations on custom grid topology definitions. Therefore, DSF-SE is essential for accomplishing all use cases involving simulation in the S4G project. Besides, DSF-SE has been integrated with other DSF components, in order to extend the capabilities of the power flow simulator. In this regard, PROFESS and PROFEV are generating the control set points for controlling ESS and charging stations, respectively during the simulation time; DSF-connectors deliver predictions about price, PV generation and load for a specific test site; GESSCon generates control set points for ESS considering a global view of the system; the Professional GUI serves as a visual interface for the professional users with emphasis on grid analysis and planning.
In fact, the DSF-SE is a powerful tool that allows not only to perform power flow simulations of a grid topology, but also to investigate the sizing, distribution and impact of ESS and EVs in future grids as well as to draw conclusions on for example technical feasibility, RES exploitation and grid stability.

2.1 DSF-SE's role within the Decision Support Framework

The DSF-SE plays a key role in accomplishing some of the project's goals. The expected outputs from the Decision Support Framework are shown in Figure 1, whereby some of these outputs are given out by or are based on the Simulation Engine. In the following, we'll explain the role of the DSF-SE concerning some of these outputs.

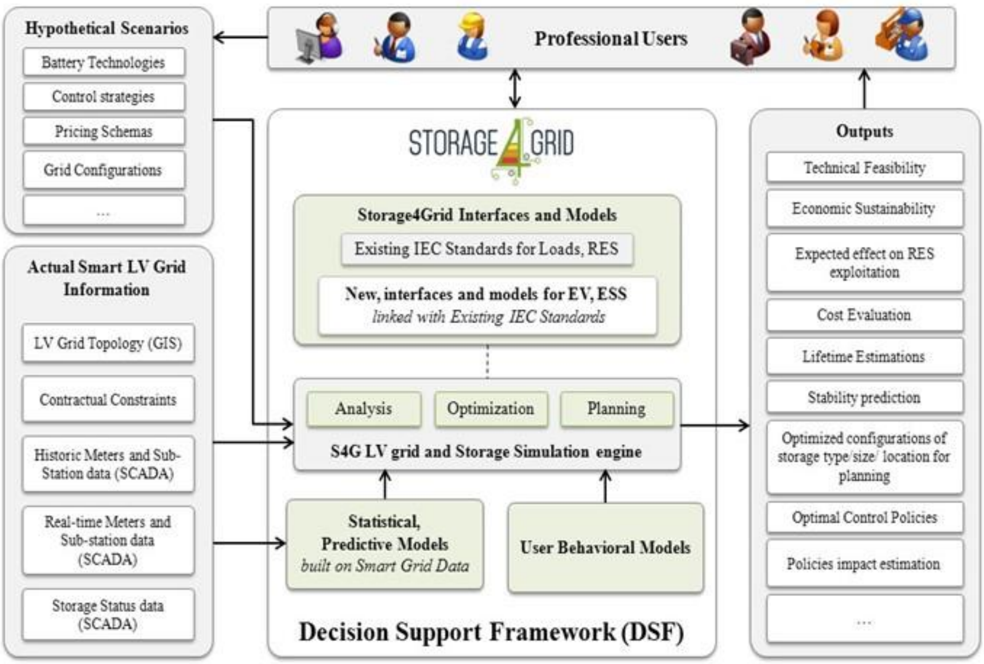

Figure 1 The S4G Decision Support concept

Technical Feasibility: The DSF-SE allows by means of simulation to examine the technical feasibility of a variety of configurations of ESS and/or PVs in a given grid. It allows the simulation of different penetration levels of ESS and PVs, as well as the addition of single ESS or PVs elements into the grid. Visualization of the grid and user interface is being developed into the Professional GUI (D6.9). Therefore, the user is able to generate and evaluate different scenarios including ESS and PVs and to verify their feasibility in terms of voltage stability and overcharge in the cables. The evaluation taken by the user is focused in the values of *voltages in the nodes*, *currents in the lines* and *power losses in the grid*. Nowadays, this task is not conducted because of the problematic of the control algorithms for ESS and of the uncertainty brought by weather conditions in the case of PVs.

Economic Sustainability: This topic is related to the battery lifetime in relation to its total cost of ownership while working in the grid, either at local (low-voltage) or grid (medium-voltage) level. The professional GUI together with DSF-EE (section 4) will generate a testing scenario and calculate battery's lifetime, taking into consideration results of the simulation in DSF-SE. In this case, DSF-SE sets up the grid topology scenario and conducts a power flow simulation for a defined duration time. As a result, DSF-SE will send calculated voltages, current and power losses, which are necessary to be considered in the calculation of the economic model (see 4.2), taking into account for instance loss reduction as a benefit. Moreover, battery's lifetime, which is calculated based on the battery exploitation mode and is linked to the battery's final cost, can be translated to a storage as a service cost in the time.

Expected effect on RES exploitation: The DSF-SE allows the simulation of different levels of penetration of ESS and PVs. DSF-SE's outputs such as voltages, current, and power losses for different penetration levels will be analyzed to draw conclusions on effect of ESS usage on RES exploitation.

Optimized configurations of storage type/size/location for planning: The DSF-SE presents an API for introducing a new grid topology into the system as well as for changing its elements. This flexibility allows the user to investigate different topology configurations. In S4G, the professional GUI works as a link between the professional users and the DSF-SE, where the user can add, delete and size grid elements such as ESS and PVs. With the results of simulation summarized in voltage in the nodes, currents in the lines and power losses, the professional user can infer the optimized configuration of ESS for the grid.

Optimal control policies: One of the key features of DSF-SE constitutes the ability of simulating different control mechanisms for ESS and charging stations of EVs. For accomplishing this objective, the PROFESS and PROFEV tools developed in D4.3 and D6.7, respectively, are integrated into the DSF-SE. PROFESS allows the choice between three different optimization objectives as indicated in D4.3, while PROFEV incorporates uncertainties brought by EVs, such as plug/unplug time to the charging station. Additionally, a global scheduling tool for ESS, such as the GESSCon, can be integrated through these two tools. In general, the flexibility of integrating customized optimization algorithms to every ESS (PROFESS) and charging station (PROFEV) in simulated grids will make possible to expand the research possibilities in power system dynamics. As an example, the analysis of grid stability with a group of houses working with one optimization objective for ESS set points and another group working with another optimization objective is possible.

2.2 DSF-SE architecture

As shown in Figure 2 the DSF-SE system is composed of dockerized components, such as LinkSmart® Border-Gateway[1], Nginx[2], Flask[3], Gunicorn[4], and the DSF-SE adapter on the server side. In the following subsections, we will divide the discussion between the *Access and API architecture* and the *DSF-SE Adapter architecture*.

[1] https://docs.linksmart.eu/display/BGW
[2] https://www.nginx.com/
[3] http://flask.pocoo.org/
[4] https://gunicorn.org/

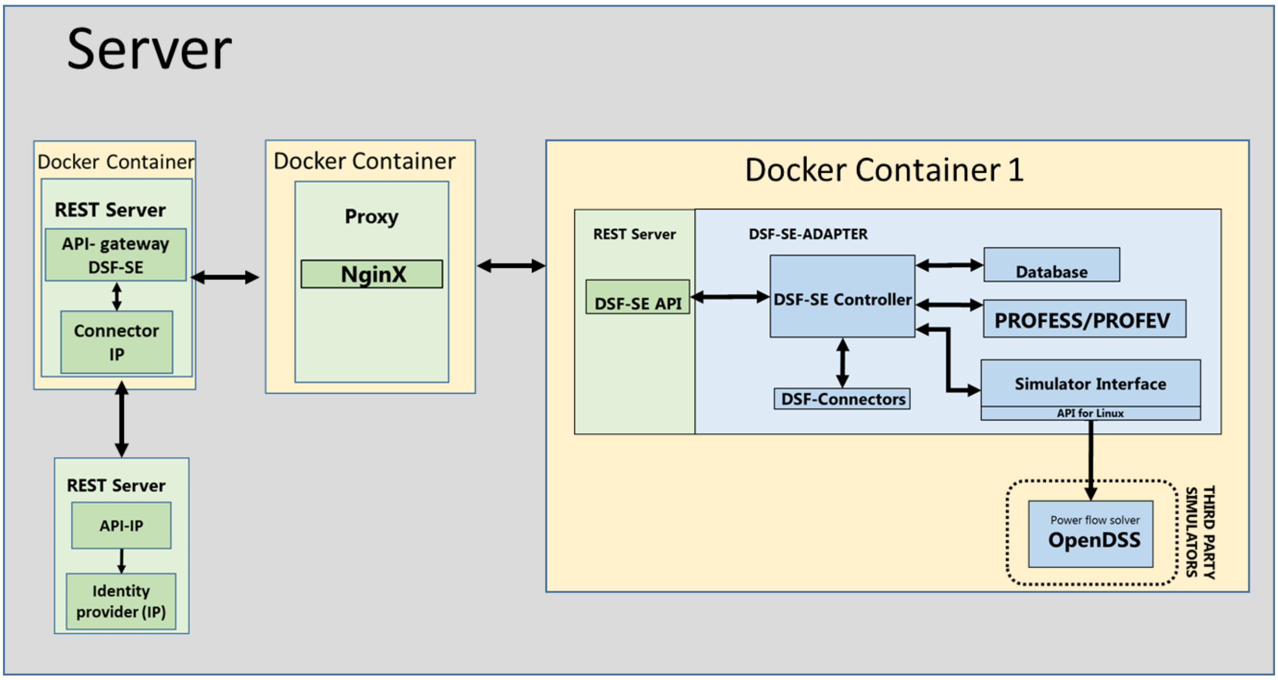

Figure 2: DSF-SE architecture overview

2.2.1 Access and API architecture

Users request access firstly through the *LinkSmart® Border Gateway* at the server side. The Border Gateway compares the token sent by the user through the communication to the Keycloak[5] server. If the user is authorized, the request is redirected to Nginx via the default HTTP port 80. Nginx communicates with Flask via port 8080 using Gunicorn as a mediator, in order to serve the client applications with data from Flask application, as explained in Figure 3.

[5] https://www.keycloak.org/

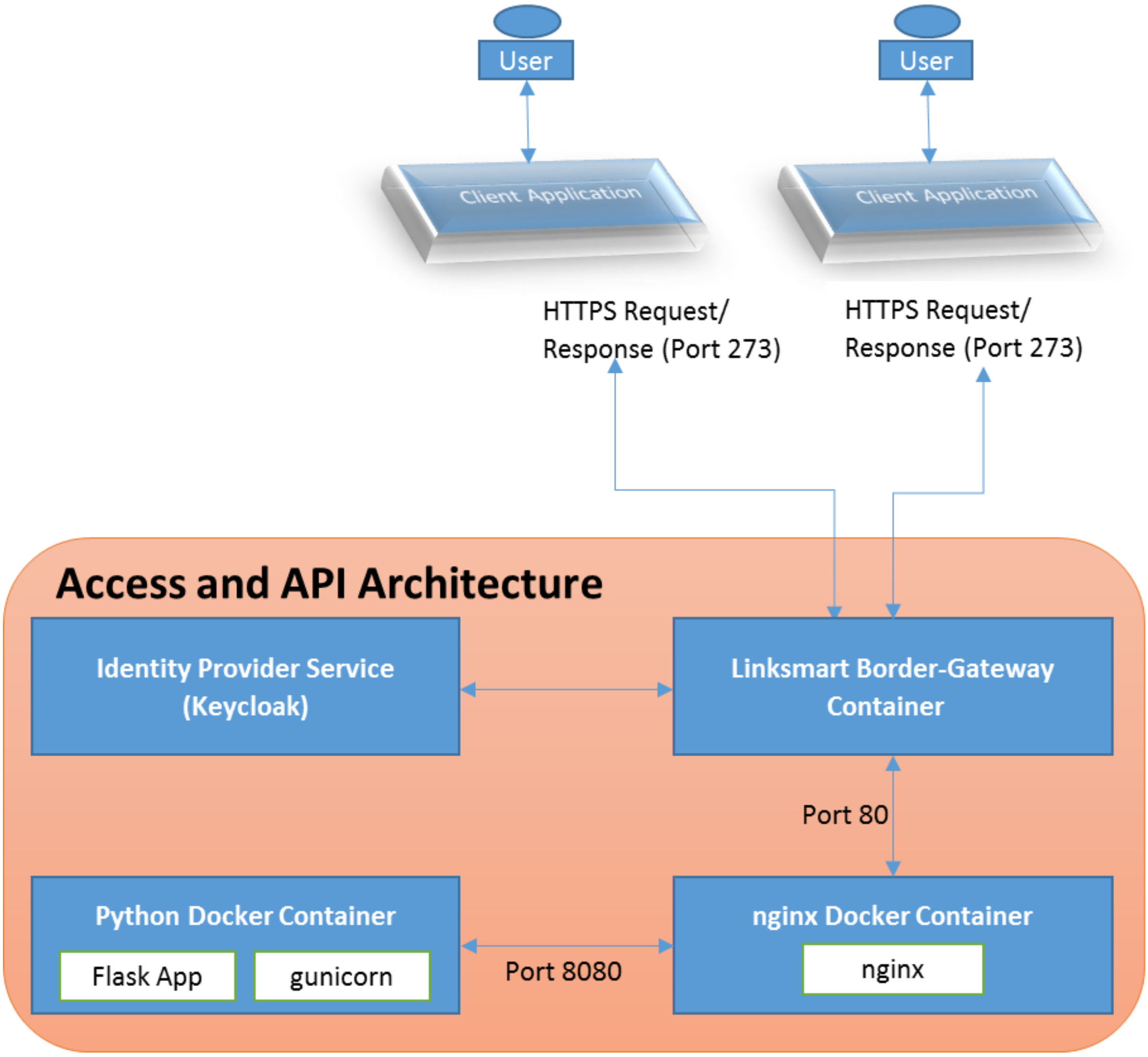

Figure 3: Architecture for authorization, authentication and DSF-SE API

The result is sent back from the Flask application via Gunicorn, Nginx and LinkSmart® Border Gateway to the clients. Each of the components are described as follows:

2.2.1.1 Flask

Flask is a very powerful framework that serves the implemented API. It is the python application implementation that works as a link to the DSF-SE logic.

2.2.1.2 Gunicorn

Web Service Gateway Interface (WSGI) is a service that enables the communication between the application and the web service. The most famous implementation of WSGI is uwsgi protocol. It provides a reliable management layer for the Flask application. It will spawn multiple workers to take advantage of multiprocessing and dispatch requests amongst them. That is done by WSGI service.
Gunicorn – an implementation of WSGI – creates a Unix socket, and serve responses to nginx via the wsgi protocol - the socket passes data in both directions, i.e., from the outside world to Nginx to Gunicorn to Flask and return.

2.2.1.3 Nginx

Nginx is a reliable web server that can handle thousands of client connections. It keeps them waiting while the application is busy and keeps connections alive after the response is sent back to the client in order to shorten future response time. It also manages services such as the negotiation of compression with each client, based on the browser used by the client.
Nginx is a gate for requests arriving from outside the server and authorized by the LinkSmart® Border-Gateway using the Keycloak system. However, it cannot talk to Flask applications directly. It needs something that will run the application, feed it with requests from the web, and return responses. That is exactly where Gunicorn comes in.

2.2.1.4 LinkSmart® Border Gateway

It provides a single point of entry to the DSF-SE service using TLS protocol. Besides, the Border Gateway provides authentication and authorization services for HTPP requests. The users and their permissions are defined using an Identity Provider, such as the Keycloak Server in the case of DS-SE. Moreover, the Border Gateway forwards the requests to the Nginx Webserver for further processing. The LinkSmart® Border Gateway is deployed in an independent docker container at the server side.

2.2.2 DSF-SE-Adapter architecture

The DSF-SE Adapter architecture is related to the python application containing the logic of the DSF-SE. The final architecture is summarized in Figure 4. Every module is explained in the following subsections.

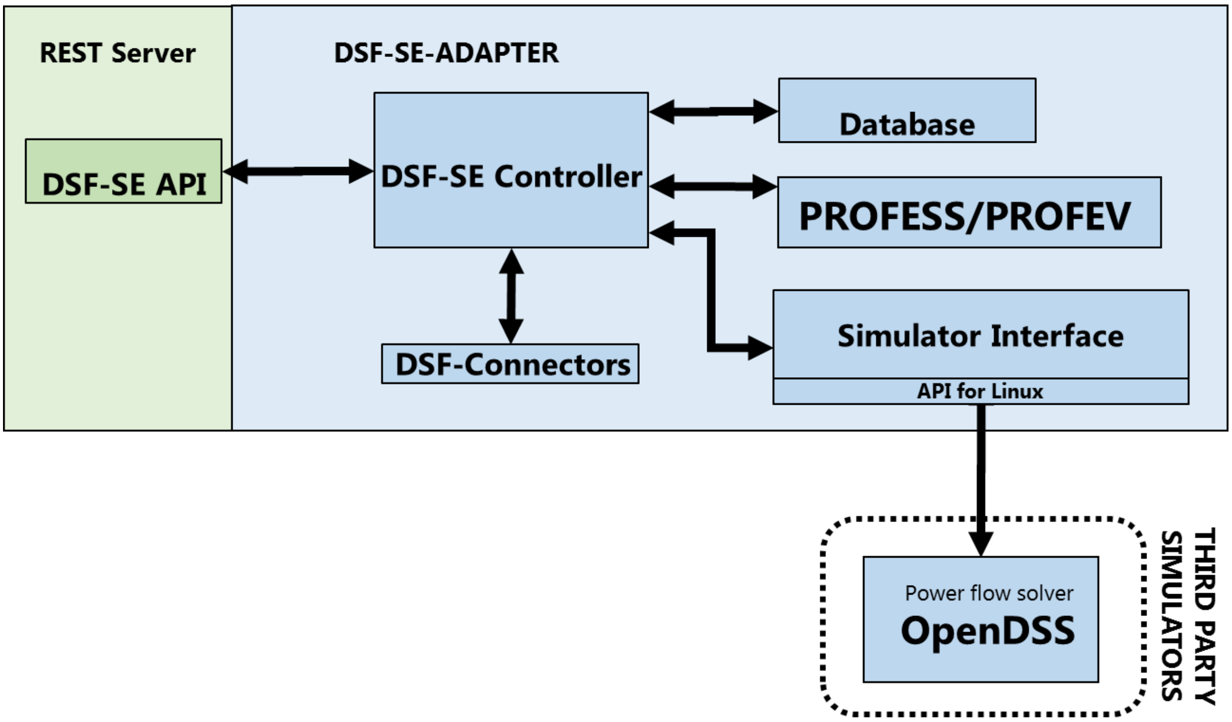

Figure 4: DSF-SE Adapter architecture

2.2.2.1 DSF-SE Controller

The DSF-SE Controller is the core of the system. It has the following functions:

- Management of information entered through the DSF-SE API. This information consists basically of the topology definition to be simulated.
- Parsing and linking of the grid topology to the power flow simulator through the simulator interface.
- Management of an internal database for storing the grid topology and of grid elements parameters. This action is useful when the user makes changes in the original topology. After a timeout the information is deleted from the database.
- Management of the DSF-Connectors module for getting load, PV generation and price profiles. The DSF-SE Controller incorporates the received profiles into the required grid element of the topology and sends it to the simulator interface to be linked to the open source power flow simulator.
- Management of the PROFESS/PROFEV module for getting set points for the control of ESS and charging stations. DSF-SE Controller incorporates the received set points into the required grid element of the topology and sends it to the simulator interface to be linked to the open source power flow simulator.
- Management of simulation steps: coordinating grid elements specified in the topology and updating their attributes; reading results at every step and; introducing new set points to the controllable grid elements.
- Management of the response sent back to the user through the DSF-SE API.

2.2.2.2 Database

For the implementation of CRUD operations via the API, a database is set up as part of the DSF-SE Adapter architecture. The database used is redisDB[6] because of its flexibility to handle unstructured data from various sources. In this implementation, as shown in Figure 4, the database is behind the Flask App in order to store data that will be used to perform retrieve and/or update operations through the API.

2.2.2.3 PROFESS/PROFEV Module

Set points for the control of ESS and charging stations are delivered by PROFESS and PROFEV, respectively. The integration with these components is further explained in section 2.5.1.

2.2.2.4 Simulator Interface

The simulator interface works as a driver that allows the integration of an open source power flow simulator. In the case of S4G, OpenDSS [1] was chosen as power flow simulator. The simulator interface is in charge of inserting, updating and deleting attributes or elements to the OpenDSS. It converts the information sent by the DSF-SE Controller into OpenDSS platform readable commands.

2.2.2.5 DSF-Connectors

The DSF-Connectors module is in charge of querying load, PV generation and price profiles from the DSF-Predictive Models. The integration with these components is further explained in section 2.5.2.

[6] https://redis.io/

2.3 DSF-SE API

The DSF-SE API[7] is a RESTful interface that uses HTTP requests to GET, POST, PUT and DELETE data about grid elements and characteristics, as well as to start, stop, get status and get results from the simulation. The DSF-SE API is shown in Figure 5.

The current DSF-SE API presents two endpoints: *simulation* and *commands*. The simulation endpoint allows the client to insert, change, delete and get information about a grid topology to be simulated. The POST command will return an Id that identifies the topology inserted. Using the Id, the client is able either to make changes to this topology, to erase it or to get information about it. The commands endpoint allows the client to control the start of the simulation defining some parameters like simulation time, the grid Id and voltage thresholds. Moreover, the client can stop the simulation or get the status and results of it through this endpoint.

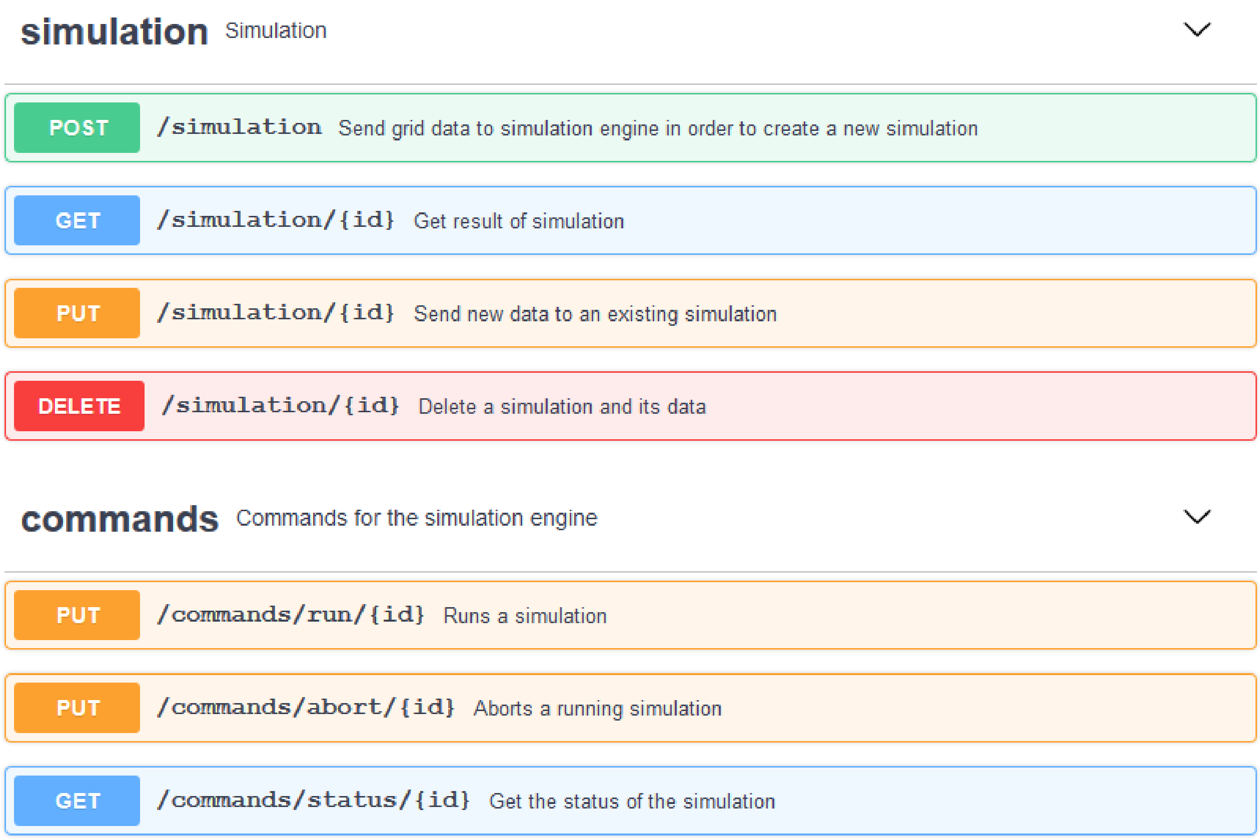

Figure 5: DSF-SE API

2.4 Grid topology and elements parameters definition

The DSF-SE API defines also the data format for introducing a grid topology and the parameters for each grid element. The following grid elements are supported by the DSF-SE API:

[7] https://raw.githubusercontent.com/linksmart/simulation-engine/master/swagger_server/swagger/swagger.yaml

- Grid
- Transformer
- Load
- Powerline
- Linecode
- Photovoltaics
- Storage unit
- Charging point
- Capacitor
- Regulator control for transformer
- Loadshapes
- Power profile
- Temperature shapes

2.5 Integration with other components

The following subsections will explain the interaction of DSF-SE with PROFESS, the DSF-Connectors and the GESSCon.

2.5.1 Integration with PROFESS

DSF-SE makes use of the PROFESS and PROFEV API for generating set points that are used in the control of ESS and charging stations defined in the grid topology. PROFESS was already presented in depth in D4.3, whereas PROFEV will be presented in D4.7.

An interaction between the DSF-SE and PROFESS takes places at every simulation step, as shown in the sequence diagram in Figure 6. In this way, the DSF-SE controller groups the elements of a grid where an ESS is located, i.e. DSF-SE looks for the existing ESS on the system. Afterwards, it looks for the electrical elements connected to the same node, such as loads, PVs, etc., and groups them together. This information is sent to the PROFESS connector, which is in charge of parsing the input data used as dataset for PROFESS/PROFEV, starting the respective optimization, checking if the optimization is finished and getting the results from it. The PROFESS connector will return to the DSF-Controller the set point to be used for ESS or charging station in the next simulation step.

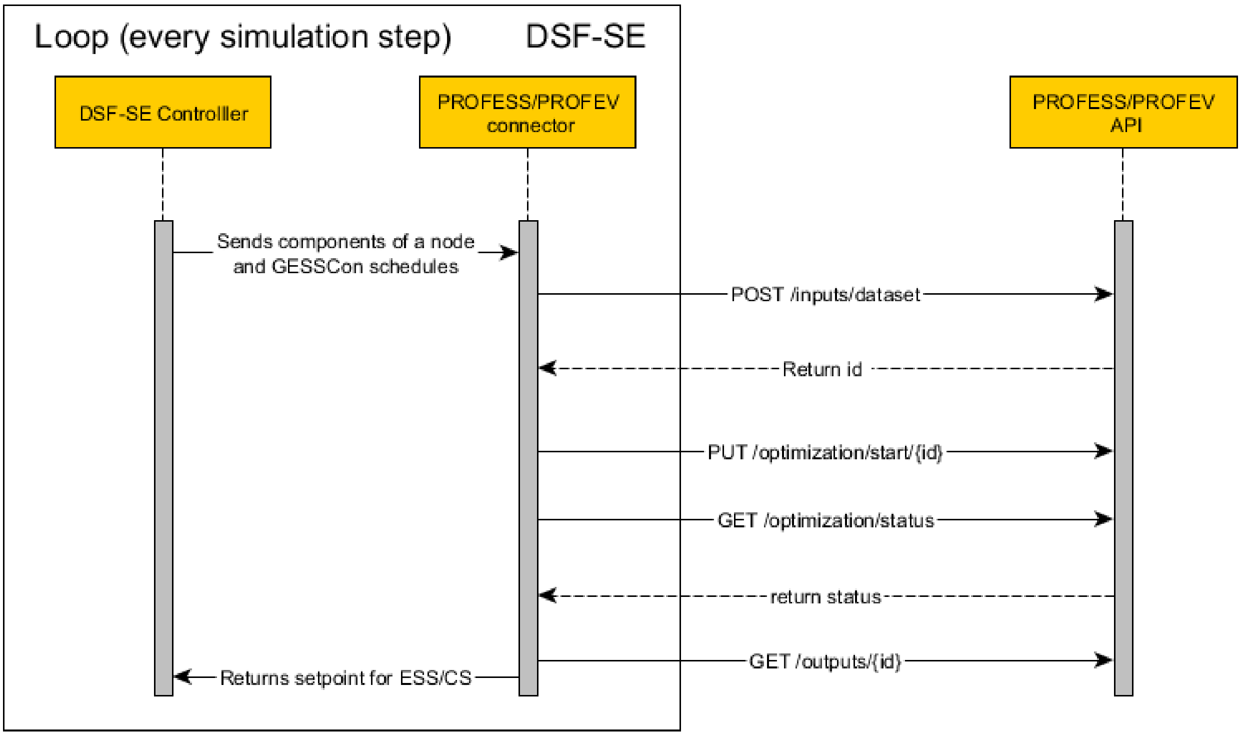

Figure 6: Integration of DSF-SE with PROFESS/PROFEV

2.5.2 Integration with DSF-Connectors

The DSF-SE makes use of the DSF-Connectors developed in Task 5.4 for requesting data about load profiles, PV generation profiles and price profiles. This data is required once at the beginning of the simulation for initializing the different grid elements. The DSF-SE Controller will manage the profiles and integrate them into the grid elements that require it, as for example loads and PVs. The price forecast will be used by PROFESS for calculating the set points of the ESS and by GESSCon for providing ESS scheduling for the next 24h.
The goal of this integration is to achieve more realistic simulations using predicted profiles for the various test cases analyzed in S4G. Figure 7 presents the interaction between DSF-SE and DSF-Connectors.

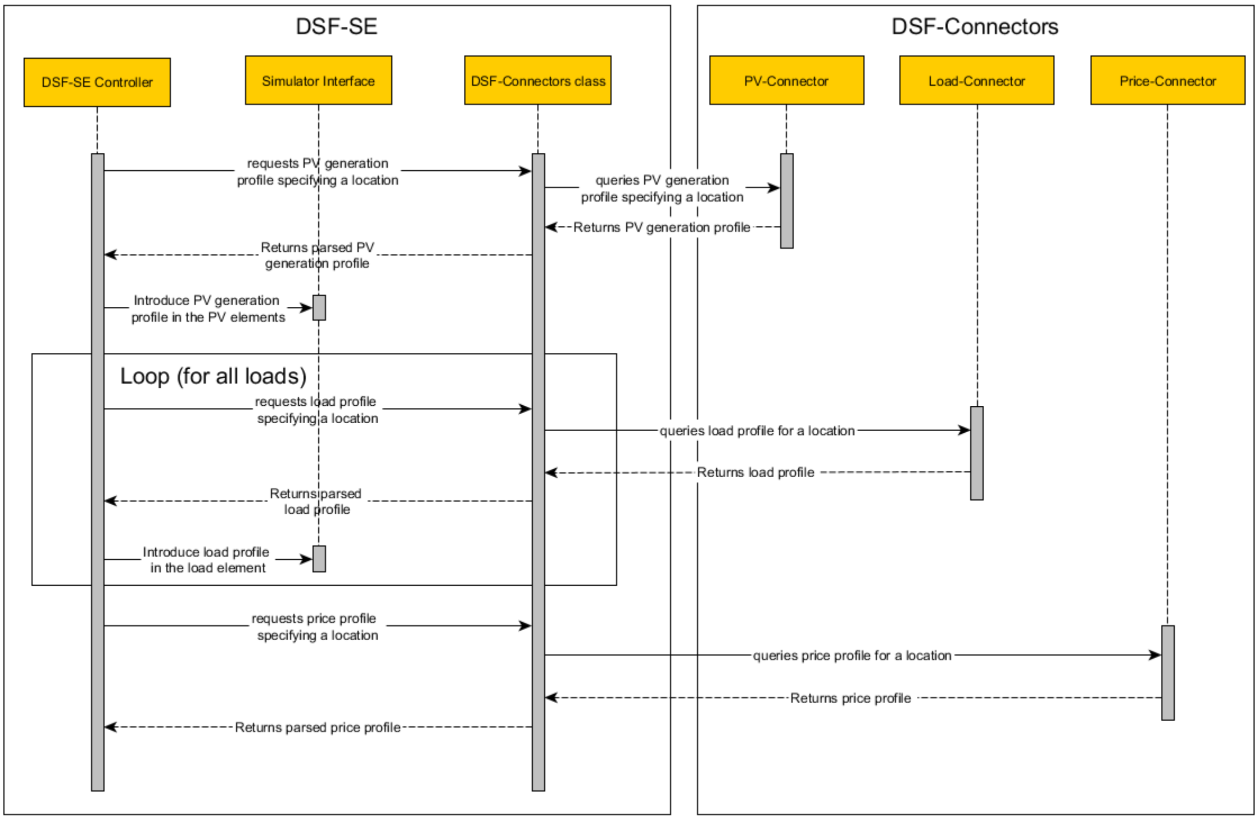

Figure 7: Integration of DSF-SE with DSF-Connectors

2.5.3 Integration with GESSCon

GESSCon is in charge of providing the ESS schedules for the next day taking into consideration a global vision of the grid. PROFESS will include these schedules into the calculation of the local ESS set points. This use case is explained in HLUC3-PUC-3 in D2.2.

The communication between DSF-SE and GESSCon uses the MQTT-Protocol. In fact, DSF-SE inputs to GESSCon information about the grid in a specific MQTT-topic and GESSCon answers with the respective ESS schedules for the next day in another specific MQTT-topic. The necessary information and the data format for this communication are explained in D4.5.

DSF-SE Controller is in charge of managing the inputs to be sent to GESSCon and of sending the schedules to PROFESS for further analysis. Figure 8 presents the interaction between DSF-SE and GESSCon.

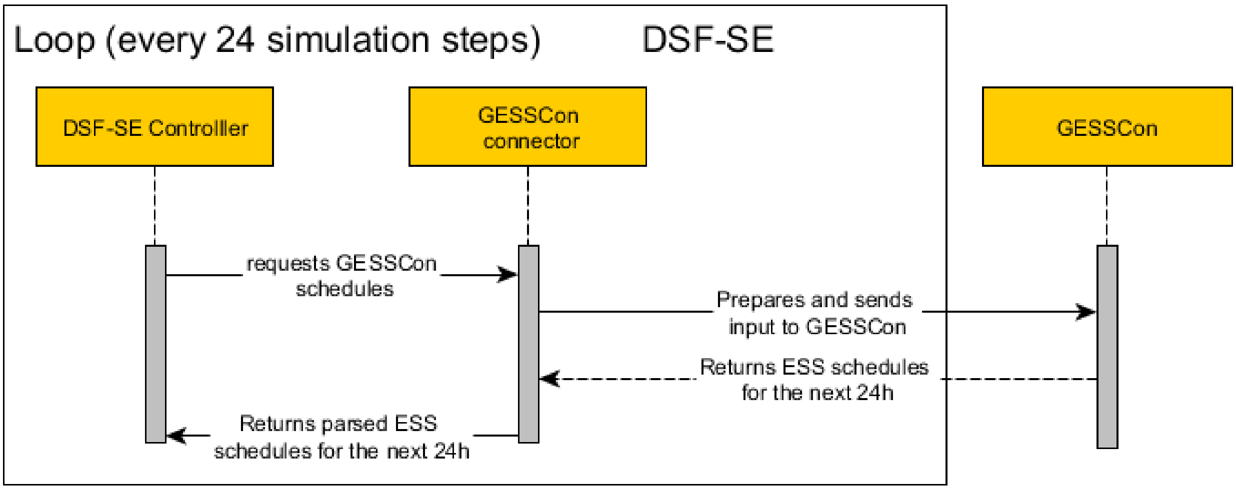

Figure 8: Integration of DSF-SE and GESSCon

2.6 DSF-SE - Simulation results

The DSF-SE returns as answer three different parameters as response. These parameters are:

- Voltage on the grid nodes
- Currents in the lines
- Power losses of the lines of the grid

These parameters were required by professional users during evaluation workshops of the Professional GUI, as explained in D6.11.

For obtaining the solution of a simulation, the DSF-SE API presents a GET HTTP command for the *simulation/results* endpoint. The definition of the data format of the response is also documented in the DSF-SE API. One example of the response message is presented in appendix C below.

2.7 Simulation example using the professional GUI

The simulation engine was already tested together with the Professional GUI. The grid topology of Fur, Denmark was used for testing. The final professional GUI is presented in detail in D6.9, here we focus on showing the interaction between professional GUI and DSF-SE. This interaction has been summarized in Figure 9.

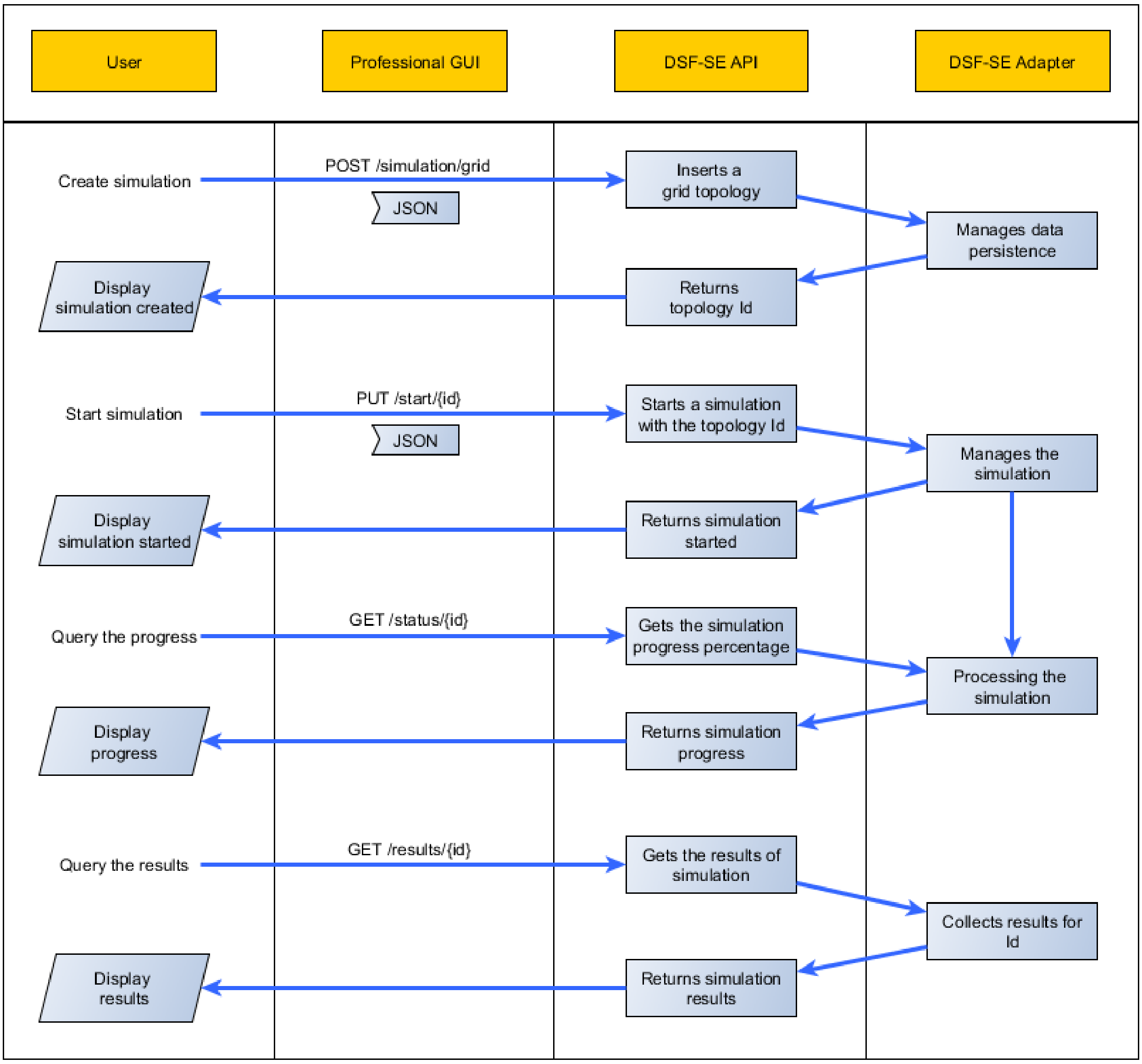

Figure 9: Usage example of DSF-SE through the professional GUI

As shown in Figure 9, the professional GUI uses the DSF-SE API for sending the grid topology. An example of this data has been included in appendix A below. The DSF-SE persists this data in an internal database in order to manage requests of changes in the topology. As result, DSF-SE returns an Id which will identify the entered topology.

Once the grid topology is available in the DSF-SE, the professional GUI makes a request for starting the simulation. An example of the body for this request is included in the appendix B below. The DSF-SE answers to this request. In this point, the DSF-SE conducts a power flow simulation in OpenDSS using the topology entered before. The simulation will work step by step during the time horizon introduced by the professional GUI in an hourly resolution. Meanwhile, the professional GUI has the option of requesting the progress of the simulation that will be answered with a percentage value of the whole optimization steps.

If the simulation is finished, the professional GUI can request the results from the simulation. DSF-SE will return the values of voltage on the nodes, currents on the lines and power losses as answer. An example of the results is included in appendix C below.

3 DSF-SE - Plug-in for Hybrid-Simulation

Early deployment of innovative components and configuration within a system imposes relatively high risks both for hosting system and the component itself. S4G has been a base-ground for Energy Router (ER) prototype development and testing therefore, its safe operation/response for certain scenarios should be verified in some way. A classic approach for such verification/test is Hardware-in-the-Loop (HIL) which is widely used where integration of a physical component is intended. HIL mainly consist of a simulated environment, the physical system to be integrated, and the intermediary elements such as connectors, converters, controllers etc.
DSF-SE has been designed and developed to address this need by a Plug-in Hybrid Simulation Add-on that makes it possible to simulate the electricity network operation while a deployed ER in one of its nodes is physically working.

Hybrid Simulation mainly consists of three main components listed as following:

- Real-time Simulator
- Connectors
- Physical device

3.1 Distribution System Real Time Simulator

Distribution system Real Time Simulator (DRTS) is the core part of ad-hoc simulation framework that allows execution of HIL simulation. DRTS generates a simulation case according to the user settings through a python console, and performs the simulation for entire horizon by regular steps (set to one second by default) at which the electrical equations are solved in a “snapshot” mode. DRST instructs the set-points and reads the monitoring results by a dedicated connector to/from ER.

3.1.1 Software architecture

Real time simulator is designed as a modular software, and its modules are mainly:

- Simulation Management: This module incorporates a class named Simulation that is the main simulation execution core, containing the simulation clock handles the simulation run time and logic based on a predefined sequence.
- Data Management: different classes and functions in this module have the duty of communication with DWH, DSF-Connector Server and in turn with 3rd party services such as weather forecast and also grid database (GridDB). Record and monitoring the data flow is handled by a class named Monitor within this module.
- Application Management: this module integrated external simulator into the platform. External simulator in this case is OpenDSS which is used as a power-flow solver.
- Prediction Management: includes the functions that are needed for integrating various predictions in the simulation.
- Control Management: a module that includes the control logics for controllable components such as ER and ESS.

Figure 10 depicts the overall arrangement of various modules.

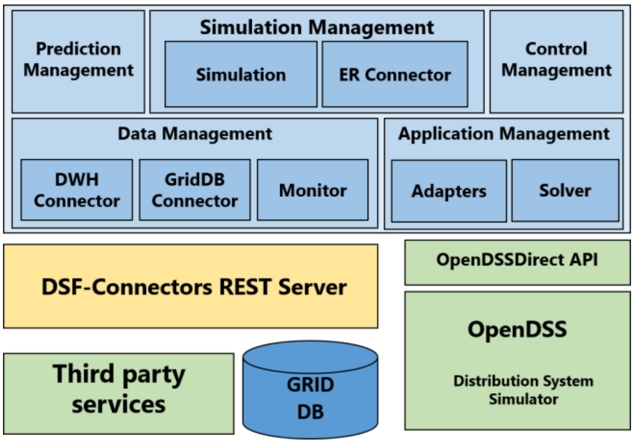

Figure 10. DSF-SE Real-Time Simulator and interacting services.

Essentially, DRTS through relevant connector gets the grid model from GridDB, then parses it to the OpenDSS adapted format. The simulation time and step is set by the user which can be accelerated (e.g. emulating 1 simulation time to 1 second of real-time) or execute in real-time with minimum granularity of one second. The PV and load prediction is available by Predictive Module, the inputs can also be set to use instead the sent data by the ER. The acronyms SM, AM, and DM stand for Simulation Management, Application Management and Data Management respectively.

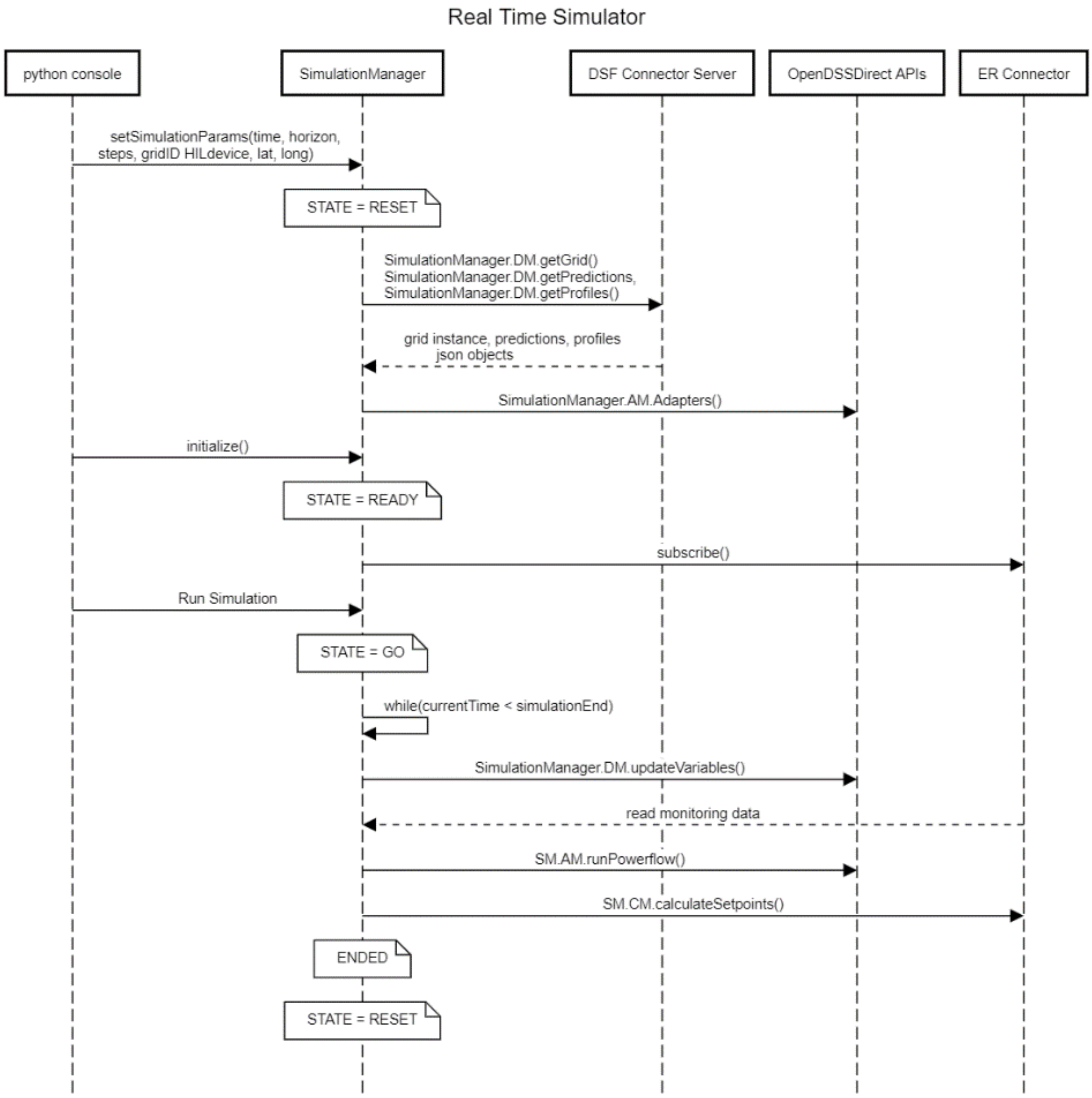

Figure 11. Execution and progress of Real Time Simulator.

3.2 Integration with Hardware

One or more physical systems can be integrated into the simulation as the HIL components. The interaction is being made possible through dedicated connectors, to manage the monitoring and control data flow between the DRTS and HIL subject device.

3.2.1 ER Connectors

A dedicated connector has been developed for real-time communication between DRTS and the ER controller. The data flow from ER towards DRTS contains battery's state of charge, power of battery, PV grid for last time step. The values are being aggregated, filtered and made in a regular time-steps then sent to the DRTS. The connector's being used is described in D4.10 [S4G-D4.10] and D5.5 [S4G-D5.5].

Another connector steers the control operational mode and set-points from DRTS towards ER. The operational mode can be grouped in grid connected and isolated modes, and sub-grouped in Reference Power Point Tracking, Maximum Power Point Tracking and no power from PV.

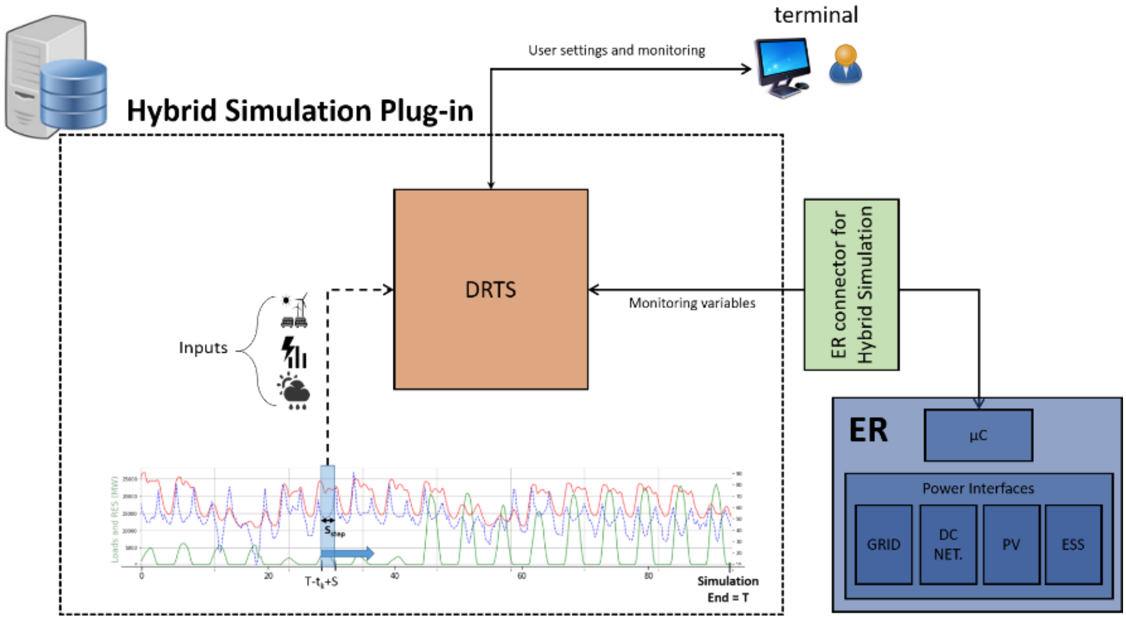

Figure 12. Hybrid Simulation plug-in implementation.

3.3 Hybrid-Simulation Implementation Case

To test and verify the correct function of developed connectors in the context of the S4G project, the plug-in Hybrid Simulation has been tested with the single-phase ER deployed in Bucharest test site. The integration has been implemented by using the ER in "Grid ON" mode where a hysteresis control logic gets as input the ER's coupled battery SoC from ER directly, and also nodal voltage obtained by the simulator then interpret these values into set-points for the next time-steps. The execution is proceed successfully for the simulation runtime. Following figures picture some monitored and control set-points during the implementation.
An example of data flow from measurements by the ER, in Hybrid Simulation test is brought in the following:

/ER/SMX/EnergyRouterInverter/MMXN1.Watt.instMag.f [
  {
    "v": -56.950108,
    "u": "",
    "t": 1562680740755,
    "n": ""
  }
]
/ER/SMX/EnergyRouterInverter/MMXN1.Vol.instMag.f [

```
  {
    "v": 277.3788,
    "u": "",
    "t": 1562680742285,
    "n": ""
  }
]
/ER/SMX/EnergyRouterInverter/MMXN1.Amp.instMag.f [
  {
    "v": 0.3286731,
    "u": "",
    "t": 1562680742269,
    "n": ""
  }
]
```


Example of the resulting control set-points instructed by the DRTS versus ER on the specified topic is brought in the followings:

/DSF/SMX/EnergyRouterInverter/DRCC1.DERStr.ctlNum [{"v": 2, "u": "W", "t":1560038400.0,"n":"DERStart"}]
/DSF/SMX/EnergyRouterInverter/ZBTC1.BatChaPwr.setMag.f [{"v":479.64, "u": "W", "t":1562680841,"n":"PBatRef"}]
/DSF/SMX/EnergyRouterInverter/ZBTC1.BatChaPwr.setMag.f [{"v": 500.0, "u": "W", "t":1562680858,"n":"PBatRef"}]
/DSF/SMX/EnergyRouterInverter/ZBTC1.BatChaPwr.setMag.f [{"v": 500.0, "u": "W", "t":1562680874,"n":"PBatRef"}]

The monitored voltages for the Hybrid Simulation test case is depicted in the Figure 13.

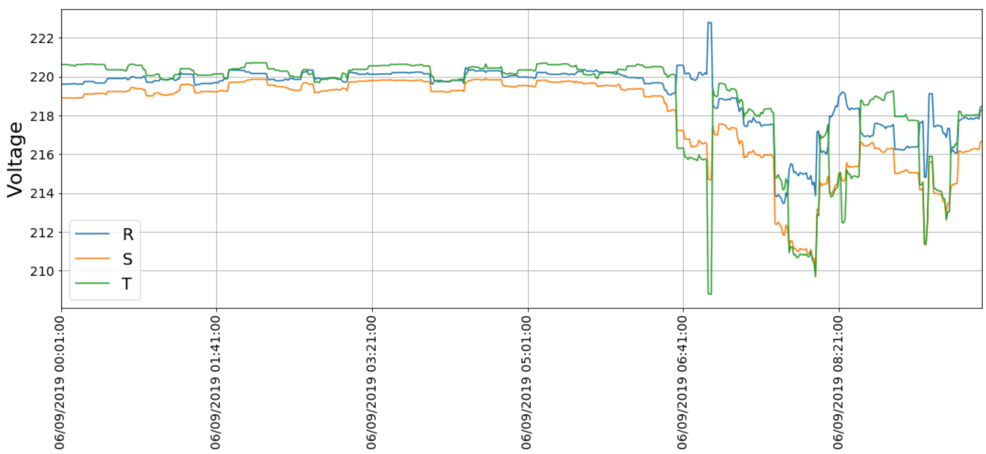

Figure 13. Voltage monitoring for specific node during Hybrid Simulation test.

4 DSF - Economic Engine (DSF-EE)

4.1 Introduction

The economic model tool as a component of the Decision Support Framework – Economic Engine (DSF-EE) has the goal to add to the DSF-SE technical outcomes providing economic insights of scenarios with distributed storage systems at sub-station and prosumer level. This chapter describes the methodological approach followed for building and deploying DSF-EE, its interaction with Professional GUI and the financial quantitative outcomes generated by the model.

The economic model has been already partially introduced in D2.4 [S4G-D2.4] as a tool useful for the business evaluation related to some of the business models (HLUCs) described in Bolzano and Fur/Skive. This model represents a quantitative evaluation for the business analysis to enrich the decision-maker evaluation. Indeed, it can be used by the professional end-user (e.g., DSO, policy maker, storage enterprises, prosumer, etc.) to simulate which could be the outcome in case of deployment of storage systems in the grid respect to a counterfactual scenario where no storage system.

The deployment of this model will be done also by collecting inputs both from the DSF-SE and from the Professional GUI where the end-users can insert information and get as a result insights useful for their own investment evaluation (Figure 14).

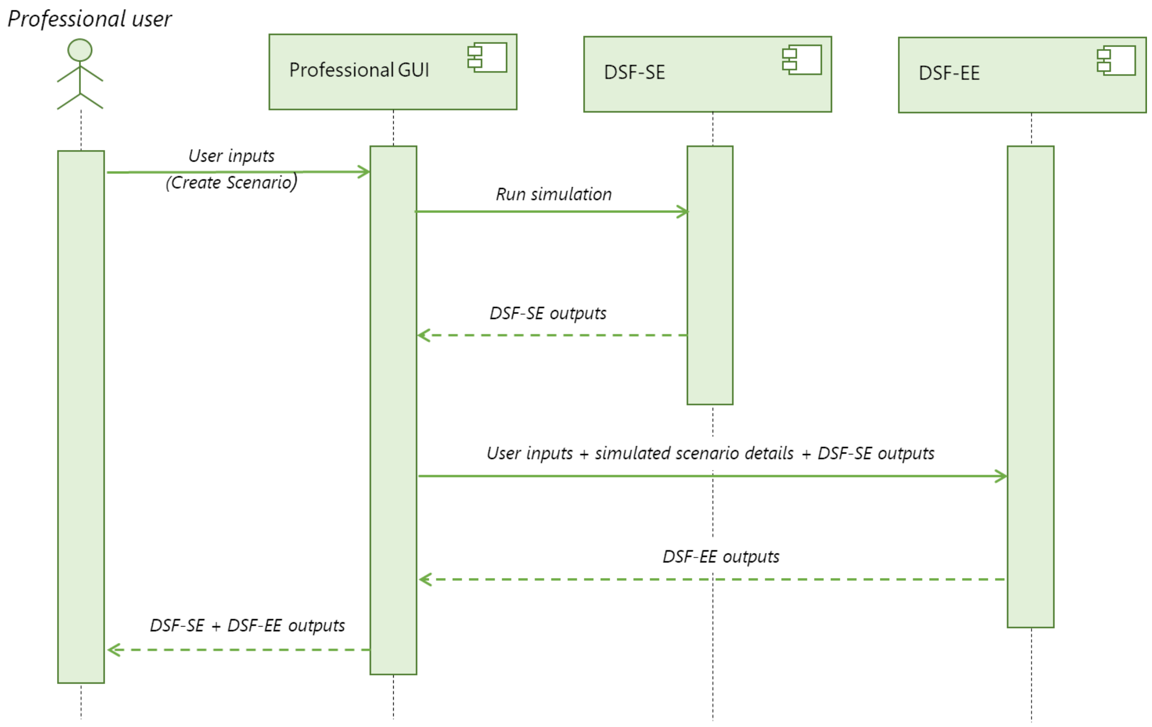

Figure 14 – DSF-EE simplified sequence interaction with Professional GUI and DSF-SE

4.2 The economic model: definition

The logical flow for building the theoretical DSF-EE and the related economic model will be described in depth in the following paragraphs and it is based on the side of the cost, in particular, on the total cost of ownership (TCO) function. The goal of the economic model is to provide outcomes for stakeholders interested in finding the economic results of the infrastructure deployment in a specific area.

This chapter is divided in several sections where the methodological approach for the implementation of the DSF-EE is characterized by the following steps:

a) Identification of the stakeholders to which the economic analysis is referred;
b) Selection of four scenarios to be used for the economic simulation;
c) Identification of the geographical area of reference (i.e., Fur/Skive and Bolzano);
d) Selection and description of the main variables;
e) Interaction of the economic model with the Professional GUI (Input/Output) and the DSF-SE;
f) Definition of the functional form (i.e., TCO);

g) Example of implementation of the model where the results of the DSF-EE will be displayed for the four selected scenarios.

4.2.1 Stakeholders identification

A long debate about the definition of the actors to whom should be addressed the DSF-EE has been done internally in the Consortium. The main actors to be considered in this framework are DSO, TSO, prosumers, suppliers of storage systems, aggregators, storage owners, service companies etc. Finally, it was proposed to consider the DSOs and prosumers for the final outcomes. Each stakeholder have different rationale and opportunities to use the DSF-EE for their own economic evaluation, as shown in the Table 1, and the results of the economic model should provide, to all the stakeholders, insights for the estimation of the impacts in different scenarios.

Table 1 – Stakeholders and DSF-EE (Source: LINKS elaboration)

Stakeholder	Rationale	Interaction with the Professional GUI	Degree of benefit
DSO	DSO is the main actor in grid strengthening that can play a crucial role in developing strategies for incentivise storage penetration. DSO can find several useful information from the DSF-EE by simulating and comparing several scenarios	DSO can decide the penetration of PV and storage distribution in the grid, the timeline of the investment, etc.	Very High
TSO	Similar to DSO, the tool can be useful also for TSO for strategic grid planning decisions.	TSO can decide the penetration of PV and storage distribution in the grid, the timeline of the investment, etc.	High
Policy maker (e.g., government, EU community, etc.)	Policy makers plays a crucial role in the definition of incentives and strategic planning for storage systems. The tool permits to show how storage penetration can affect the overall welfare analysis in terms of RES exploitation.	Policy maker can decide the penetration of PV and storage distribution in the grid, the timeline of the investment, etc.	High
Prosumers	Prosumers can find information for battery exploitation and how different storage system and timeline affects the investment	Prosumers can focus more in the storage selection	Medium
Supplier of technology	Enterprises of storage systems could find opportunity to monitor the grid network and find in which condition they can have more business opportunities	They can introduce new more precise indication about storage systems and simulate with more accuracy the different scenarios	Medium

Aggregators	Aggregators plays a role in the decision to purchase storage system and provide as a service in an area where prosumers can find less convenient to buy. Aggregators can investigate their own investment decision based on the output of DSF-EE	Aggregators can simulate different scenarios by combining different storage systems and find the optimal numerical outcome from a financial point of view	Low

4.2.2 Scenarios selection

The definition of the scenarios is another important wedge for the DSF-EE. At this stage of the project, several high-level use cases (HLUC) and business models (BM) have been analyzed in deliverable D2.2 [S4G-D2.2] and D2.4 [S4G-D2.4]. As a consequence, the economic model should compare different scenarios focusing on the main relevant ones for our financial projections. For this reason, it has been decided to choose the following four scenarios:

- Scenario 0, grid strengthening without any storage system deployed along the grid, that is referred to HLUC-3-PUC-1-BM-1 (baseline) and that it will be the counterfactual scenario to be compared with the other ones;
- Scenario 1, grid strengthening with different degree of decentralized household storage penetration;
- Scenario 2, grid strengthening with a storage system deployed by DSO at sub-station level;
- Scenario 3, grid strengthening with both decentralized household storage penetration and storage system deployed by DSO at sub-station level.

A better description of each scenario is depicted in the next paragraphs.

4.2.2.1 Scenario 0 - grid strengthening with different level of PV penetration

This scenario represents the AS-IS situation in which DSO put all the resources to strengthen the grid in order to reinforce the network for different level of PV penetration, without any storage system installed along the grid. This is useful to have a counterfactual analysis to be compared with the other scenarios where storage is introduced. An example of this has been already implemented in the Fur/Skive grid where Figure 15 highlights the distribution of PV along the feeder, with different levels of installed power [kW] (a schematic example is provided by Figure 16).

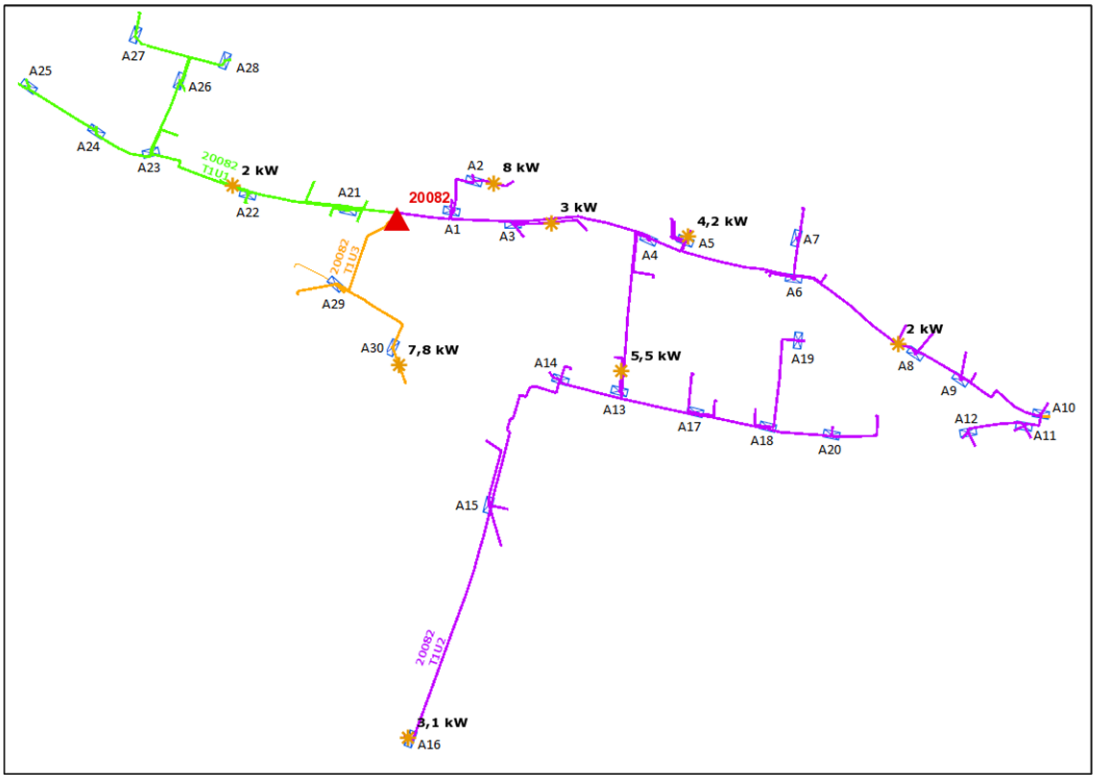

Figure 15 - Topology for grid network in in Scenario 0 or HLUC-3-PUC-1-BM-1 (Source: ENIIG elaboration)

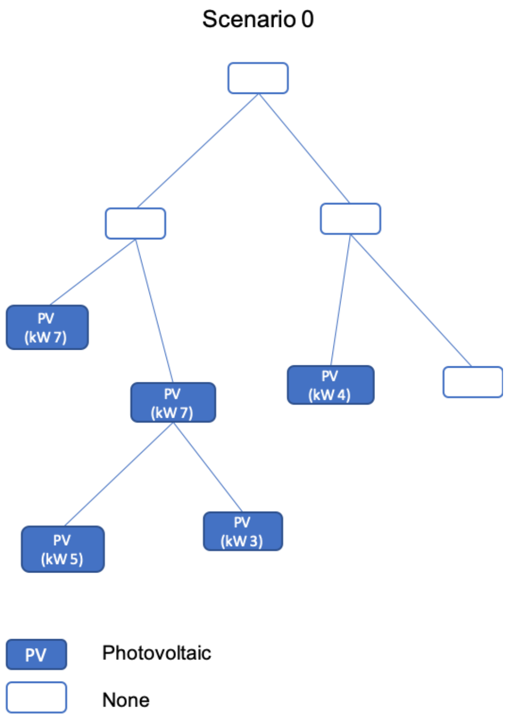

Figure 16 – Example of scheme for Scenario 0, HLUC-3-PUC-1-BM-1 (Source: LINKS elaboration)

The choice of the PV penetration will be done by the end-user in the Professional GUI. The main assumption, for simplicity of computation, is that the end-user starts from 0% of PV penetration every time he will run a new simulation. The S4G consortium has already computed a set of values for the cost of grid strengthening (i.e., capital expenditure, CapEx) respect to different levels of power (kWp) of the PV penetration (Table 2) where for each value of PV penetration we have assumed the cost of grid strengthening starting always from the value of PV = 0. As it shown in the table, the costs are not increasing monotonic function, due to the flicker issue.

Table 2 – PV penetration, kWp and associated CapEx for grid strengthen (Source: ENIIG elaboration)

PV penetration	kWp	Grid strengthening cost (Euro) – CapEx
24% flicker	36	27,300
64%	96	9,850
74%	111	21,000
84%	126	41,600
94%	141	43,100
100%	150	47,500

In order to have more degree of freedom in the selection of different PV penetration, a simple (quadratic) regression model has been developed to calculate a continuous function and compute the missing values of the previous Table 2 (see Figure 17 and Table 3);

Regression model: $Cost_{GS} = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \alpha_3 x^3 + \alpha_4 x^4$

Where α_i are the parameters of the regression and x^i are the values of kWp.

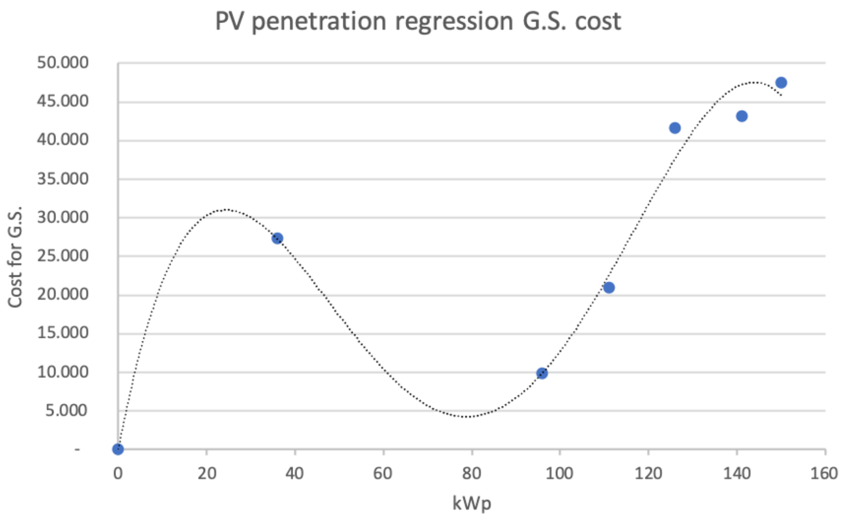

Figure 17 – PV penetration and grid strengthening cost (GS) – regression curve (Source: LINKS elaboration)

Table 3 – PV penetration after the regression model (Source: LINKS elaboration)

PV penetration	PV power (kWp)	Grid strengthening cost (Euro) – CapEx
0	0	0
…	…	…
24% flicker	36	27,300
…	…	…
40%	60	15,930
64%	96	9,850
74%	111	21,000
…	…	…
100%	150	47,500

4.2.2.2 Scenario 1 - grid strengthening with different degree of decentralized household storage penetration

Scenario 1 assumes that a number of prosumers investing in household energy storage system (ESS) in a grid where different PV systems have been already installed before. The storage system could be installed separately or integrated with PV, with different impact on the prosumer investment costs (see D2.4 for a simulation of cost for prosumers). This scenario considers different levels of PV and storage (ESS) penetration with different level of power for each component [kW] (Figure 18).

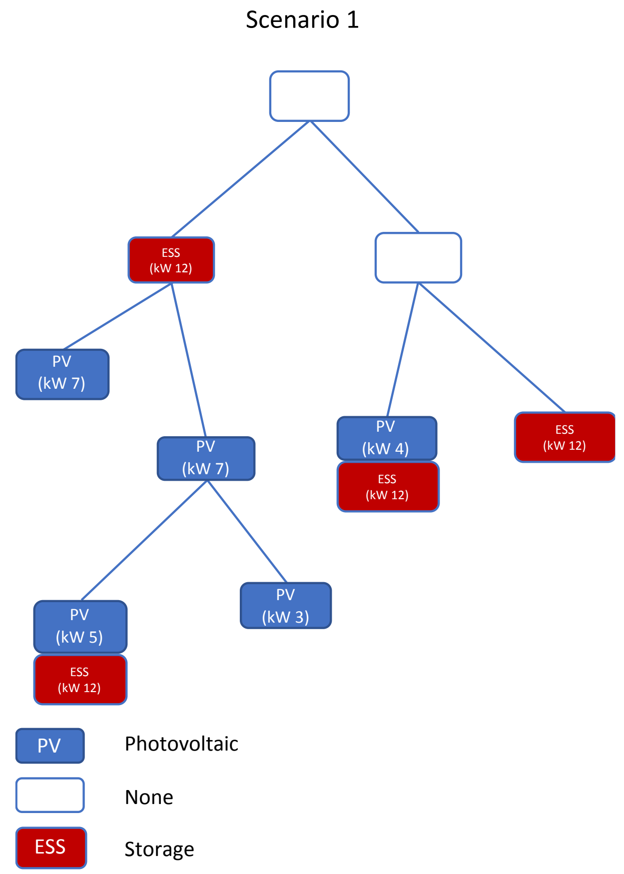

Figure 18 - Example of scheme for Scenario 1 (Source: LINKS elaboration)

Also in this case, the end-user shall decide in the Professional GUI interface:

- Which storage systems he would select (i.e., typology of battery);
- How many storage systems to be installed in the grid (i.e., number of batteries);
- Where the ESS should be installed, through a manual choice (i.e., residential, sub-station, etc.).

After the user selection, the DSF-SE will compute the technical validation of the choice done by the end-user and the related kW and kWp – where kWp is referring to the feeder's transformer nominal and therefore allowed power- for the new grid allocation and, if the technical validation will occur, the DSF-EE will compute the associated costs after the introduction of new ESS in the grid, considering a 1:1 ratio between ESS power and energy.

To make a numerical example, suppose the end-user decides to simulate a PV penetration[8] of 64% for scenario 0. In this case, the CapEx will be 9,850 euro with 96 kWp in case of introduction of PV in the grid.

Then, if the end-user should decide to add also ESS in the grid, as a consequence, now the grid strengthening should be not more equal to the grid strengthening for PV penetration of 64%, since ESS have been introduced (e.g., suppose the end-user would add 5 batteries), hence, *ceteris paribus* (i.e., with the same amount of PV penetration selected before), we can expect the cost for grid strengthening should be different than the initial case.

In order to compute the cost for grid strengthening of this new scenario, the DSF-SE simulator will compute the new value for the maximum active power passed through the feeder transformer during simulation horizon, known as kWp after introduction of the ESS and, from this, it was introduced a new variable, that can be called "Equivalent PV penetration", which will compute the correspondent value of kWp and, in turns, we compute

[8] The DSO usually knows PV penetrations (and storage systems) in the grid. The DSO does not know anything about EV's since it is not mandatory to declare to the DSO when people buy an EV.

the new grid strengthening cost value by using the previous Table 3. The end-user can make several numerical simulations for different degree of ESS allocation in the grid by dragging the batteries in different nodes as they prefer, and he will see the final results of technical feasibility and final economic results.
For instance, assuming the PV penetration of 64% and ESS penetration of 5 batteries and supposing the DSF-SE simulator provides the final value of 60 kWp, as a result, it was associated associate this new value of 60 kWp, where the grid strengthening cost corresponding to the new PV penetration (i.e., Equivalent PV) will correspond to the value of 40% of PV penetration, hence, in turn, it corresponds to the value of grid strengthening cost of Euro 10,514 (see Table 4).

Table 4 – PV penetration, ESS penetration, kWp, CapEx for grid strengthening and Equivalent PV (Source: LINKS elaboration)

PV penetration	P(PV) kWp	Grid strengthening cost (Euro)	ESS penetration	kWp after introducing ESS	Equivalent PV penetration	New Grid strengthening cost (Euro)
...	...	...	...	...	...	...
50%	63	...	...	...	...	...
64%	96	10,716	5 batteries	60	40%	10,514
...	...	...	...	...	...	...
100%	150	...	...	...	...	...

4.2.2.3 Scenario 2 - grid strengthening with a storage system deployed by DSO at sub-station level

This scenario is the case when storage systems are deployed by DSO at substation level that is the case at the new place in Skive, Spøttrup Kulturhal (Denmark). The capacity and the power of the battery should be different (higher) with respect to the batteries in Scenario 1, but the logic is the same for scenario 1 (Figure 19).

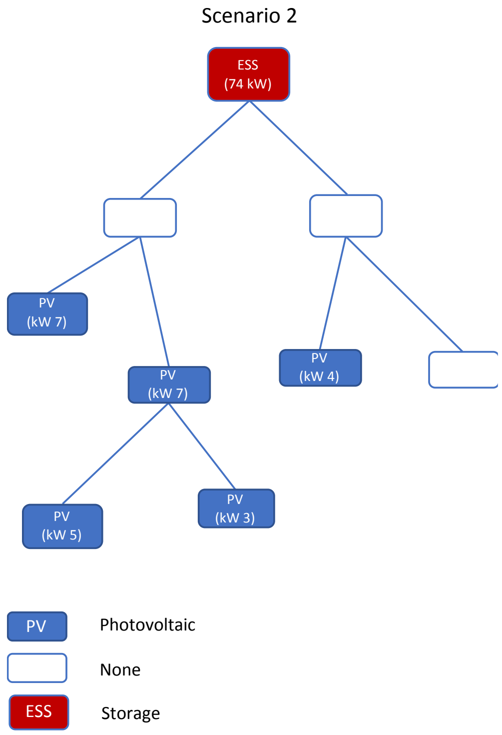

Figure 19 – Example of scheme for Scenario 2 (Source: LINKS elaboration)

4.2.2.4 Scenario 3

This scenario represents a mix between scenario 1 and scenario 2 where both centralized and decentralized storage systems are deployed along the grid (Figure 20).

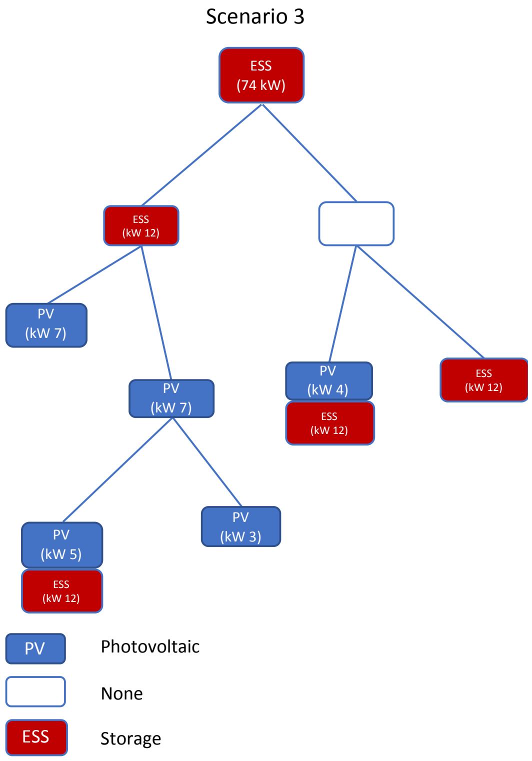

Figure 20 – Example of scheme for Scenario 3 (Source: LINKS elaboration)

4.2.3 Selection of the geographical area

The DSF-EE is a model implemented with real data and it is referred to the real test sites developed by the consortium to validate S4G solution. However, it is the ambition of the model to be deployed and easily adapted for other areas not included in this simulation tool. The current sites where the DSF-EE has been tested are three: Fur, Skive and Bolzano.

4.2.4 Description of the variables for DSF-EE

This paragraph is a deep description of the variables used for the construction of algorithm where the final outcome of the model will be to provide an indication about economic sustainability in terms of cost evaluation, that is, the evaluation of four TCO functions to compare the baseline scenario (grid strengthening without any storage systems but with different level of PV and/or EV penetration) with the other three scenarios with storage system both at substation level and at household side.
Each variable will be described in the following way:

- Description;
- Variable name;
- Variable acronym;
- Link with Professional GUI, DSF-SE, Input or Output (I/O), etc.

4.2.4.1 Time horizon for the investment

- *Description*: It is important to define a time horizon for all the selected scenarios in order to compare the final results in a logic of long term financial sustainability of the investment for the end-user. The basic assumption is to consider the maximum length for the grid strengthening duration of around 20 years, even if grid strengthening has a depreciation period of 40 years. The time horizon will be selected by the end-user, through the Professional GUI, independently on the scenario. For the final numerical simulation, we should assume an equal time horizon for all the scenarios in order to make the financial evaluation more homogeneous. Finally, a sensitivity analysis with different duration of time will be done in order to make the results more robust.
- *Variable Name*: Time of investment for both grid the strengthening and the battery deployment
- *Variable acronym*: T
- *Input/Output*: Input of the Professional GUI.

4.2.4.2 PV penetration

- *Description*: PV penetration in the grid in terms of percentage and power (kWp, meaning kW peak power) as computed by the quadratic regression model. The PV penetration is assumed to start from the value of zero (i.e., PV = 0% at time = 0). The PV penetration will be computed for each scenario, independently.
- *Variable Name*: PV penetration
- *Variable acronym*: $PV(kWp)$
- *Input/Output*: Input of the Professional GUI.

4.2.4.3 Equivalent PV penetration

- *Description*: See description in Section 4.2.2. This is the PV penetration after the introducing of storage systems at substation or residential level. The computation will be got from the DSF-SE after the electrical simulation in each scenario.
- *Variable Name*: Equivalent PV equivalent
- *Variable acronym*: $\widehat{PV}_{eq}(kWp)$
- *Input/Output*: Output of the DSF-SE.

4.2.4.4 Estimation of the CapEx for grid strengthening

- *Description*: When the grid strengthening is necessary, CapEx is calculated as the necessary cost for traditional grid strengthening in the low voltage grid, where the main items included are components, equipment, labour cost, etc. The calculation, in particular, includes (in percentage of CapEx):
  - Cables (37%);
  - Digging (31%);
  - Connection equipment, such as cable boxes (32%).

  The calculation is excluding project design, management and documentation, since this will be similar as with battery calculations. In this table the maximum of PV power (kWp) is 150 and it depends on the size of transformer.

Finally, we are assuming that the cost for grid strengthening is an 'overnight cost', in other word, the deployment of grid strengthening can occur in a very short period of time so that it is not relevant for our economic analysis.

- *Variable Name*: CapEx for grid strengthening
- *Variable acronym*: $CapEx_{GS}(PV(kWp))$
- *Input/Output*: DSF-EE economic model.

4.2.4.5 The cost of maintenance (OpEx) for grid strengthening

- *Description*: the yearly (or monthly) evaluation of the maintenance costs for grid strengthening is based on different level of PV penetration, where the indication of the maintenance activities needed along the years is represented by workers, equipment maintenance, equipment failure cost, etc. The evaluation of the OpEx (as a percentage of CapEx) has been computed as shown in the following Table 5 and if it seems to be feasible to use an average value for OpEx between 1% and 2% of CapEx.

Table 5 – OpEx from grid strengthening for different value of PV penetration (Source: ENIIG elaboration)

Calculation of OpEx	Value	Currency				
Different OpEx cost	1,389,000	kr				
Different OpEx cost	1,389,000	kr				
Different OpEx cost	902,000	kr				
Summa	3,680,000	kr				
Amount of km of low-voltage cables in total	16,624	km				
Price per km	221.37	kr/km				
Amount of km in baseline calculation			OpEx		CapEx	OpEx (% of CapEx)
PV penetration	Km		Kr/year	Euro/year	Euro	%
24%	0.727	km	160.93	21.18	27,300	0.08
64%	0.262	km	58.00	7.63	9,850	0.08
74%	0.535	km	118.43	15.58	21,000	0.07
84%	1.279	km	283.13	37.25	41,600	0.09

94%	1.372	km	303.72	39.96	43,100	0.09
100%	1.712	km	378.98	49.87	47,500	0.10

- *Variable Name*: Operating Expenditure for grid strengthening
- *Variable acronym*: $OpEx_{GS}(PV(kWp))$
- *Input/Output*: DSF-EE economic model.

4.2.4.6 Power Losses in energy production

- *Description*: the grid losses during the distribution of electricity are defined as the difference between the amount of energy that is fed into the grid and the amount of energy that is consumed or exported, i.e. taken out of the grid. Network losses are an indicator for an efficient utilization of the power grid since network losses have a direct impact on network costs and energy consumption. Network losses can be computed using historical data as the share of network losses for each DSO during the regulatory period (e.g., 2016-2019) and it is computed to the energy price per MWh for network losses calculated as an average price of energy during the regulatory period (2016-2019) = EUR/MWh [2]. Power losses can be paid with a high percentage from prosumers and a lower percentage from DSO. In some countries, regulation gives incentives to DSO such as requirement that no outages should be above 24 hours and individual customer compensation for outages above 12 hours, since outages >12/24 hours are not tolerated [3]. Furthermore, the Swedish Energy Markets Inspectorate (EI) has specified that no customer should have more than 11 outages per year [2].
  In case of short outages (0.05–12 h), the upcoming tariff regulation will be based on reported SAIDI and SAIFI. The possible consequence for the DSO is decreased income limit, i.e., all customers collectively obtain revised tariff levels. To avoid "double penalization", outages from other categories are excluded. If customers are given sufficient notice of outages, the economic impact will be lower.
  In case of long outages (>12 h), the Table 6 summarizes the model for determining customer outage compensation to affected customers (example in Sweden).

Table 6 – Example of customer outage compensation (Source: [3])

CONSEQUENCES OF OUTAGES >12 h

Length of the outage	Compensation to customer	Minimum compensation[1]
12-24 hours	12.5 % of α	2 % of β
24-48 hours[2]	+ 25 % of α	4 % of β
Following 24 hour periods[2]	+ 25 % of α	+ 2 % of β
⋮	⋮	
Max[2]	300 % of α	-

α = Individual customer's annual network tariff; this value depends on both the main fuse (power allowed) and annual energy consumption.
β = Yearly set base amount (42 400 SEK 2010, ~4700 €, ~6100$))
[1]Is always set to even 100 SEK values, rounded up → 2 % β is rounded up to 900 SEK (~100 €, ~140$)
[2]Additional consequences are likely , since >24 hours outages not are tolerated by the law from 2011

A more detailed explanation about network losses and compensation mechanism is provided by Wallnerström [3]. For our computation in the DSF-EE, the DSF-SE will provide the value of power losses (kWh) per day and per year. Most losses in the grid is from the cable box into the house which is not part of the DSO grid. In Denmark, for instance, the power loss is approximatively 5% in the DSO grid and this is payed as part of the grid tariff.

- *Variable Name*: Power Loss, expressed in kWh
- *Variable acronym*: $PwLoss$
- *Input/Output*: Output of DSF-SE.

4.2.4.7 Battery exploitation and lifetime

Description: this variable represents the average load profile that an end-user would follow during the investment period. We supposed to have three kinds of load profiles: high, medium, low level of exploitation. Concerning the lifetime, the model should know the duration of different kind of batteries (i.e., power [kW], energy [kWh]). Based on the usage/duty/destination use of the ESS, the S4G Consortium provides an estimation of the lifetime of the battery. Indeed, lifetime does not depend much on the size of the battery but on the exploitation profile. ESS can be deployed both by households (with a range of size from 3-5 kWh to around 12 kWh) and by DSO (with 50-100 kWh). DSO can deploy one ESS at substation level or more ESS in different points of the grid.

- *Variable Name*: Battery lifetime
- *Variable acronym*: $ESS_{k\text{-}time} = f(Expl_e)$, where e = (high, medium, low) and Expl is the type of exploitation of the battery (i.e., usage)
- *Input/Output*: Input from Professional GUI.

4.2.4.8 Type and Cost of battery for different type of exploitation

- *Description*: this is the price for batteries that can be computed for different level of installation. Indeed, the batteries used in our model can be at substation level (scenario 2) or at residential level (scenario 1). We propose to select a restricted number of batteries. For what concerns the market price of the batteries we considered the trend of the future prices across the years collected from different sources in order to compute an expected value for those prices. LINKS will use the literature of battery price costs to simulate those values. Currently, we have computed the following estimation of expected cost of storage per kWh (Table 7) for the next 10 years where we expect the prices for batteries will decrease in the short run period. Finally, we also estimate an average rate of decreasing for batteries price around – 7% per year (Figure 21)[9].

Table 7 – Estimation of prices for batteries from different sources (Source: LINKS elaboration from different sources)

Source: IFC 2017 [4]		Source: REA 2016 [5]		Source: BSW 2017	
Year	$	Year	$	Year	$
2014	1,100	2014	1,493	2014	1,400
2015	1,037	2015	1,400	2015	1,222
2016	978	2016	1,307	2016	1,066
2017	922	2017	1,220	2017	930
2018	869	2018	1,139	2018	812
2019	819	2019	1,064	n.a.	n.a.
2020	772	2020	993	n.a.	n.a.
2021	728	2021	927	n.a.	n.a.
2022	686	2022	866	n.a.	n.a.
2023	647	2023	808	n.a.	n.a.
2024	610	2024	755	n.a.	n.a.
n.a.	n.a.	2025	705	n.a.	n.a.
n.a.	n.a.	2026	658	n.a.	n.a.
n.a.	n.a.	2027	614	n.a.	n.a.
n.a.	n.a.	2028	574	n.a.	n.a.

[9] The prices are all expressed in dollar, hence, we compute these values for the current exchange rate.

n.a.	n.a.	2029	536	n.a.	n.a.
n.a.	n.a.	2030	500	n.a.	n.a.
Rate of discount	**Yearly rate**	**Rate of discount**	**Yearly rate**	**Rate of discount**	**Yearly rate**
-44,55%	**-5,73%**	**-64,29%**	**-6,63%**	**-42,00%**	**-12,73%**

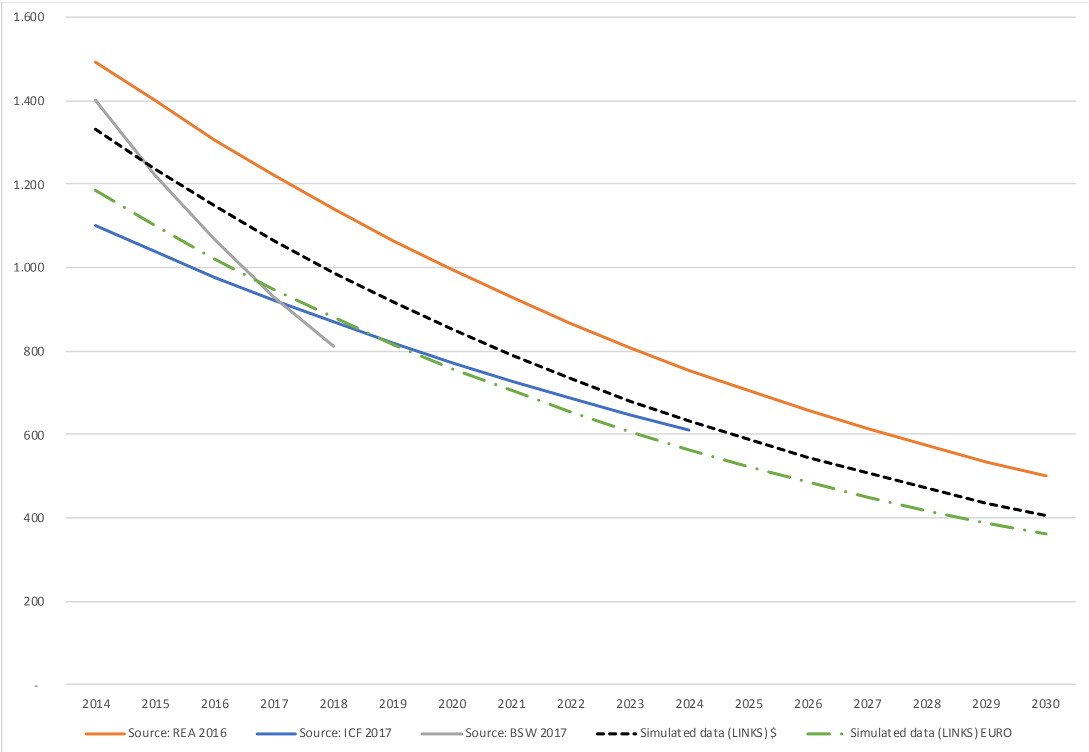

Figure 21 – Estimation of price for batteries – dollar per kWh (Source: LINKS elaboration)

- *Variable Name*: Battery price
- *Variable acronym*: p_{kWh}^{ESS}
- *Input/Output*: input from DSF-EE.

4.2.4.9 Storage penetration

- *Description*: this represents the number of ESS installed along the line by household prosumers. This value should be provided by the end-user in the Professional GUI. Usually, DSO should know how many storage systems are installed in the area, since they must be registered at the DSO. In the DSF-SE, the end-user can choose how and where to insert ESS in the network by providing the technical feasibility of the choice. If the DSF-SE validate the selection of the ESS in the grid, this will become an input for the economic model. Concerning to storage penetration indicator, we will consider the total number of batteries installed, the size and the typologies.
- *Variable Name*: Storage penetration
- *Variable acronym*: $n_{ESS,size}$
- *Input/Output*: Input from Professional GUI.

4.2.5 Other variables and interaction with the Professional GUI and the DSF-SE

In the following Table 8, a synthetic list of the variables with the meaning and the acronym is provided in order to ease the reading for the TCO formula.

Table 8 – List of variables for the DSF-EE model (Source: LINKS elaboration)

Variable	Acronym	Interaction with Professional GUI, DSF-SE, DSF-EE ('drop down' menu)	Unit of measure	Description	Examples of values to be validated by all the Partners
PV penetration	$PV(kWp) = \bar{x}\%$	End-user inserts this value in the Professional GUI	kWp and/or percentage (%)	Penetration of photovoltaic systems in the grid in terms of kWp or percentage of actual trafo nominal power	150 kWp (Max kWp)
Time	T	End-user inserts this value in the Professional GUI	Year	Timeline of the investment	T = 20
Interest Rate	r	Input from LINKS	Percentage (%) on yearly basis	Cost of capital	r = 7%
Power Losses	$PwLoss$	DSF-SE computation	kWh	The degree of loss of energy in the grid due to the different PV penetration	See Table 9
Energy price	p_{EN}	Input from LINKS	Euro/kWh	Current energy price for energy in the selected country	0.31 Eur/kWh
Power Losses cost	$C(PwLoss)_{SC_i,t}$	DSF-EE computation	Euro	Total cost for power losses	See Table 9
Power Consumption	$PwCons_{SC_i}$	LINKS computation	kWh/year	This is an average power consumption per year to be purchased in the market from a typical household	See Table 9
Power Consumption cost	$C(PwCons)_{SC_i}$	LINKS computation	Euro/year	This is an average cost of power consumption of a typical household during	See Table 9

Households	h	DSF-SE	#	This is the number of households that represent the nodes of the grid	21 households (nodes)
Households with PV	h_{PV}	DSF-SE	#	This is the number of households that represent the nodes of the grid and that own a PV system	See Table 9
Equivalent PV penetration	$\widehat{PV}_{eq}(kWp)$	DSF-SE computation and DSF-EE computation	kWp and/or percentage (%)	Equivalent PV penetration after the introduction of a storage system	See Table 9
Capital expenditure	$CapEx_{GS}(PV(kWp) = \bar{x}\%)$	Input from partnership	Euro	Cost for the installation and building the grid reinforcement and strengthening, as a function of PV penetration	See Table 9
Operating Expenses	$OpEx_{GS}$	Input from partnership	Euro per year	Cost for maintenance of the grid, as a function of PV penetration	1% of CapEx
Storage penetration	n_{ESS}	End-user inserts this value in the Professional GUI and DSF-SE validates it or not	#	Number of batteries installed in the scenario i	See Table 9
Battery size	kWh_{ESS}	Input from Professional GUI	kWh	Size of battery installed in every scenario and in every household	• 12 kWh for households • 70 kWh for substation
Battery price	p_{kWh}^{ESS}	Input from LINKS	Euro per kWh	Current price of batteries in the market	817 Eur/kWh
Battery total cost	$CapEx_{ESS,size}$	DSF-EE computation	Euro	Total cost for different size and typologies of battery	See Table 9
Battery price trend	$\Delta\%(\overline{Price}_{ESS-trend})$	Input form LINKS	Percentage (%)	Trend percentage of costs for the future prices of storage systems	- 7.6% per year
Bureaucracy costs	$Cost_{bur}$	Input from Partners	Euro	Cost for documentation and network connection that it will be computed in the initial phase of the project. Initial cost for	9,000 Eur per year

				bureaucracy to install a storage system	
Battery Lifetime	ESS_{k-time}	Input from DSF-SE	Years	This is the lifetime of the battery selected from the end-user. After the selection, the DSF-SE shows the lifetime and it will be an input for the DSF-EE	15 years for households 18 years for substation

4.2.6 Functional form for TCO

The functional forms or algorithms used in the DSF-EE are based on the final computation of a total cost of ownership (TCO) function for each scenario, both from the DSO and prosumer point of view. The final outcome will be a comparison between the two stakeholders and the aggregate values get from the sum of these values to analyse from a welfare point of view which scenario produce higher benefit (in terms of less costs). The TCO is an approach under the Life-Cycle Costing methodology that allows entities to carry out an economic evaluation of the possible direct costs involved during the life cycle of a good, service or work, bringing out the "hidden" costs of the next-to-be-purchased items, along with the acquisition price (Figure 22).

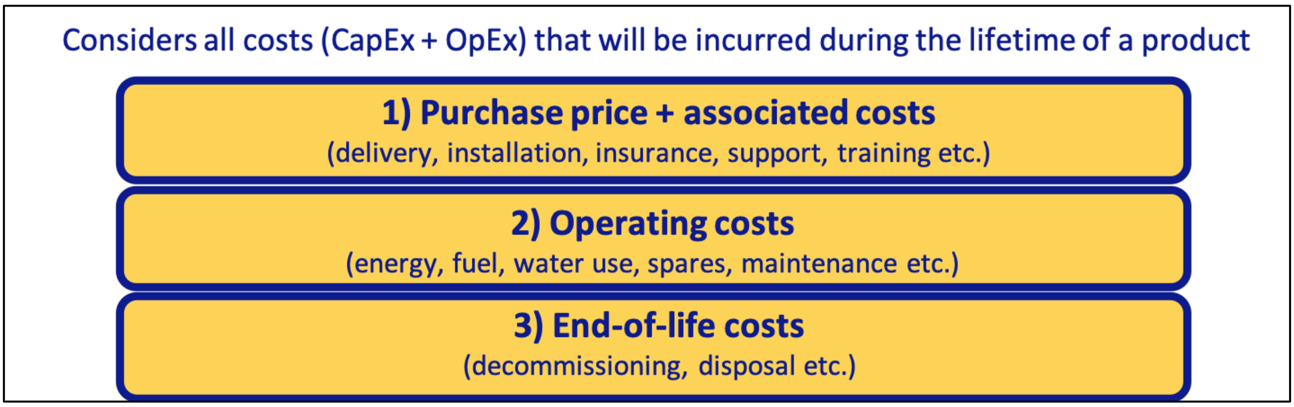

Figure 22 – Total Cost of Ownership (TCO)

4.2.6.1 TCO for Scenario 0

The TCO for DSO in case of grid strengthening is depicted as follows:

$$TCO\ (DSO)_{SC_0} = CapEx_{GS}(PV(kWp) = \bar{x}\%) + \sum_{t=1}^{T} \frac{OpEx_{GS}(PV = \bar{x}\%)_t + 0.5 \cdot C(\widehat{PwLoss})_{SC_i,t}}{(1+r)^t}$$

Where:

- i is the scenario $i = \{0,1,2,3\}$;
- 0.5 (i.e., 50%) is the percentage of total power losses in the grid to be charged for the DSO and to the prosumers, respectively;
- $\bar{x}\%$ is the value of PV penetration chosen by the end-user through the Professional GUI (this value should remain constant for all the scenarios in order to compare theme in a homogeneous way);
- kWp is information get from DSF-SE after the technical simulation of scenario i;
- T is the time value of the investment chosen by the end-user through the Professional GUI (this value should remain constant for all the scenarios in order to compare theme in a homogeneous way);
- $C(PwLoss)_{SC_i,t}$ is the yearly cost of power losses computed by the DSF-SE in all the scenario i = 0, 1, 2, 3, that is computed as follows:

$$C(\widehat{PwLoss})_{SC_i,t} = \bar{p}_{EN} \cdot kWh\ of\ power\ losses\ per\ year$$

- $\bar{p}_{EN}$ is the current price of energy in the selected country (i.e., Denmark and Italy);

- r is the interest (discount) rate chosen for the financial computation;
- $CapEx_{GS}$ is the capital expenditure for grid strengthening which values are computed by the Table 3 after a regression model;
- $OpEx_{GS}$ is the yearly operating expenditure for grid strengthening.

The TCO for prosumer is:

$$TCO\ (Prosumer)_{SC_0} = \sum_{t=1}^{T} \frac{0.5 \cdot C(\widehat{PwLoss})_{SC_i,t} + (h - h_{PV}) \cdot \bar{p}_{EN} \cdot PwCons_{SC_i,h} + h_{PV} \cdot \bar{p}_{EN} \cdot PwCons_{SC_i,h_{PV}}}{(1+r)^t}$$

Where:

- h is the number of households (nodes) in the grid;
- h_{PV} is the number of households with a PV installed in the house;
- $PwCons_{SC_i,h}$ is the level of power consumption for which consumers without a PV pay an annual fee and it is computed for every scenario and every household (i.e., for scenario 1, it will be supposed that power consumption will be lower thanks to the introduction of storage system in the grid);
- $PwCons_{SC_i,h_{PV}}$ is the level of power consumption for which consumers with a PV pay an annual fee and it is computed for every scenario and every household.

The aggregate TCO is computed by the sum of TCO of DSO and prosumer:

$$TCO\ (aggreagate)_{SC_i} = TCO\ (DSO)_{SC_i} + TCO\ (Prosumer)_{SC_i}$$

4.2.6.2 TCO for Scenario 1

The TCO for DSO in case of distributed storage systems is depicted as follows:

$$TCO\ (DSO)_{SC_1} = CapEx_{GS}\left(\widehat{PV}_{eq}(kWp) = \hat{x}\%\right) + \sum_{t=1}^{T} \frac{OpEx_{GS}\left(\widehat{PV}_{eq}(kWp) = \hat{x}\%\right)_t + 0.5 \cdot C(\widehat{PwLoss})_{SC_i,t}}{(1+r)^t}$$

Where:

- $\widehat{PV}_{eq}(kWp)$ is the value of PV penetration computed by the Table 3;
- $CapEx_{GS}$ is referred to the Table 3.

The TCO for prosumer is:

$$TCO\ (Prosumer)_{SC_1} =$$
$$= \sum_{k=0}^{T} \frac{n_{ESS} \cdot CapEx_{ESS}(Usage, Capacity) \cdot \left(1 - \Delta\%(\overline{Price}_{ESS-trend})\right)^{k \cdot ESS_{k-time}}}{(1+r)^{k \cdot ESS_{k-time}}} +$$
$$+ \sum_{t=0}^{T} \frac{Cost_{bur} + 0.5 \cdot C(PwLoss)_{SC_i,t} + n_{ESS} \cdot p_{EN} \cdot PwCons_{SC_i} + (h - n_{ESS}) \cdot p_{EN} \cdot PwCons_{SC_i}}{(1+r)^t}$$

Where:

- k is the multiple of the number of times according which you should compute the cost for battery installation that depends on the lifetime of battery. Indeed, k is the number of times the battery should be replaced due to its own lifetime and usage (i.e., if the lifetime of a battery is 8 years and the investment is 20 years, you should compute at least three installation of storage systems: the first in year 0, the second in year 8, the third in year 16). $k - time$ is computed by S4G Consortium and it depends on the usage (see 4.2.4.7);

- n_{ESS} is the number of batteries installed by the end-user in her grid (i.e., the expected ESS penetration). This value will be provided by the end-user through the Professional GUI;
- $\Delta\%(\overline{Price}_{ESS-trend})$ is the 'expected' trend of decreasing prices for ESS, in percentage terms, that have computed by LINKS according to several literature sources (see Table 9 and Figure 21);
- $CapEx_{ESS}(Usage, Capacity)$ is the cost of batteries that can be computed based on two variables:
  - $Capacity$ is the kWh of the battery that will be multiplied for the current price for ESS;

$$CapEx_{ESS,size} = p_{kWh}^{ESS} \cdot kWh_{ESS}$$

  - $Usage$ is the type of use of batteries based on the Table 8;
- $Cost_{bur}$ is the cost for bureaucracy that is fixed by LINKS.

The aggregate TCO is computed by the sum of TCO of DSO and prosumer:

$$TCO\ (aggreagate)_{SC_i} = TCO\ (DSO)_{SC_i} + TCO\ (Prosumer)_{SC_i}$$

4.2.6.3 TCO for Scenario 2

The TCO for DSO in case of centralized storage system is depicted as follows:

$$\begin{aligned} TCO\ (DSO) = & \sum_{k=1}^{T} \frac{CapEx_{ESS}(Usage, Capacity) \cdot \left(1 - \Delta\%(\overline{Price}_{ESS-trend})\right)^{k \cdot ESS_{k-time}}}{(1+r)^{k \cdot ESS_{k-time}}} \\ & + \sum_{t=1}^{T} \frac{Cost_{bur} + 0.5 \cdot C(PwLoss)_{SC_i,t}}{(1+r)^t} + CapEx_{GS}\left(\widehat{PV}_{eq}(kWp) = \hat{x}\%\right) \\ & + \sum_{t=1}^{T} \frac{OpEx_{GS}\left(\widehat{PV}_{eq}(kWp) = \hat{x}\%\right)_t}{(1+r)^t} \end{aligned}$$

The TCO for prosumer is:

$$TCO\ (Prosumer) = \sum_{t=1}^{T} \frac{0.5 \cdot C(PwLoss)_{SC_i,t} + (h - h_{PV}) \cdot \bar{p}_{EN} \cdot PwCons_{SC_i,h} + h_{PV} \cdot \bar{p}_{EN} \cdot PwCons_{SC_i,h_{PV}}}{(1+r)^t}$$

The aggregate TCO is computed by the sum of TCO of DSO and prosumer:

$$TCO\ (aggreagate)_{SC_i} = TCO\ (DSO)_{SC_i} + TCO\ (Prosumer)_{SC_i}$$

4.2.6.4 TCO for Scenario 3

The TCO for DSO in case of both centralized and decentralized storage system is depicted as follows:

$$TCO\ (DSO) = \sum_{k=1}^{T} \frac{CapEx_{ESS}(Usage, Capacity) \cdot \left(1 - \Delta\%\left(\overline{Price}_{ESS-trend}\right)\right)^{k \cdot ESS_{k-time}}}{(1+r)^{k \cdot ESS_{k-time}}} + \sum_{t=1}^{T} \frac{Cost_{bur} + 0.5 \cdot C(PwLoss)_{SC_i,t}}{(1+r)^t} + CapEx_{GS}\left(\widehat{PV}_{eq}(kWp) = \hat{x}\%\right) + \sum_{t=1}^{T} \frac{OpEx_{GS}\left(\widehat{PV}_{eq}(kWp) = \hat{x}\%\right)_t}{(1+r)^t}$$

The TCO for prosumer is:

$$TCO\ (Prosumer)_{SC_1} = \sum_{k=0}^{T} \frac{n_{ESS} \cdot CapEx_{ESS}(Usage, Capacity) \cdot \left(1 - \Delta\%\left(\overline{Price}_{ESS-trend}\right)\right)^{k \cdot ESS_{k-time}}}{(1+r)^{k \cdot ESS_{k-time}}} + \sum_{t=0}^{T} \frac{Cost_{bur} + 0.5 \cdot C(PwLoss)_{SC_i,t} + n_{ESS} \cdot p_{EN} \cdot PwCons_{SC_1} + (h - n_{ESS}) \cdot p_{EN} \cdot PwCons_{SC_i}}{(1+r)^t}$$

The aggregate TCO is computed by the sum of TCO of DSO and prosumer:

$$TCO\ (aggreagate)_{SC_i} = TCO\ (DSO)_{SC_i} + TCO\ (Prosumer)_{SC_i}$$

4.3 Integration with DSF components

The Economic Engine collects the following inputs from the Professional GUI and the DSF-SE:

- Professional GUI:
  - Time of the length of the grid investment (years);
  - ESS related information (for each battery) about: ID, size (kWh), lifetime (years), position (household or substation level);
  - Grid name (e.g. Skive, Bolzano).
- DSF-SE:
  - PV penetration (kWp) (the aggregated one observed at the transformer);
  - Power Losses per year (kWh);
  - The outputs provided by the DSF-EE are total cost of ownership from DSO, prosumer and aggregate point of view.

The endpoint built to provide the Economic Model results is the following:
https://dwh.storage4grid.eu:9082/EE/input

In order to provide confidentiality over the communication with the DSF-EE, it is built to respond only to https requests. The outcomes will be presented to the grid planner user through the Professional GUI. The interface is REST-based and the inputs/outputs payloads are JSON-based. Below there are two examples written in the JSON format:

- Input

```
{ "grid_name": "Skive",

"kw_peak": 20,

"kwh_losses": 100,

"yearly_simulation_time": 10,

"ESS_info":
[{ "id": "fronius_1", "kwh": 10, "yearly_lifetime": 10, "location": "household"},

{"id": "fronius_1", "kwh": 20, "yearly_lifetime": 20, "location": "household"},

{"id": "fronius_2","kwh": 15, "yearly_lifetime": 25, "location": "substation"} ] }
```


- Output


```
{
  "scenario_id": 1,

  "scenario_name": "Decentralized Storage at household level",

  "TCO_DSO": 10,

  "TCO_Aggregated": 110,

  "TCO_Community": 90

}
```


The outcomes will be presented to the grid planner user through the Professional GUI. Further details about the integration with other DSF components are presented in Section 4.4.

4.4 Economic insights from simulation engine

The economic model described in the section 4.2 has been implemented as a real-time simulation engine (DSF-EE) to estimate the TCO of one independent scenario. Its interface has been described in the previous section. However, it has been done an offline version aiming at comparing different scenarios simultaneously by using data (input) from a simulated technical engine. The offline version extends the real-time simulation but it has not been integrated into the REST-based server.

4.4.1 Inputs for the offline simulation economic model

The goal of this paragraph is provided the outcomes from the simulation of all the four scenarios described before and get some economic insights useful to analyse some corner solutions. For this purpose, the model, indeed, will consider a set of values and figures that are depicted in the following Table 9 (Bolzano test site).

Table 9 – Inputs for the offline simulation of the DSF-EE (Source: LINKS elaboration)

Scenario	Variables	Low	Medium	High
	Location (test site)	**Bolzano**		
	Number of nodes (households)	**21**		
	Reduction of power consumption in scenario 1 with respect scenario 0 (LINKS assumption)	**-23%**		
	PV penetration (%)	**15%**	**50%**	**100%**
	PV penetration (kWp)	**22**	**75**	**150**
	Number of PVs	**3**	**11**	**21**
	Number of ESS (only for scenario 1 and 3)	**3**	**11**	**21**
Scenario 0	Power Losses (kWh in the worst-case scenario[10])	19,612	18,824	29,194
	Total power consumption (kWh)[10]	166,568	112,325	28,561
Scenario 1	Power Losses (kWh in the worst-case scenario)[10]	19,445	17,433	23,000
	Total power consumption (kWh)[10]	163,339	107,126	28,561
Scenario 2	Power Losses (kWh in the worst-case scenario)[10]	19,449	15,564	24,000
	Total power consumption (kWh)[10]	166,568	112,325	28,561
Scenario 3	Power Losses (kWh in the worst-case scenario)[10]	19,449	15,564	23,000
	Total power consumption (kWh)[10]	160,636	102,775	16,494

In order to simplify the computation, we assume that all the household storage systems have a nominal energy of 12 kWh in scenario 1 while the DSO deploy a battery of 70 kWh in scenario 2. The offline simulation engine has been realized with a spreadsheet available for the S4G consortium where the results have been simulated to find the following outcomes.

4.4.2 Outcomes from the economic simulation engine

With the goal to implement the economic model engine and to provide some indication for the decision maker, we applied the numerical computation to three cases with a low, medium and high PV penetration, respectively. The results have been divided for different case studies where we relaxed some variables, with other variables constant (in the logic of partial derivatives), in order to understand which scenario could be more economically feasible. In particular, we consider a sensitive analysis by using the following variables and related values to build 4 case studies, *ceteris paribus* (Table 10).

[10] All these values have been computed in simulation engines as OpenDSS and Script of Pyton

Table 10 – Case studies for the (offline) economic simulation engine (Source: LINKS elaboration)

Case study/variables	**Price of energy** p_{EN}	**Price of batteries** p_{kWh}^{ESS}	**Lifetime (both for 12 and 70 kWh)** ESS_{k-time}	**Percentage of decreasing of storage prices across the years** $\Delta\%(\overline{Price}_{ESS-trend})$
Case study 0 (Base)	0.31 (Eur/kWh)	735 (Eur/kWh)	15 (years)	-7.16% (per year)
Case study 1	0.31 (Eur/kWh)	735 (Eur/kWh)	**6, 15, 21(years)**	-7.16% (per year)
Case study 2	0.31 (Eur/kWh)	735 (Eur/kWh)	15 (years)	**-15% (per year)**
Case study 3	**0.21, 0.31 (Eur/kWh)**	735 (Eur/kWh)	15 (years)	-7.16% (per year)
Case study 4 (Best scenario)	0.31 (Eur/kWh)	735 (Eur/kWh)	**21(years)**	**-35% (per year)**

The results of the simulation are shown in the next sections. Each figure considers the following:

- The scenarios (see Section 4.2.2):
- The level of PV penetration
  - Low = 15%
  - Medium = 50%
  - High = 100%
- The groups of reference:
  - DSO (blue bar);
  - Prosumers (orange bar);
  - Community as a whole, i.e. DSO + Prosumers (green bar).

4.4.2.1 Case Study 0

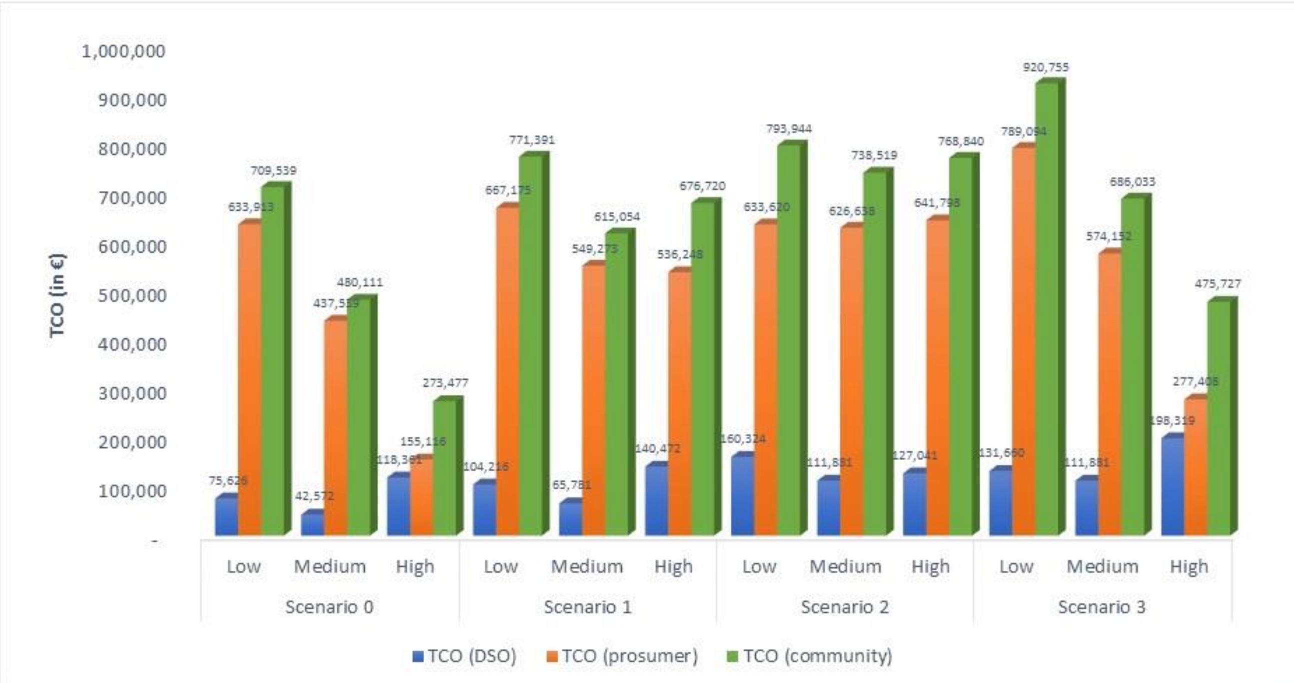

Figure 23 – Case study 0: TCO (in €) per scenario (Source: LINKS elaboration)

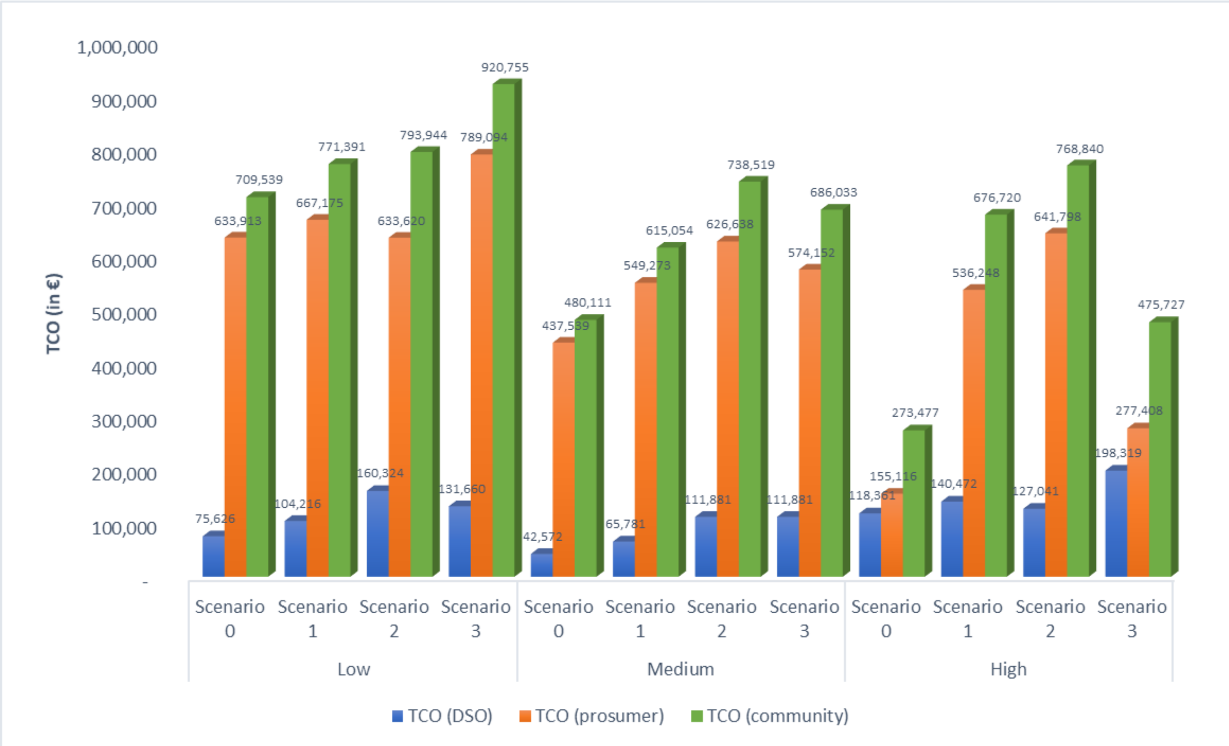

Figure 24 – Case study 0: TCO (in €) per PV penetration (Source: LINKS elaboration)

4.4.2.1 Case Study 1

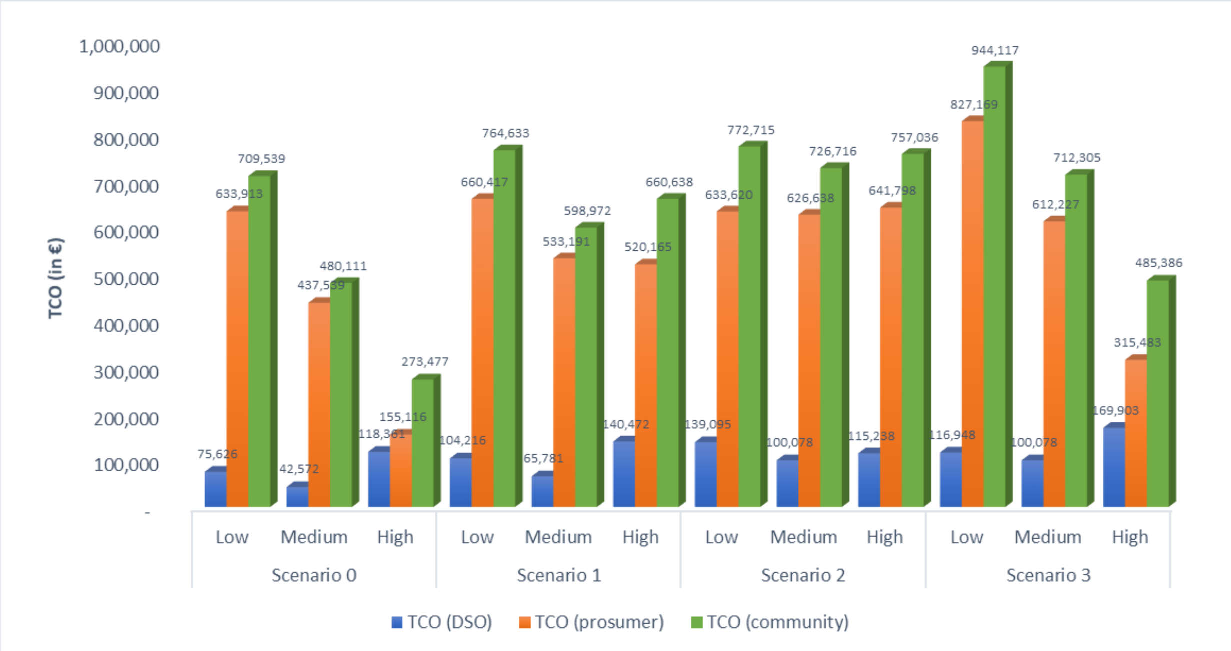

Figure 25 – Case study 1: TCO (in €) per scenario with lifetime of battery = 21 (Source: LINKS elaboration)

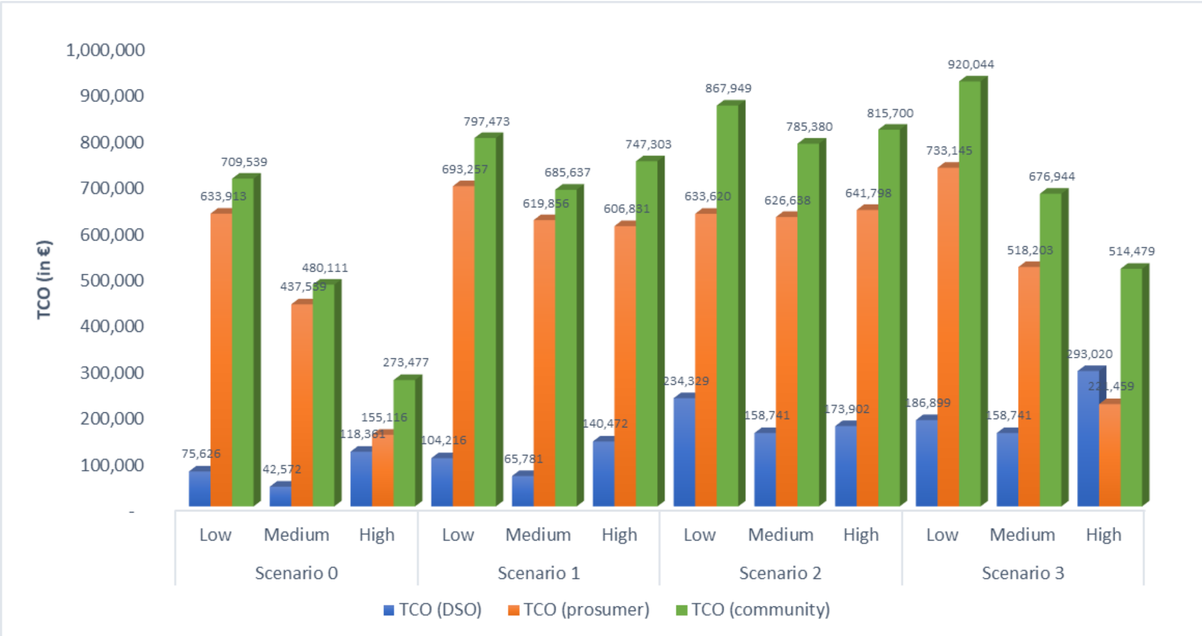

Figure 26 – Case study 1: TCO (in €) per scenario with lifetime of battery = 6 (Source: LINKS elaboration)

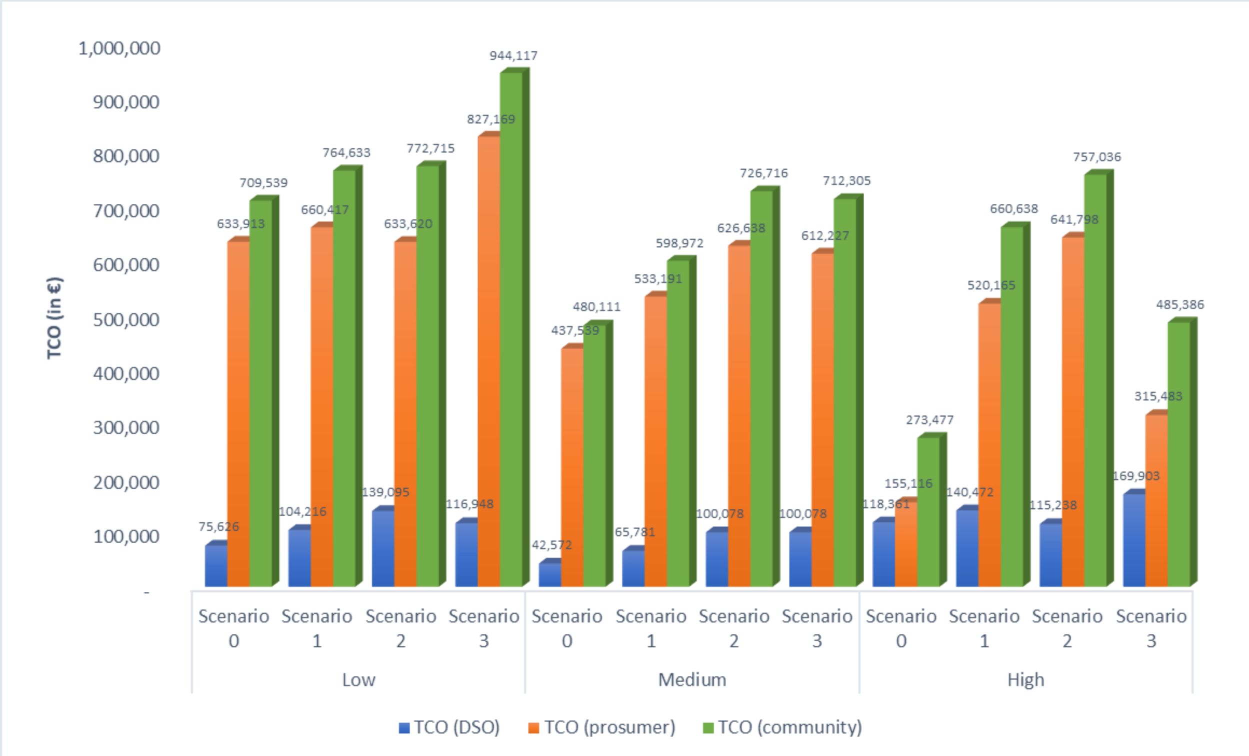

Figure 27 – Case study 1: TCO (in €) per PV penetration with lifetime of battery = 21 (Source: LINKS elaboration)

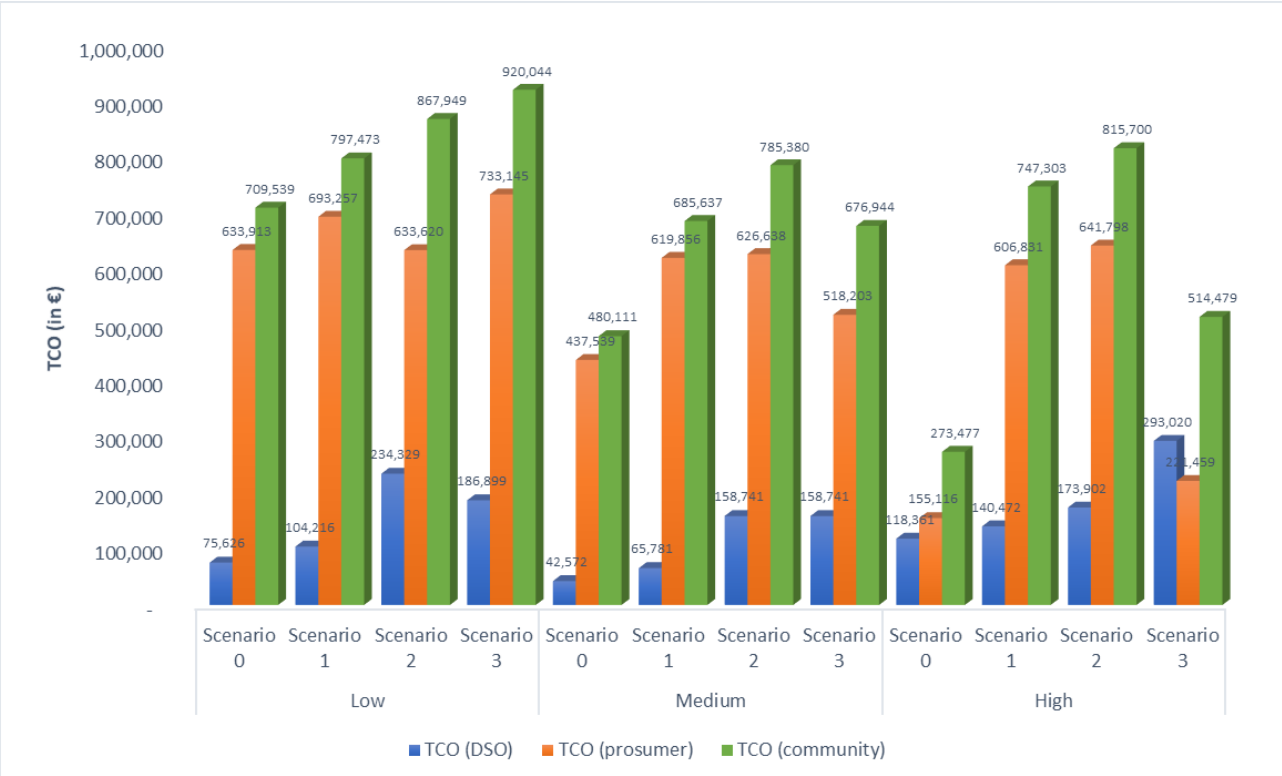

Figure 28 – Case study 1: TCO (in €) per PV penetration with lifetime of battery = 6 (Source: LINKS elaboration)

4.4.2.2 Case Study 2

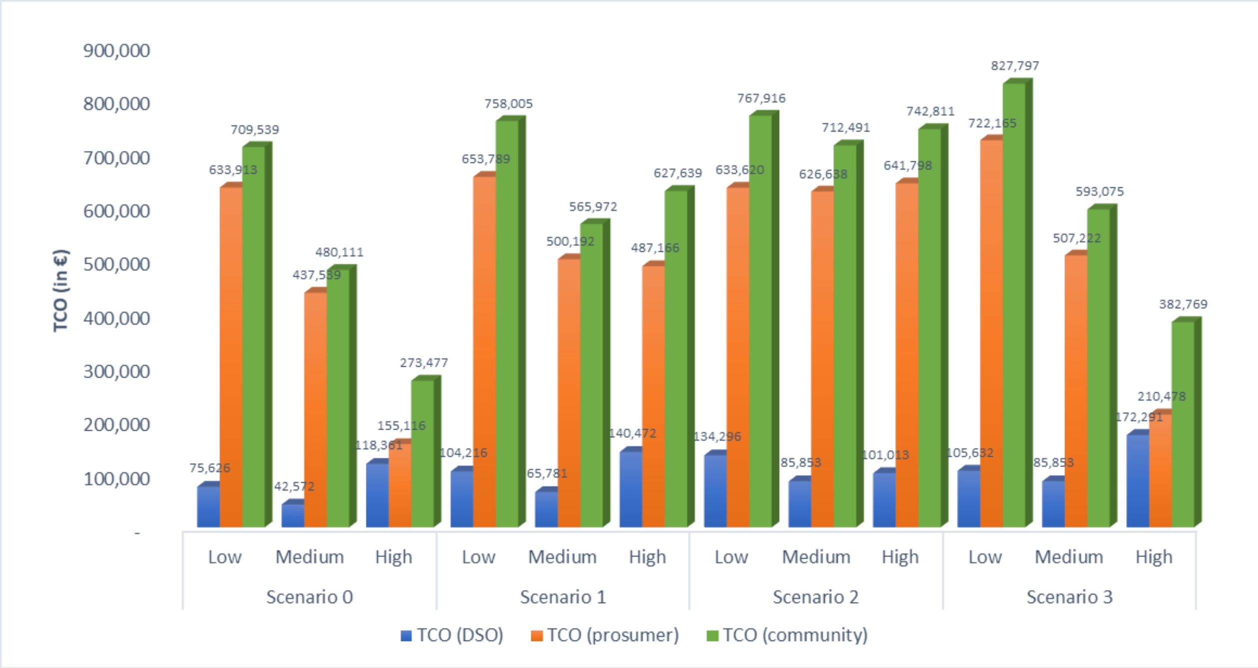

Figure 29 – Case study 2: TCO (in €) per scenario with trend of storage prices = -15% (Source: LINKS elaboration)

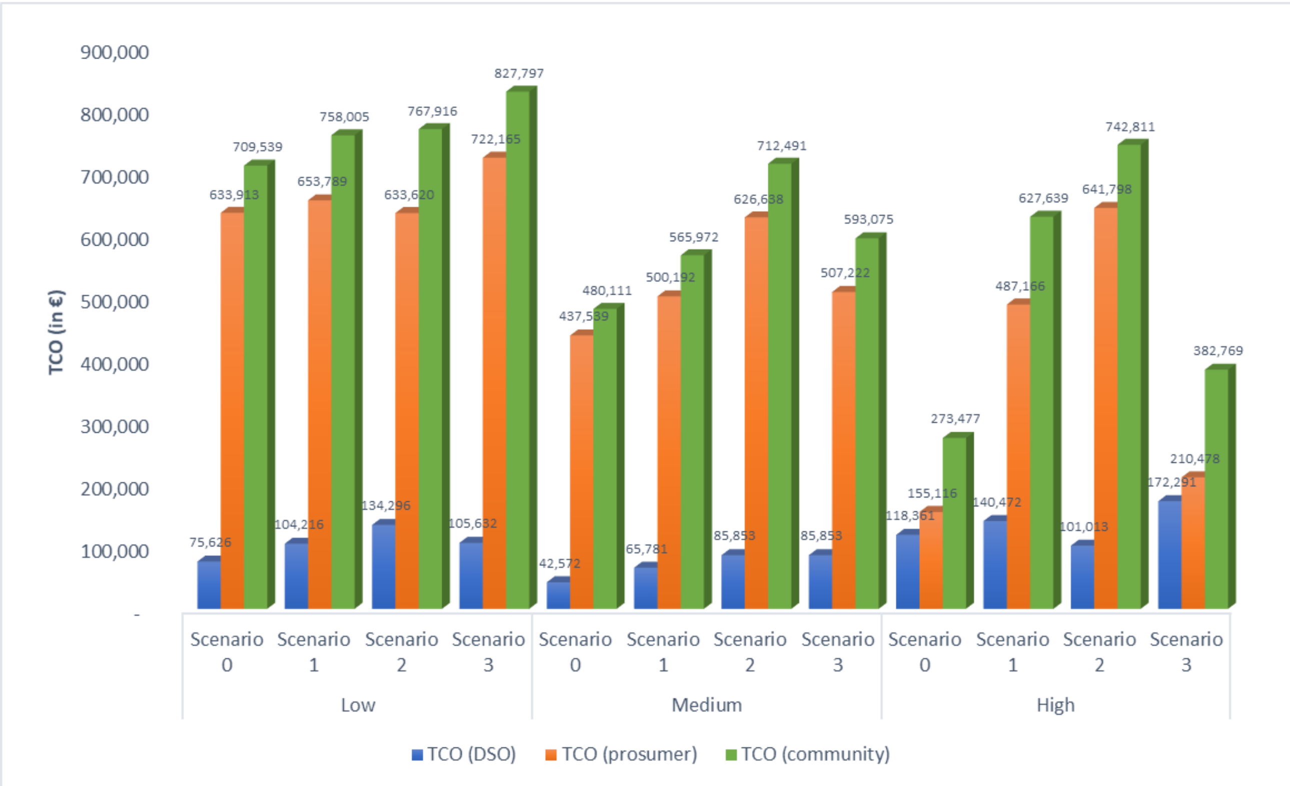

Figure 30 – Case study 2: TCO (in €) per PV penetration with trend of storage prices = -15% (Source: LINKS elaboration)

4.4.2.3 Case Study 3

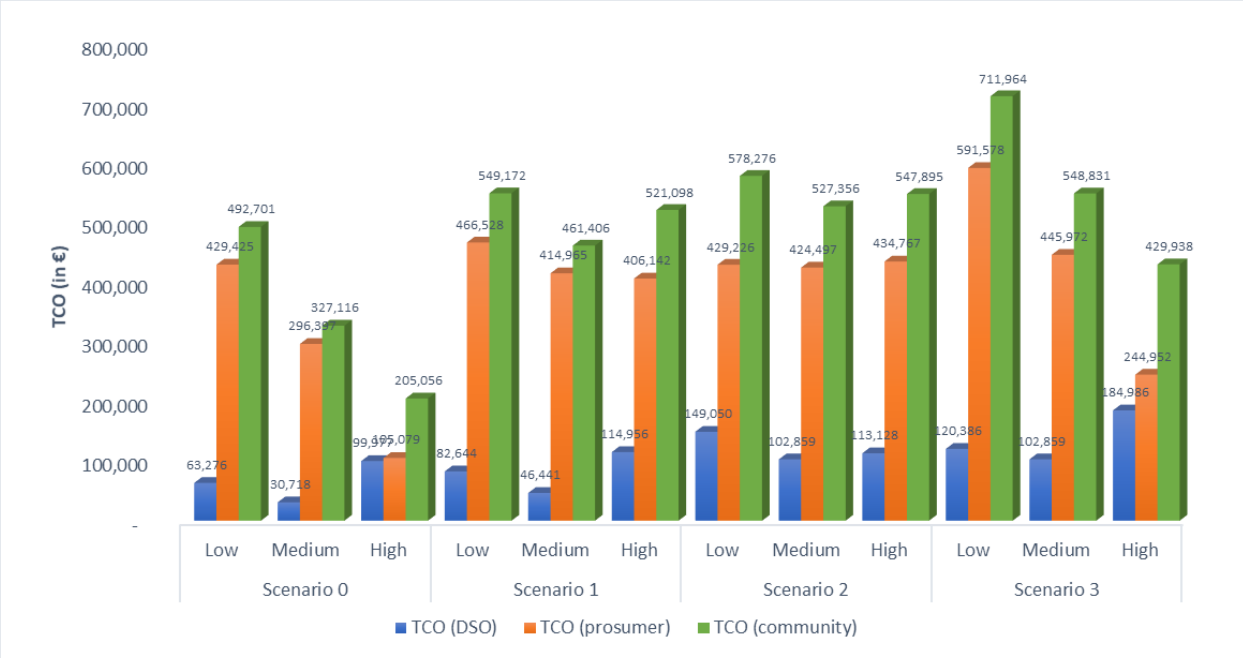

Figure 31 – Case study 3: TCO (in €) per scenario with price of energy = 0.21 Eur/kWh (Source: LINKS elaboration)

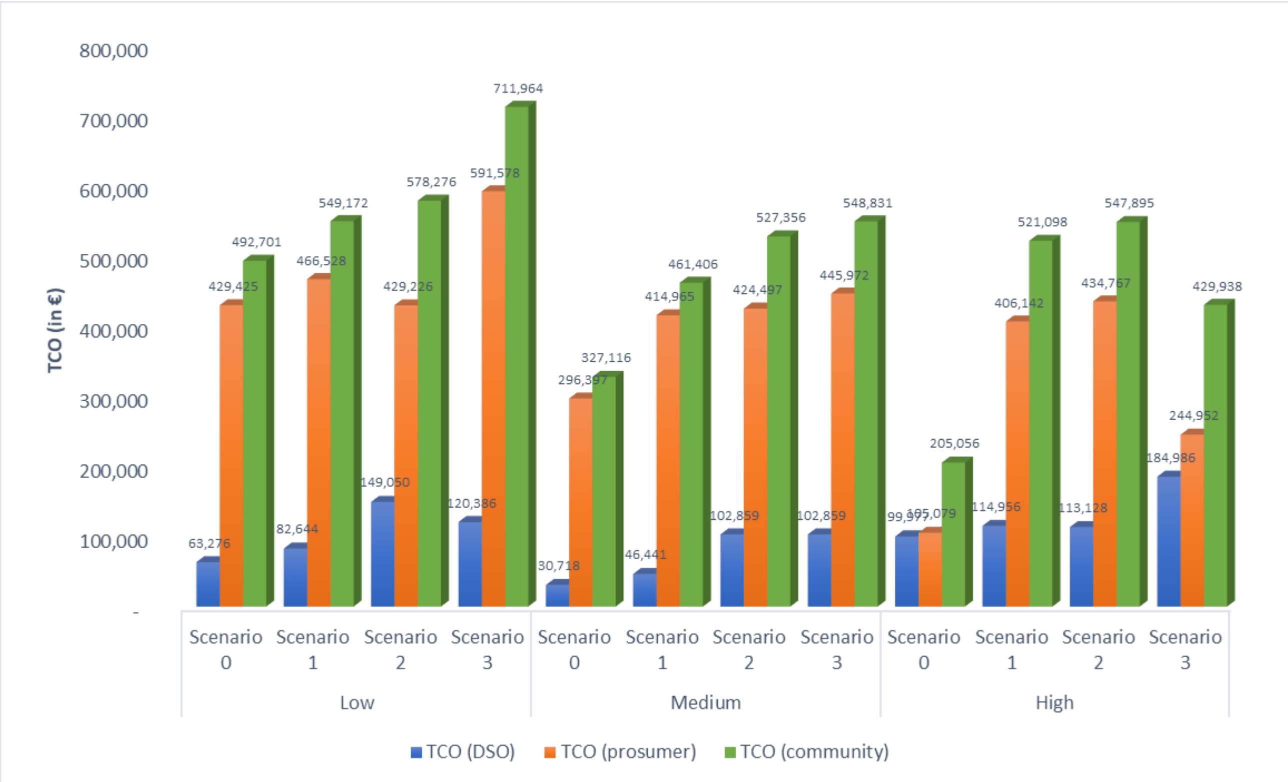

Figure 32 – Case study 3: TCO (in €) per PV penetration with price of energy = 0.21 Eur/kWh (Source: LINKS elaboration)

4.4.2.4 Case Study 4

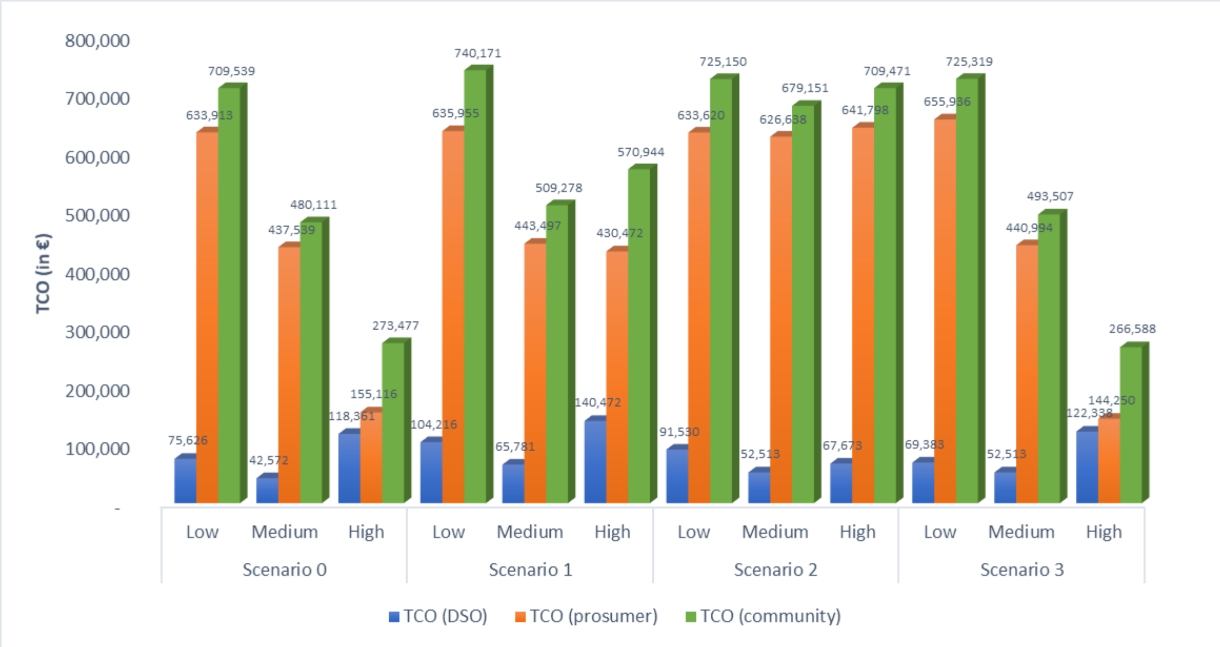

Figure 33 – Case study 4: TCO (in €) per scenario lifetime = 21 and delta storage price = -35% (Source: LINKS elaboration)

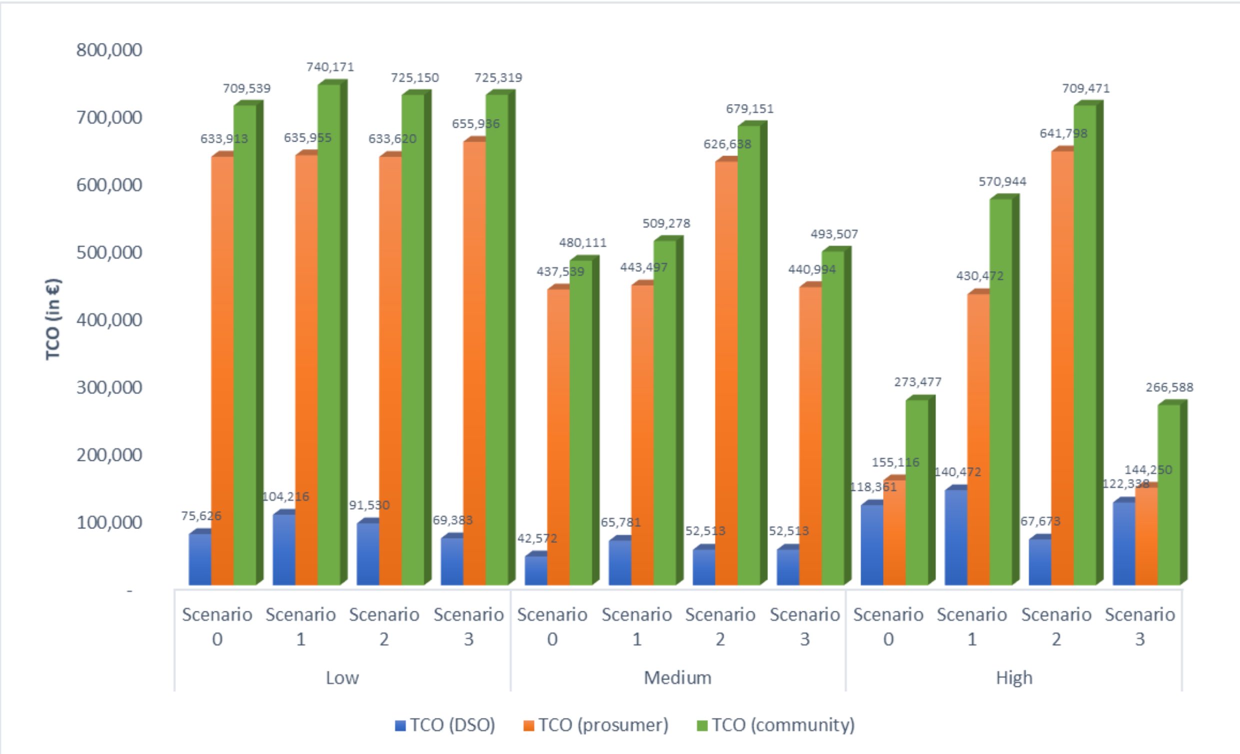

Figure 34 – Case study 4: TCO (in €) per PV penetration lifetime = 21 and delta storage price = -35% (Source: LINKS elaboration)

4.4.3 Conclusion from the economic simulation

After the sensitivity analysis of all the scenarios we highlight the following generic conclusions:

- DSO shows always, for each scenario and every simulation, a higher convenience for grid strengthening in medium degree of PV penetration (around 50%);
- Prosumers, as a whole have, presents more benefits from high PV penetration in the most scenarios, even when they have to support also the investment of storage systems;
- As a net result of the previous two sentences, the total community cost seems to be lower with the medium PV penetration;
- However, the TCO seems to be always lower in scenario 0 with respect to all scenarios for all the stakeholders, as a consequence of high cost of storage systems and low lifetime of batteries;
- If we compute the thresholds for having a scenario 1 and 2 as best solution, we find that the lifetime of batteries should be at least 21 years and the trend for decreasing price of batteries should be at least -35% that correspond to around 135 Euro per kWh, where the scenario 1 is better than scenario 2;
- Finally, we can compute the level of incentive for each scenario simply as a difference of the TCO of scenario 1 and 2 with respect to the scenario 0. As Table 10 shows, some values are negative and it means the TCO of the selected scenario is lower than the scenario 0, hence, it is more convenient.

All the figures computed in this chapter represents a first outcome of how the economic model can be applied. After a collection of more accurate and real inputs, the DSF-EE should become an important tool of evaluation for stakeholders deciding to invest in order to stimulate in a specific area if it could be economically feasible investing in storage system, computing or the threshold and the level of incentives that permits to reach the final advantage.

Storage system development seems to be not yet economically efficient if we look only on the side of costs but further detailed analysis of revenues generation should be added to this analysis to find the right break-even point for all the stakeholders. Storage development requires an improvement of the storage market that could reduce the price of batteries (i.e., increasing technology and competition). Incentive and subsidies can play a relevant role if part of these can cover both the expenses for prosumers and DSO. Finally, bureaucracy costs and time represent a barrier for many operators, mainly for smallest stakeholders, as the prosumers.

5 Deployment instructions

In this section, the deployment instructions of DSF-SE and DSF-EE will be presented.

5.1 DSF-SE deployment

DSF-SE uses a container architecture which simplifies its deployment. Images of the software are uploaded into an open space of Docker Hub [6]. The user has to download the images and make them run into the Linux server.

In summary, the installation consists of downloading the docker-compose file from the repository, pulling the images and starting the container. The current docker-compose file is the following:

```
version: '3'
services:
  redis:
    image: redis:latest
    command: redis-server
    ports:
      - "6379:6379"
```

```
se:
  image: "simulation_engine"
  container_name: "se"
  ports:
    - "9090:9090"
  command: ["python3", "-u", "main.py"]
  logging:
    driver: "json-file"
    options:
      max-size: "10m"
      max-file: "10"
```

The source and associated docker files of this system are pushed on to the open source LinkSmart® repository[11].

5.2 DSF-EE deployment

DSF-EE exploits a containerized architecture which simplifies its deployment. The user must download the proper image and run it into the Linux server docker environment. The dockerized solution is built as a standalone component that do not require any further software configuration.
The instruction to run the DSF-EE docker image is the following:
docker run –restart always --name economicserver -p 9082:9081 -d economicserverimage

6 Software dependencies and requirements

Table 11 – Software Dependencies

Dependency	License	Role
Docker and docker-compose for Raspbian	Apache License 2.0	Docker is used to facilitate the installation of PROFESS
Keycloak service	Apache License 2.0	Identity provider
Nginx	2-clause BSD	Webserver
LinkSmart® Border-Gateway	Apache License 2.0	Authorization and authentication
OpenDSS	BSD-new	Power flow simulator

[11] https://github.com/linksmart/simulation-engine.git

7 Conclusions

This document presents the prototype deliverable D5.2 - "Final DSF Hybrid Simulation Engine" prototype, developed by the Storage4Grid project. No further updates of this deliverable are expected. However, minor modifications and improvements might need to be implemented during the final phase of integration and deployment.

This deliverable presented the structure of DSF-SE, a description of its components as well as examples of its use. It introduced the DSF-SE plug-in for hybrid simulation and the DSF Economic Engine. Deployment instructions as well as software dependencies and requirements were described.

DSF-SE will be evaluated in the different S4G-use cases in order to verify its contribution to the planning and analysis of grids including PV, ESS and EVs together with the Professional GUI. The evaluation will also take into consideration different algorithms for the local control of ESS and charging stations running in PROFESS and PROFEV modules. Moreover, DSF-SE will be evaluated integrating the GESSCon service for generating global ESS-profiles. In fact, DSF-SE will integrate not only S4G control modules, but it will also make use of DSF-Connectors for predictions needed in the simulations.

The Hybrid Simulation plug-in functionalities will be extended to cover dynamic-domain simulation. This requires introduction of a new architecture and integration of a Dynamic Simulator capable of solving differential equations, as well as re-definition of hardware interfaces. Such system could be a valuable product to test and simulate dynamic impact of ramping up/down of various electrical components.

The DSF-EE algorithm will be further refined following technological advancements and market driven economical aspects. Aiming to provide a more effective tool, the DSF-EE, actually offering an offline comparative analysis of different simulated scenarios, could be adapted to provide real time feedback to the end users. The new versioning of the DSF-EE tool will support decision makers with the best scenarios from an economical point of view. Further refinements on CapEx, OpEx estimations considered in the model itself shall be achieved by a wider market oriented analysis. The regulation framework will be considered and keep up to date to guarantee an overall legislative compliancy.

Acronyms

Acronym	Explanation
DSF	Decision Support Framework
DSF-SE	Decision Support Framework - Simulation Engine
OpenDSS	Open Distribution System Simulator
PROFESS	Professional Realtime Optimization Framework for Energy Storage Systems
PROFEV	Professional Realtime Optimization Framework for Electric Vehicles
PV	Photovoltaics
S4G	Storage4Grid
ESS	Energy Storage System
EV	Electrical Vehicle
GESSCon	Grid-side Energy Storage System Control
API	Application Program Interface
TOC	Total Cost of Ownership
DSF-EE	Decision Support Framework – Economic Engine
DRTS	Distribution System Real Time Simulator
ER	Energy Router

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8 References

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[3] J. Wallnersrom, «Vulnerability Analysis of Power Distribution Systems for Cost-Effective Resource Allocation» *IEEE Transactions on Power Systems,* vol. 27, n. 1, February 2012.

[4] *IFC Energy Storage Trends and Opportunities in Emerging Markets,* 2017.

[5] KPMG, «REA, Development of decentralized energy and storage systems in the UK» 2016.

[6] «Docker Hub,» May 2019. [Online]. Available: https://hub.docker.com/.

Appendix A – An example of grid topology and elements parameters definition


```
{
	"common": {
		"id": "Fur",
		"base_kV": 10,
		"per_unit": 1.0001,
		"phases": 3,
		"bus1": "bus_001",
		"angle": 30,
		"MVAsc3": 20000,
		"MVAsc1": 21000,
		"base_frequency": 60,
		"VoltageBases": [10, 0.4, 0.23],
		"url_storage_controller": "http://192.168.99.100:8080",
		"city": "Fur",
		"country": "Denmark"

	},
	"radials": [{
		"transformer": [{
			"id": "transformer_20082",
			"phases": 3,
			"windings": 2,
			"buses": ["bus_001", "bus_002"],
			"kvas": [150, 150],
			"kvs": [10, 0.4],
			"conns": ["delta", "wye"],
			"xsc_array": [0.008],
			"percent_rs": [0.0005, 0.0005],
			"percent_load_loss": 0.001,
			"taps": [1, 1]

		}],
		"photovoltaics":[{
			"bus1": "consumer_4006773",
			"id": "PV_1",
			"max_power_kW":4,
			"phases":3,
			"kV":0.23
		}],
		"storageUnits": [
	  {
	    "id": "Akku1",
	    "bus1": "consumer_4006773",
	    "phases": 3,
	    "soc": 30,
	    "kv": 0.23,
	    "max_charging_power": 1.5,
	    "max_discharging_power":1.5,
	    "storage_capacity": 3,
	    "optimization_model": "Maximize Self-Consumption",
	    "powerfactor":1

    }],
		"loads": [{
			"id": "consumer_4018368",
			"bus": "node_a1.2",
			"phases": 1,
```

```
                "connection_type": "wye",
                "kV": 0.23,
                "kW": 3,
                "powerfactor": 0.95,
                "power_profile_id": "string"
            }],
            "powerLines": [{
                "id": "powerline_w1",
                "phases": 3,
                "bus1": "bus_002",
                "bus2": "node_a1",

                "length": 0.434,
                "r1": 0.207,
                "x1": 0.078,
                "c0": 0,
                "unitlength": "km"
            }],
            "linecode": [{
                "id": "CU_4x10",
                "nphases": 3,

                "rmatrix": [
                    [1.83],
                    [0, 1.83],
                    [0, 0, 1.83]
                ],
                "xmatrix": [
                    [0.089],
                    [0, 0.089],
                    [0, 0, 0.089]
                ],
                "units": "km"
            }]
        }]
}
```

Appendix B – An example of the body for starting a simulation

PUT http://ip_address:9090/se/commands/run/a4961bc466c1


```
{
	"sim_duration_in_days":365
}
```

Appendix C – An example of results from the DSF-SE


```
{

    "bus_001":{
        "Phase_1":{
            "Current":802727.9237274672,
            "Loss":-73.59113968632535,
            "Voltage":{
                "max":0.8020025607741897,
                "min":0.8020025511975333
            }
        },
        "Phase_2":{
            "Current":-830197.5028882897,
            "Loss":-43.86058900468296,
            "Voltage":{
                "max":0.8020021774423186,
                "min":0.8020021690608984
            }
        },
        "Phase_3":{
            "Current":-1120336.0895479869,
            "Loss":0.0005037984995178704,
            "Voltage":{
                "max":0.8020024271892154,
                "min":0.802002418413445
            }
        }
    },
    "bus_002":{
        "Phase_1":{
            "Current":-280084.02268185065,
            "Loss":0.004155408051779887,
            "Voltage":{
                "max":0.833393406570399,
                "min":0.8333933533285587
            }
        },
        "Phase_2":{
            "Current":317608.16606943886,
            "Loss":2.959058258243992,
            "Voltage":{
                "max":0.8333881188755303,
                "min":0.8333880709901232
            }
        },
        "Phase_3":{
            "Current":1110281.5256531134,
            "Loss":1.5971249464971957,
            "Voltage":{
                "max":0.8333901311822143,
                "min":0.8333900778245282
            }
        }
```

```
    }
}
```