



TITLE

Development of Energy Planning & Transition Decision Support Toolset

AUTHORS:

Athanasios Bachourmis, Katerina Drivakou, Anastasis Tzoumpas (UBE)

Petros Iliadis, Niki Skopetou, Yannis Mamounakis, Nikolas Tagkoulis, Dionisios Stefanitsis, Thomas Bebis,

Nikos Nikolopoulos (CERTH)

Selma Causevic (TNO)



H2020-LC-SC3-2018-2019-2020 / H2020-LC-SC3-2020-EC-ES-SCC
EUROPEAN COMMISSION

Innovation and Networks Executive Agency
Grant agreement no. 957810

PROJECT CONTRACTUAL DETAILS

Project title	IntegrAted SolutioNs for the DecarbOnization and Smartification of Islands
Project acronym	IANOS
Grant agreement no.	957810
Project start date	01-10-2020
Project end date	30-09-2024
Duration	48 months
Project Coordinator	João Gonçalo Maciel (EDP) - JoaoGoncalo.Maciel@edp.com

DOCUMENT DETAILS

Deliverable no.	D3.5
Dissemination level	Public
Work package	WP3
Task	T3.3
Due date	31-03-2022
Actual submission date	31-03-2022
Lead beneficiary	UBITECH ENERGY



Version	Date	Beneficiary	Changes
0.1	1/02/2022	UBE	First draft of ToC
0.2	15/02/2022	UBE	Refinement of ToC and allocation of work to the involved partners
0.3	23/02/2022	UBE	Draft of Chapters 1,2,3
0.4	28/02/2022	TNO	Provision of chapter 4
0.5	04/03/2022	CERTH	Data exchange format and chapter 6
0.6	14/03/2022	CERTH	Provision of chapter 5
0.7	15/03/2022	UBE	Deliverable ready for official review
0.8	18/03/2022	CERTH	Review by Thomas Bebis
0.9	24/03/2022	UNINOVA	Review by Anabela Gonçalves Pronto
1.0	29/3/2022	UBE	Feedback integration and deliverable ready for submission

Executive Summary



The assessment of investment activities is a pillar in strategic management at any level. When investment activities involve the deployment of projects, project evaluation aims at determining the effects caused to foster the best allocation of scarce resources. In project evaluation, laws of economics are pivotal to determine the profitability of an initiative. However, projects that have also a social interest have to be assessed considering a broader range of impacts. Assessment shall be performed before project deployment to forecast the effects expected (ex-ante), during project deployment to check the performance level to identify corrective measures (in medias res) or after the time horizon of the project to verify the actual impacts generated (ex-post). Cost-benefit analysis (CBA) is the most acknowledged tool for financial viability assessment. A wider project assessment is obtained where soft effects, and intangible and non-monetizable impacts are included in the project assessment.

Therefore, the decision-makers across the energy value chain need a tool that is able to provide quantifiable insights supporting their potential investments decisions in clean and smart energy interventions. Towards that direction, the activities of WP3 aim at proposing an IANOS Energy Planning and Transition (IEPT) suite that supports the investments of the different stakeholders providing a holistic approach that quantifies both the costs and benefits of the IANOS interventions in the demonstration sites, i.e., Lighthouse and fellow islands of IANOS, as well as providing a tool that facilitates the fundraising campaigns.

To reach the objectives of the WP3, D3.5 (which is the 1st version of the deliverable related to Task 3.3) elaborates on the architecture and the main components of the IEPT suite. Through an API Gateway, the different modules which are deployed as dockerized microservices, communicate and exchange the calculated values of Key Performance Indicators (KPIs). Those KPIs will quantify the benefits of the smart grid interventions from a technical, economic, and environmental perspective.



In addition, the overview, functionalities, and technology stack of each internal module of the IEPT suite is thoroughly described. Briefly, those deployed microservices are:

- a) Cost-Benefit analysis (CBA) tool: The CBA tool will be based on the JRC's and ENTSO-E's CBA methodologies and will offer an analytical approach for the stakeholders/ investors that provides a quantifiable insight regarding whether a smart grid intervention exceeds the existing baseline scenario in terms of cost and benefits.
- b) Energy System Simulator (ESSIM) system modeler: This tool simulates network balancing and the effects thereof, in an interconnected hybrid energy system over a period of time. It takes as inputs the energy system defined in ESDL and calculates optimal schedule of flexible producers and the effect of this schedule in terms of emissions, costs, load on the network, etc.
- c) INTegrated Energy Management (INTEMA.grid) Simulator: It is an energy system modelling and simulation platform. It is based on open-source non-proprietary tools. It is composed by the following main components: (a) Power System Simulations–Based on the acausal, object-oriented, equation based Modelica language to conveniently model complex physical systems, (b) Power Optimization–Ability to construct optimization problems using Python optimization tools pyomo along with the neos-server that provides the required solvers., and (c) Power Forecasting–Utilizing open-source Machine Learning (ML) frameworks in Python, i.e., scikit-learn and Keras.
- d) VERIFY District Platform (VERIFY-D): Environmental and economic analyses are expected through the computation of emissions extracted (life cycle environmental footprint), which depend on the technology applied in the grid and type of fuel mixture used to generate energy in the LH islands. Also, this tool will compute the life cycle costing based on the energy components that appear in the energy grid.
- e) Equity crowdfunding tool: This tool will create a crowd-equity (or crowdfunding) platform, where actors (i.e., project investors, islanders, other



key stakeholders) will be able to register their foreseen projects and set a funding goal in return for equity, creating a fundraising campaign. The platform would ultimately enable fractional ownership of RE assets, supporting projects' fundraising and transactions either via normal FIAT currency or tokenized energy over Distributed Ledger Technology (DLT).

Finally, this deliverable elaborates on the way that the IEPT suite is leveraged and employed for the evaluation of the Lighthouse islands, as well as for the purposes of the CBA, and the scalability and replicability activities for the fellow islands.



Table of Contents

List of Abbreviations and Acronyms	10
1. Introduction	12
1.1 <i>Objectives and Scope</i>	12
1.2 <i>Relation to other IANOS activities</i>	12
1.3 <i>Deliverable outline</i>	14
2. IEPT suite	16
2.1 <i>Description and Functionalities</i>	16
2.2 <i>Architecture</i>	18
Overview-Context view	19
Functional view	20
Information view	25
3. CBA module	39
3.1 <i>Overview</i>	39
3.2 <i>Functionalities and Methodological Approach</i>	40
3.3 <i>Implementation and technology stack</i>	47
4. ESSIM module	48
4.1 <i>Overview</i>	48
ESDL	49



ESDL MapEditor	50
4.2 <i>Functionalities</i>	51
4.3 <i>Implementation and technology stack</i>	54
5. INTEMA.grid module	57
5.1 <i>Overview</i>	57
5.2 <i>Functionalities</i>	58
5.3 <i>Implementation and technology stack</i>	66
Sequence diagram	66
Data exchange model and synergy with the rest of IEPT tools	67
Integration: exposed services/ API	68
6. VERIFY-D module	71
6.1 <i>Overview</i>	71
6.2 <i>Functionalities</i>	71
6.3 <i>Implementation and technology stack</i>	72
7. Conclusions	73
8. Appendix A- Description of the INTEMA.grid model components	74
9. References	102

List of Tables



Table 1: INTEMA.grid Microservice.....	21
Table 2: ESSIM Microservice.....	22
Table 3: CBA Microservice.....	22
Table 4: VERIFY-D Microservice.....	23
Table 5: CrowdEquity Microservice.....	23
Table 6: API Gateway.....	23
Table 7: Initial draft of the IEPT suit's API is presented, according to the documentation of Swagger.....	24
Table 8: Data interfaces of the components of IEPT suite.....	25
Table 9: Table of Class and Attributes for the JSON files contain the KPIs requested to be computed by the CBA Microservice.....	26
Table 10: Table of Class and Attributes for the JSON files of the calculated KPIs data.....	26
Table 11: The top-level class and attributes description for the JSON-request timeseries data, sent by VERIFY-D tool to the INTEMA.grid and/or ESSIM, respectively.....	28
Table 12: The nested class and attributes description for the JSON file containing the timeseries data requested by the VERIFY-D tool from INTEMA.grid and/or ESSIM tools.....	29
Table 13: Table of class and attributes for the JSON file that contains the timeseries data provided back to VERIFY-D tool from INTEMA.GRID and/or ESSIM tools.....	35
Table 14: Recommendation for investments based on BCR values.....	43
Table 15: Mapping of KPIs to the specific components of the IEPT suite.....	45
Table 16: Functionalities attributes and development timeframe for IANOS.....	58
Table 17: INTEMA.grid frontend – components and required parameters.....	65
Table 18: Dynamic models development timeframe.....	69
Table 19: Suwotec battery specifications as provided by the manufacturer.....	85
Table 20: Number of installed HHP units in 135 Ameland apartments per manufacturer model.....	87
Table 21: Technical specifications of Elga Ace HHP.....	87
<i>Table 22: Elga Ace HHP nominal COP and heating power values for varying outdoor air temperature.....</i>	<i>88</i>
Table 23: Elga Ace HP COP results comparison against available manufacturer data.....	89
Table 24: Elga Ace HP heating power results comparison against available manufacturer data.....	90
Table 25: Teraloop flywheel system parameters.....	91
Table 26: Parameters of the hybrid transformer according to IEC 60076.....	93



Table 27: Operating conditions of the geothermal plant [46].....	97
Table 28: Feedstock composition	100
Table 29: Simulation results for the Autogenerative High Pressure Digestion.....	101



List of Figures

Figure 1: PERT diagram showcasing the relation of T3.3 with the rest IANOS tasks.....	14
Figure 2: Graphical outline of the deliverable.....	15
Figure 3: Context view of IEPT suite.....	20
Figure 4: Component Diagram of IEPT suite.....	21
Figure 5: The CBA methodology and its materialization in the IANOS project interventions.....	41
Figure 6: Position of the CBA component in the IEPT suite and its interconnection with the rest components.....	44
Figure 7: An overview of the functionalities of ESSIM.....	48
Figure 8: ESSIM output: Hourly data showing imbalance.....	51
Figure 9: ESSIM used in the planning-design phase of Energy Transition.....	52
Figure 10: All implemented asset models in ESSIM.....	53
Figure 11: Splitting of an energy system into constituent transport (transmission) networks.....	54
Figure 12 ESSIM Technology stack.....	55
Figure 13: INTEMA.grid frontend- network selection page.....	61
Figure 14: INTEMA.grid frontend - buses definition page.....	61
Figure 15: INTEMA.grid frontend - lines definition page.....	62
Figure 16: INTEMA.grid frontend - loads definition page.....	62
Figure 17: INTEMA.grid frontend - generators definition.....	63
Figure 18: INTEMA.grid frontend - thermal plants definition.....	63
Figure 19: INTEMA.grid frontend - batteries definition.....	64
Figure 20: INTEMA.grid frontend - photovoltaics definition.....	64
Figure 21: INTEMA.grid frontend - wind turbines definition.....	65
Figure 22: INTEMA.grid sequence diagram using the web interface.....	67
Figure 23: INTEMA.grid sequence diagram for data retrieve.....	67
Figure 24: CERTH developed steam power plant model.....	76
Figure 25: Steam turbine governor IEEE-TGOV [30].....	77
Figure 26: Automatic voltage regulator (AVR) IEEE T1 [31].....	78
Figure 27: Simple PSS model [32].....	78
Figure 28: Gas turbine model type GAST [32].....	79
Figure 29: Diesel turbine governor DEGOV [30].....	80



Figure 30: Doubly-fed induction generator with cycloconverter of the experimental Growian wind turbine..... 81

Figure 31: Direct drive permanent magnet synchronous generator wind turbine energy conversion principle scheme. 81

Figure 32: HYGOV hydro turbine-governor model [19]..... 82

Figure 33: The generalized Equivalent Circuit Model (ECM) [26]..... 83

Figure 34: CERTH battery cell model with 1 RC branch and thermal dependence 84

Figure 35: Saline battery model..... 86

Figure 36: CERTH model of hybrid heat pump..... 86

Figure 37: COP simulation results against data provided by manufacturer 89

Figure 38: Heating power simulation results against data provided by manufacturer 90

Figure 39. Developed flywheel energy storage model..... 91

Figure 40: Modelica example of a hybrid power electronic transformer driving a dynamically changing asymmetric load..... 93

Figure 41: Modelica example featuring a SOFC model operating in conjunction with components of the PowerSystems library..... 95

Figure 42: Comparison of the Modelica efficiencies with the experimental data. Left: BG efficiencies as a function of the generated power in W (adapted from [32]). Right: As in left, but for the efficiencies calculated for the Modelica model..... 95

Figure 43: Two-phase recuperated ORC flow diagram [46]..... 97

Figure 44: Developed dynamic model for the geothermal power plant in Pico Alto. 98

Figure 45: CERTH PCM model..... 99

Figure 46: Flow diagram of the Autogenerative High Pressure Digestion process..... 100

List of Abbreviations and Acronyms

<i>Acronym</i>	<i>Meaning</i>
API	Application Programming Interface
BaU	Business as Usual
BCR	Benefit Cost ration
CBA	Cost Benefit Analysis
DCF	Discounted Cash Flow
DLT	Distributed Ledger Technology
DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators
ESDL	Energy System Description Language
ESSIM	Energy System Simulator
FI	Fellow Islands
HTTP	HyperText Transfer Protocol
IEPT	IANOS Energy Planning and Transition
INTEMA	INTEgrated Energy Management Simulator
IRR	Internal Rate of Return
KPI	Key Performance Indicators
LCA	Life Cycle Analysis
LCC	Life Cost Cycle
LH	Lighthouse Islands
ML	Machine Learning
MQTT	MQ Telemetry Transport
NPV	Net Present Value
OAS	OpenAPI Specification
PERT	Program evaluation and review technique
RE	Renewable
RES	Renewable Energy Sources
REST (RESTful)	Representational state transfer

ROI	Return of Investment
TSO	Transmission System Operators
UC	Use Case
UI	User Interface
UML	Unified Modelling Language
WP	Work Package

1. Introduction

1.1 Objectives and Scope

Work Package 3 (WP3) of IANOS is entitled as “Transition and Investment Decision Support Framework”. During the Work Package 3 (WP3) activities, a concrete IANOS Energy Planning and Transition decision-making (IEPT) suite will be developed to assist the energy transition of the Lighthouse islands (LH) and Fellow islands (FI). IEPT will constitute a holistic tool able to evaluate the overall benefits expected from clean energy/smart grid interventions, from various perspectives, based on the viewpoint of each stakeholder, i.e., Municipality, Distribution System Operator (DSO), community representatives, etc. This will be pre-validated, where the LH and FI Use Cases (UCs) will be evaluated holistically for their sustainability, scalability, and replicability potential.

Within WP3, Task 3.3 entitled as “Energy Planning & Transition Decision Support Toolset” aims at providing information about the architecture and the communication of the different components under the umbrella of the IEPT suite, as well as presenting extensively the methodology for the Cost Benefit Analysis (CBA), which is considered as the cornerstone of the IEPT suite. The different components that are integrated in the IEPT suite are also thoroughly described in this deliverable. The information included in both D3.1 “Development of LCA/LCC tool for Transition Support” and D3.3 “Equity crowdfunding tool for Community driven Investments” is complementary to the work documented here, and duplications have been omitted. Hence, we advise the reader to also read those deliverables, in order to have a complete view of the functionalities of the IEPT suite and its internal modules.

1.2 Relation to other IANOS activities

As can be seen in *Figure 1*, T3.3 needs to consider the interactions with several task in multiple WPs of the IANOS projects. There is a strong interconnection with those tasks as concisely described below:

a) T3.3 builds on the findings of:

- T3.1: The extensive description of the VERIFY-D tool, i.e., a Life Cycle Analysis (LCA)/ Life Cycle Cost (LCC) tool, is given in this task. As described later in this deliverable, this component is an important element of the IEPT suite.
- T2.3: The activities and vision of the various stakeholders, the factors of interest have been selected and respective KPIs have been introduced which will be used as an input for the CBA approach.
- T2.5: The architecture of the IANOS solutions that have been introduced is used as a cornerstone for the definition of IEPT architecture.
- T3.2: The equity crowdfunding tool, as thoroughly described in this task, is an internal component of the IEPT suite, and along with the outcome of the CBA provide a tool for stakeholders to invest in smart grid interventions.

b) T3.3 constitutes an important input for:

- T3.4: The suite will be tested and fine-tuned by the pre-validation/assessment of the selected UCs in LHs and FIs.
- T5.3: For the evaluation of the demonstration campaigns in LH of Ameland, the functionalities of the IEPT suite are leveraged.
- T7.3: The CBA that will be conducted in the context of this task will leverage the functionalities of the IEPT suite.
- T7.2: The environmental impact assessment that will be conducted in the context of this task will use the capabilities of the VERIFY-D component, which is an integral element of the IEPT suite.
- T6.3: For the evaluation of the demonstration campaigns in the LH of Terceira, the functionalities of the IEPT suite are leveraged.

- T9.2: The scalability and replicability activities of this task will use the functionalities of the component of the IEPT platform.

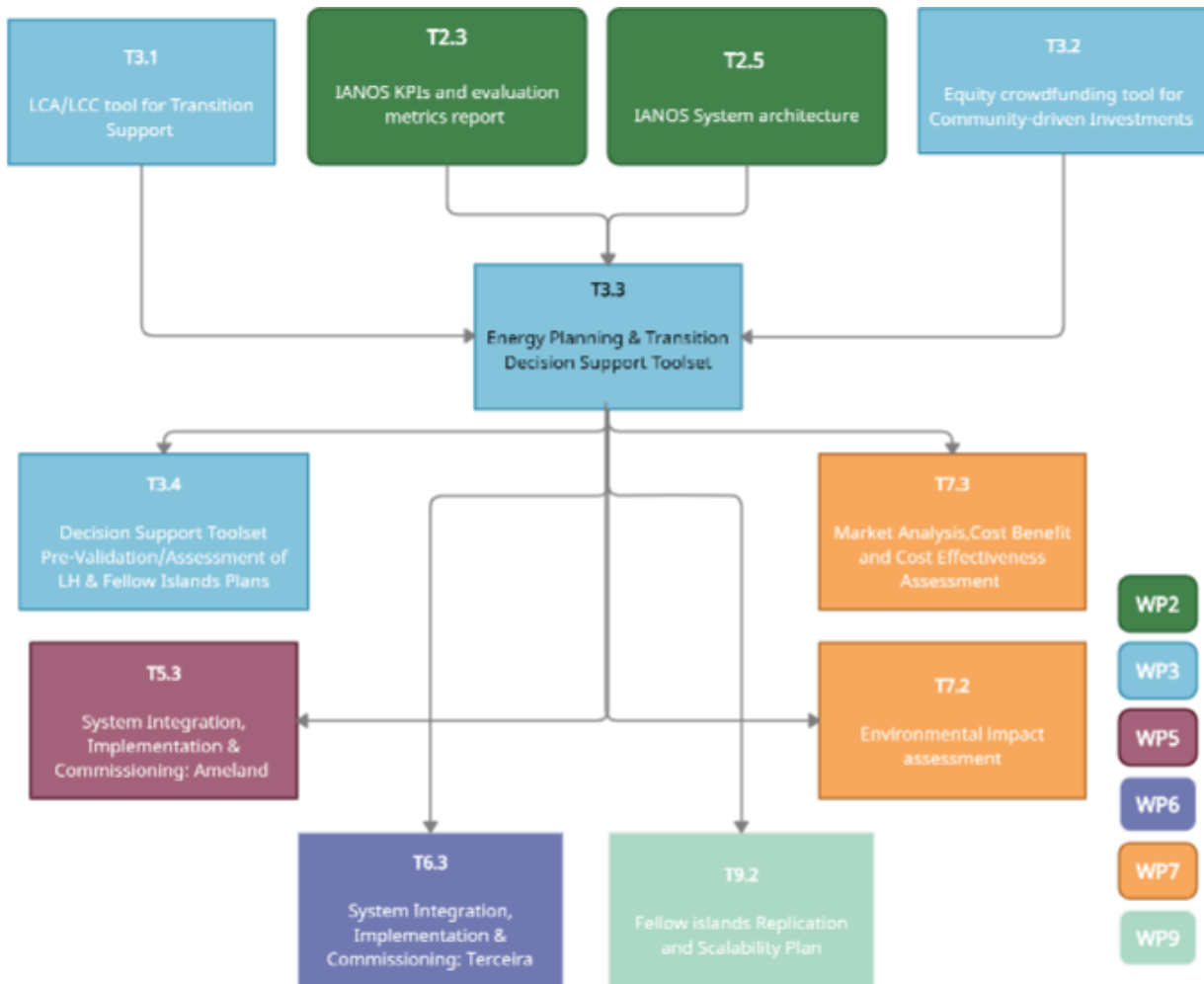


Figure 1: PERT diagram showcasing the relation of T3.3 with the rest IANOS tasks.

1.3 Deliverable outline

Figure 2 provides a graphical outline of D3.5. This deliverable aims at describing the IEPT suite, its architecture, functionalities and internal components. Specifically, chapter 2 provides an extensive description of the first two points, i.e., the architecture and the functionalities of the IEPT suite. Chapters 3 to 6 provide an overview of the components of the internal components of the IEPT suite, along with the specific functionalities of each tool and the description of the used

technology stack. Finally, chapter 7 concludes the presentation of the IEPT suite briefly providing its main characteristics and functionalities, as well as the connection with the rest tasks of IANOS.

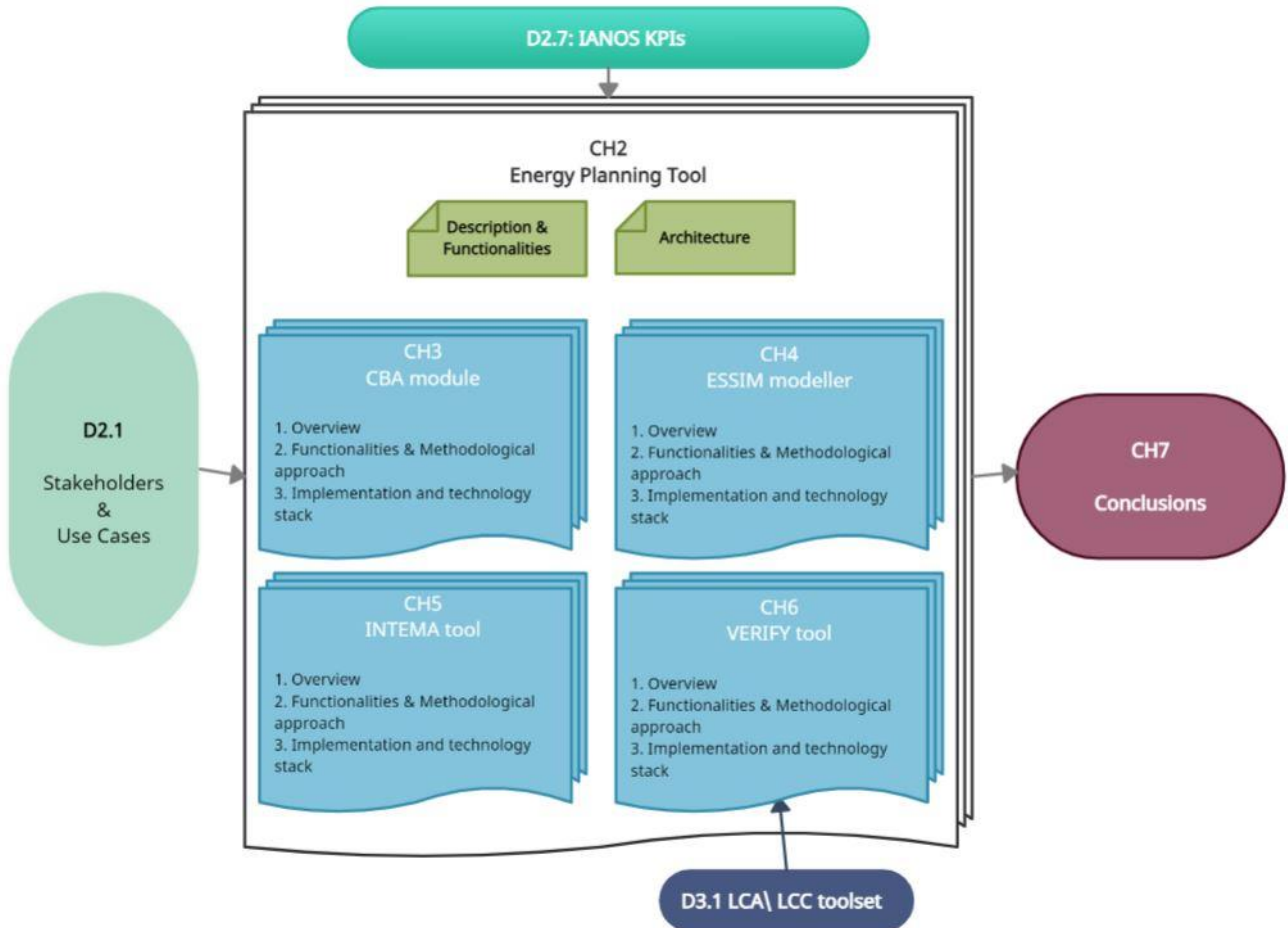


Figure 2: Graphical outline of the deliverable.

2. IEPT suite

2.1 Description and Functionalities

During the Work Package 3 activities, a concrete IANOS Energy Planning and Transition decision-making suite (IEPT) will be developed to assist the energy transition of the Lighthouse (LH) and Fellow (FI) islands. IEPT will constitute as a holistic tool able to evaluate the overall benefits expected from clean energy and smart grid interventions, from various perspectives, based on the viewpoint from each stakeholder (Building owner, RES owner, Municipality, DSO, community representatives, etc.). This will be pre-validated, where the LH and FI use cases will be evaluated holistically for their sustainability, scalability, and replicability potential.

The different components that will be integrated under a unified concept are the following:

- a) **VERIFY District Platform (VERIFY-D):** A dedicated web platform for Life Cycle Analysis (LCA)/Life Cost Cycle (LCC) studies. Environmental and economic analyses are expected through the computation of emissions extracted (life cycle environmental footprint), which depend on the technology applied in the grid and type of fuel mixture used to generate energy in the LH islands. Also, this tool will compute the life cycle costing based on the energy components that appear in the energy grid. Finally, the comparison between baseline and target scenario in terms of the environmental gains and economic profits,
- b) **An equity crowdfunding tool (CrowdEq):** This tool will create a crowd-equity (or crowdfunding) platform, where actors (i.e., project investors, islanders, other key stakeholders) will be able to register their foreseen projects and set a funding goal in return for equity, creating a fundraising campaign. The platform would ultimately enable fractional ownership of RE assets, supporting projects' fundraising and

transactions either via normal FIAT currency or tokenized energy over Distributed Ledger Technology (DLT),

- c) **Energy System Simulator (ESSIM):** This tool simulates network balancing and the effects thereof, in an interconnected hybrid energy system over a period of time. It takes as inputs the energy system defined in ESDL and calculates optimal schedule of flexible producers and the effect of this schedule in terms of emissions, costs, load on the network, etc.

- d) **INTEgrated Energy Management Simulator (INTEMA.grid):** It is an energy system modelling and simulation platform. It is based on open-source non-proprietary tools. It is composed by the following main components: (a) Power System Simulations–Based on the acausal, object-oriented, equation based Modelica language to conveniently model complex physical systems, (b) Power Optimization–Ability to construct optimization problems using Python optimization tools pyomo along with the neos-server that provides the required solvers, and (c) Power Forecasting–Utilizing open-source Machine Learning (ML) frameworks in Python, i.e., scikit-learn and Keras,

- e) **A Cost-Benefit analysis tool (CBA):** The CBA tool will be based on the JRC’s and ENTSO-E’s CBA methodologies. To do that and depending on the activities and vision of the various stakeholders, the factors of interest will be selected and respective KPIs will be calculated to assist them in setting strategic priorities, aligning horizontally in all cases with the priorities set by the Green Deal. The CBA tool offers an analytical approach for the stakeholders/investors that provides a quantifiable insight regarding whether a smart grid intervention exceeds the existing baseline scenario in terms of cost and benefits. This task is considered as the cornerstone of the IEPT suite and will assist the activities in several tasks across the WPs of IANOS, such as the CBA of

WP7 and the scalability and replicability studies activities that will be conducted in WP9.

2.2 Architecture

The system design is a conceptualization depicting its fundamental characteristics, while demonstrating the means to fulfil its individual requirements. The methodology adopted to report the design is based on the Viewpoints and Perspectives framework [1] and ISO/IEC/IEEE 42010:2011 “Systems and software engineering-Architecture description”[2]. According to that concept, an architecture description may be organised in different views using viewpoints, providing a mechanism for the separation of concerns among the stakeholders, while at the same time providing the description of the whole system that is fundamental to the notion of architecture. A viewpoint describes how certain stakeholders - with a particular concern - interpret the system. An architecture viewpoint frames one or more concerns, providing the conventions for constructing, presenting and analysing views. A view is a representation of an entire system from the perspective of a related set of concerns. It expresses the architecture of the system-of-interest in accordance with an architecture viewpoint.

For the proper reporting of the first version of the IEPT suite, i.e., design and development phase, the following viewpoints have been selected:

- **Overview-Context:** Describes the main interactions of the system with its environment, providing a high-level concise overview,
- **Functional:** Describes the system’s functional elements, their responsibilities, interfaces, and primary interactions. A Functional view is the cornerstone of most architectural designs and is often the first part of the description that stakeholders try to read,
- **Information:** Describes the way that the architecture stores, manipulates, manages, and distributes information. The ultimate purpose of virtually any computer system is to manipulate information in some form, and this

viewpoint develops a complete but high-level view of static data structure and information flow.

In the second version of the deliverable (to be delivered in M30), those views will be updated and refined, and new views will be added to report the final design of the IEPT suite.

In order to facilitate the reader and provide a well-established approach across software engineering industry about the modelling of the system's views, the Unified Modelling Language (UML) is used [3]. Specifically, component diagrams are used to model the aspects concerning the functional viewpoint.

OpenAPI Specification (OAS) - a standard, language-agnostic interface to RESTful APIs that allows both humans and computers to discover and understand the capabilities of the service without access to source code - is utilized to document REST interfaces of the suite. More specifically the Swagger tool was used to adequately report the interfaces both in file format, as well as in a more user-friendly graphical environment [4].

Overview-Context view

This subsection aims at providing a high-level view of the IEPT suite, exposing its scope, responsibilities and interfaces with its environment, i.e., people, systems, external components. The IEPT suite acts as an integration solution of existing and under-development components and provides interfaces to stakeholders to conduct planning and funding processes for smart interventions. Figure 3 illustrates the context view of the IEPT suite. The IEPT suite provides the following:

- Integration of the components developed by different providers,
- Access to data of the different Lighthouse (LH) islands of the IANOS project,
- Access analysis data from the different components and data flow coordination amongst them,
- Provision of analytics to the engaged stakeholders.

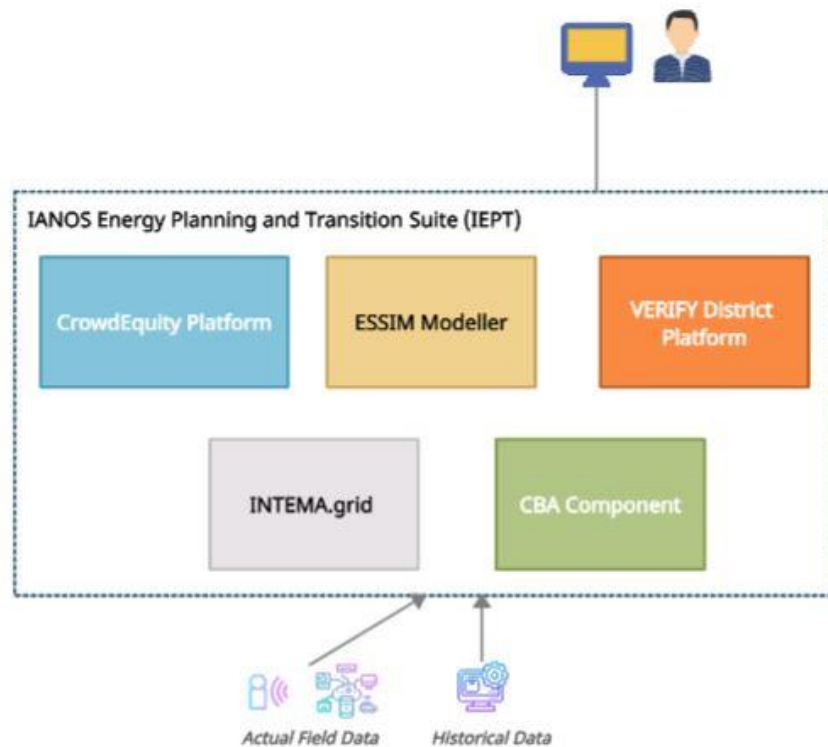


Figure 3: Context view of IEPT suite.

Functional view

The functional viewpoint describes the system's functional elements, their responsibilities, interfaces and primary interactions.

The Microservice architectural paradigm is applied for the design of the solution [5]. Following this paradigm, a collection of lightweight, loosely-coupled services is utilized - each one offering a single business capability. Those services are the following ones:

- CBA Component
- INTEMA.grid
- ESSIM System Modeler
- VERIFY District Platform
- CrowdEquity platform

This architecture offers great independence in the scalability of the solution, the development and release of the various architectural components, as well as the capability of decentralized governance (implementation decisions) offering the relevant autonomy of each component. The microservices are containerized in Dockers, simplifying the delivery and management of those microservices [6]. The process of containerization provides individual microservices with their own isolated workload environments, making them independently deployable and scalable. The main elements of the design are illustrated in the diagram of Figure 4 and are elaborated on the list of Tables below.

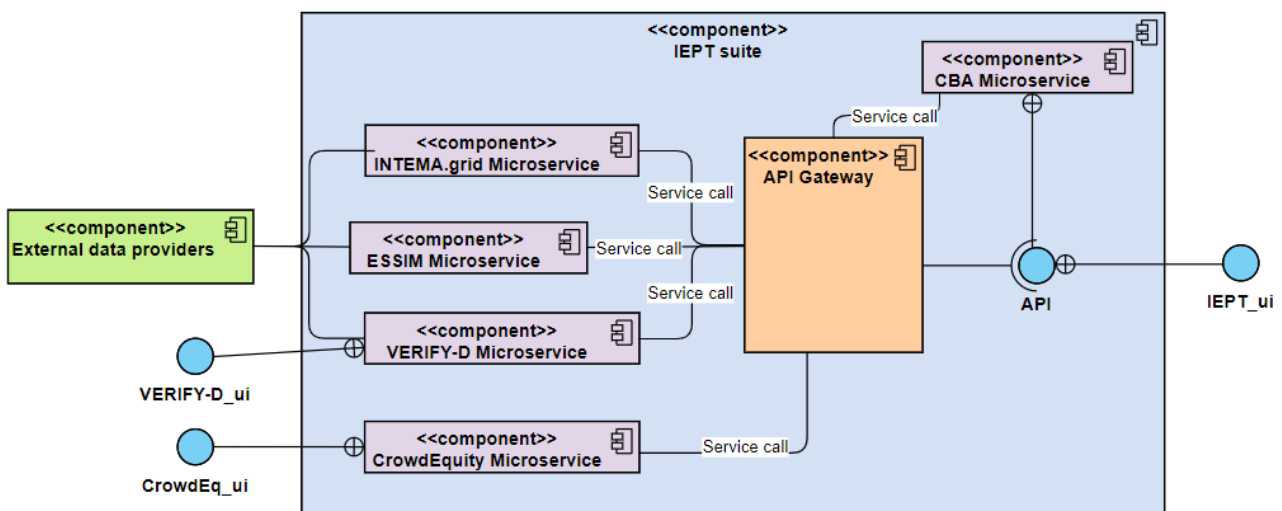


Figure 4: Component Diagram of IEPT suite.

Table 1: INTEMA.grid Microservice.

Element Name	INTEMA.grid Microservice
Responsibilities	An application offering an autonomous business capability exposed through a REST interface, via the API Gateway. This dockerized application provides system modelling capabilities for the Terceira LH island. Specific KPIs are computed and provided as an input into the CBA Microservice. Extensive description of this component is given in Chapter 5.

Interfaces	Service_call: Interface to API Gateway providing calculated KPIs values and for exposing services to the IEPT_ui.
-------------------	---

Table 2: *ESSIM Microservice.*

Element Name	ESSIM Microservice
Responsibilities	An application offering an autonomous business capability exposed through a REST interface, via the API Gateway. This dockerized application provides system modelling capabilities for the Ameland LH island. Specific KPIs are computed and provided as an input into the CBA Microservice. Extensive description of this component is given in Chapter 4.
Interfaces	Service_call: Interface to API Gateway providing calculated KPIs values, as well as for exposing services to the IEPT_ui.

Table 3: *CBA Microservice.*

Element Name	CBA Microservice
Responsibilities	An application offering an autonomous business capability exposed through a REST interface, via the API Gateway. This component conducts a CBA analysis using the KPIs values, calculated by the rest microservices. Extensive description of this component is given in Chapter 3.
Interfaces	API: Service requests for KPIs calculation. Service_call: Interface to API Gateway providing calculated KPIs values, as well as for exposing services to the IEPT_ui.

Table 4: VERIFY-D Microservice.

Element Name	VERIFY-D Microservice
Responsibilities	An application offering an autonomous business capability exposed through a REST interface, via the API Gateway. This dockerized application provides LCA/LCC capabilities for both the LH islands extensive description of this component is given in Chapter 6.
Interfaces	VERIFY-D_ui: User interface for managing and monitoring the VERIFY component directly. Service_call: Interface to API Gateway providing calculated KPIs values

Table 5: CrowdEquity Microservice.

Element Name	CrowdEquity Microservice
Responsibilities	An application offering an autonomous business capability exposed through a REST interface, via the API Gateway. Due to the non-direct communication of this component with the REST microservices, the extensive description of this component is not provided in this deliverable but in D3.3.
Interfaces	CrowdEq_ui: User interface for managing and monitoring the CrowdEquity component directly. Service_call: Interface to API Gateway for exposing services to the IEPT_ui

Table 6: API Gateway

Element Name	API Gateway
Responsibilities	Acts as a single-entry point for all requests as well as an edge service for exposing the different microservices to the CBA component. It acts as an intermediate in all the incoming

	requests and routes them towards the respective components in the IEPT suite. A detailed description of the 1 st draft version of the API is presented in Table 7.
Interfaces	API: Service requests from CBA component and the IEPT_ui. Service_call: Interface to microservices

Table 7: Initial draft of the IEPT suit's API is presented, according to the documentation of Swagger.

cba-controller CBA Controller	
POST	/dataService/CBA_KPI Endpoint to request the CBA specific KPIs from the microservices
VERIFY-D-controller VERIFY-D Controller	
POST	/dataService/VERIFY-D_KPI Endpoint to upload the specific KPI to CBA and IEPT_ui
POST	/dataService/VERIFY-D_TimeSeries Endpoint to request the timeseries data from ESSIM and/or INTEMA.grid
INTEMAgrid-controller INTEMAgrid Controller	
POST	/dataService/INTEMAgrid_KPI Endpoint to upload the specific KPI to CBA and IEPT_ui
POST	/dataService/INTEMA.grid_TimeSeries Endpoint to upload to the VERIFY-D module the requested timeseries
ESSIM-controller ESSIM Controller	
POST	/dataService/ESSIM_KPI Endpoint to upload the specific KPI to CBA and IEPT_ui
POST	/dataService/ESSIM_TimeSeries Endpoint to upload to the VERIFY-D module the requested timeseries
CrowdEq-controller CrowdEq Controller	
POST	/dataService/CrowdEq Endpoint to upload the outcome to IEPT_ui
IEPT_ui-controller IEPT_ui Controller	
POST	/dataService/Visual Endpoint to request specific KPIs for visualization

Information view

A detailed analysis of the information flows through the IEPT suite was conducted. Table 8 contains the information regarding the data interfaces in the IEPT suite.

Table 8: Data interfaces of the components of IEPT suite.

Component	Data Item	Related Data Model	Data format	Communication Information
INTEMA.grid	KPIs relevant to the Terceira LH Island	HTTP (REST)	JSON	HTTP REST services for data exchange
ESSIM	KPIs relevant to the Ameland LH island	HTTP (REST)	JSON	HTTP REST services for data exchange
CBA	Requests for data exchange with the rest components	HTTP (REST)	JSON	HTTP REST services for data exchange
VERIFY-D	KPIs relevant to both of the LH islands	HTTP (REST)	JSON	HTTP REST services for data exchange
CrowdEquity	Outcome of CrowdEquity process	HTTP (REST)	JSON	HTTP REST services for data exchange

The specific format of the exchanged data has been initially defined as follows:

a) KPIs Data Exchange

Table 9: Table of Class and Attributes for the JSON files contain the KPIs requested to be computed by the CBA Microservice.

Class	Attribute ¹
KPI_ID	<p>ID (String): The specific ID for a KPI</p> <p>Source (String): The component that originally calculated the specific KPI.</p> <p>Location (String): The demonstrator for which the specific KPI was calculated.</p> <p>UseCase (String): The specific scenario for a particular Use Case for which the KPI was calculated.</p>

Here, we provide an indicative example of the output JSON files that the CBA microservice requests from INTEMA, VERIFY and ESSIM.

```

{
  "KPI_ID": [
    {
      "ID": "T1",
      "Source": "ESSIM",
      "Location": "Ameland",
      "UseCase": "1-Baseline"
    }
  ]
}

```

Table 10: Table of Class and Attributes for the JSON files of the calculated KPIs data.

Class	Attribute ²
KPI_ID	<p>ID (String): The specific ID for a KPI</p> <p>Source (String): The component that originally calculated the specific KPI.</p> <p>Location (String): The demonstrator for which the specific KPI was calculated.</p>

¹ The ID of the specific KPIs along with the Use Cases nomenclature and the components that compute each KPI are thoroughly presented in chapter 3 of this deliverable.

² The ID of the specific KPIs along with the Use Cases nomenclature and the components that compute each KPI are thoroughly presented in chapter 3 of this deliverable.



	<p>UseCase (Integer): The specific Use Case for which the KPI was calculated.</p> <p>Timestamp: Timestamp of the KPI calculation process.</p>
KPI_value	<p>Value (Float): The value that corresponds to the specific KPI.</p> <p>Units (Sting): Units</p> <p>eventStartTime: The starting timestamp of the calculation period for the specific KPI (optional).</p> <p>eventEndTime: The ending timestamp of the calculation period for the specific KPI (optional).</p>
KPI_Valid	<p>CalculateActions (Binary): 1 whether the KPI was calculated and 0 whether the calculation was not conducted.</p> <p>DataUsed (String): Synthetic or real data stemming from demonstrator campaigns</p>

Here, we provide an indicative example of the output JSON files that the INTEMA, VERIFY and ESSIM Microservices sent to the CBA microservice after its request.

```
{
  "KPI_ID":[
    {
      "ID": "T1",
      "Source": "ESSIM",
      "Location": "Ameland",
      "UseCase": "1",
      "Timestamp": "23-02-2022 16:02:00"
    }
  ],
  "KPI_value":[
    {
      "Value": "20.2",
      "Units": "kWh",
      "eventStartTime": "22-02-2022 16:00:00",
      "eventEndTime": "22-02-2022 18:00:00"
    }
  ],
  "KPI_Valid":[
    {
      "CalculateActions": "1",
      "DataUsed": "Synthetic"
    }
  ]
}
```

}

b) Timeseries Data Exchange

Table 11: The top-level class and attributes description for the JSON-request timeseries data, sent by VERIFY-D tool to the INTEMA.grid and/or ESSIM, respectively.

Class	Attribute
GeneralInfo	<p>Name (String): The project's name assigned by the user.</p> <p>Country (String): The demonstrator's country.</p> <p>Coordinates (List<Float>): The demonstrator's exact latitude and longitude.</p> <p>Altitude (Float): The demonstrator's altitude measured from the sea level.</p> <p>Lifespan (Integer):</p>
CurrentScenario	<p>Buildings (Hash): Details about the buildings of the demonstrator's current state.</p> <p>Plants (Hash): Details about the energy production plants of the demonstrator's current state.</p> <p>EnergyStorage (Hash): Details about the energy storage systems of the demonstrator's current state.</p> <p>PublicInfrastructure (Hash): Details about the public infrastructures of the demonstrator's current state.</p> <p>Transport (Hash): Details about the vehicles of the demonstrator's current state.</p>
PlannedScenario	<p><i>Similar attributes to CurrentScenario. Details about the demonstrator's planned state.</i></p>
TimeSeriesConfig	<p>Timezone (String): Time zone of the country in which the scenario is applied.</p> <p>Timestep (Integer): Time step of the time series in minutes.</p> <p>StartDatetimeCurrent (Timestamp): Starting datetime for time series of the current scenario.</p> <p>EndDatetimeCurrent (Timestamp): Ending datetime for time series of the current scenario.</p>

	<p>StartDatetimePlanned (Timestamp): Starting datetime for time series of the planned scenario.</p> <p>EndDatetimePlanned (Timestamp): Ending datetime for time series of the planned scenario.</p> <p>RequestFrom (String): The name of the service which will generate the requested time series.</p>
FuelPrices	<p>BuildingExport (Float): Electricity export price for buildings (€/kWh).</p> <p>BuildingImport (Float): Electricity import price for buildings (€/kWh).</p> <p>PlantExport (Float): Electricity export price for power plants (€/kWh).</p> <p>NaturalGas (Float): Natural gas price (€/kWh).</p> <p>Diesel (Float): Diesel price (€/litre).</p> <p>Biomass (Float): Biomass price (€/kg).</p>

Details of the nested attributes, included in the JSON-request file are presented in Table 12.

Table 12: The nested class and attributes description for the JSON file containing the timeseries data requested by the VERIFY-D tool from INTEMA.grid and/or ESSIM tools.

Class	Attribute	
Building	<p>Type (String): The purpose of the building (e.g., single household).</p> <p>Number (Integer): The number of the buildings with the same typology and infrastructure existing on the island.</p>	
	Envelope	<p>TargetTemperature (Hash): The indoor temperature preferred by the platform user and must be achieved by thermal components. Winter and summer preference.</p>

		<p>FloorSurface (Float): The area of the building's floor measured in square meters.</p> <p>ExternalWallMaterial (String): The material used for building's external wall construction.</p> <p>Glazing (Hash): The specifications of the building's glazing infrastructure.</p> <p>Insulation (Hash): The specifications of the building's insulation infrastructure.</p>
	Electrical	<p>AnnualConsumption (Float): The building's annual electricity consumption for lighting and appliances.</p>
	Generation	<p>PV (List<Hash>): The building's installed photovoltaics specifications.</p> <p>Wind (List<Hash>): The building's installed wind turbines specifications.</p> <p>CHP (Hash): The building's installed CHP specifications.</p>
		<p>Storage (Hash): The building's installed battery's specifications.</p>
	Thermal	<p>HeatSource (Hash): The building's installed cool source (e.g., air-conditioner) specifications.</p> <p>CoolSource (Hash): The building's installed cool source (e.g., boiler) specifications.</p>
		<p>TimeSeriesNames (List<String>): The names of the energy time series to be requested by external tools for the building.</p>
Plants	Renewable	<p>Wind (List<Hash>): The specifications of wind installations.</p>

	<p>Solar (List<Hash>): The specifications of solar installations.</p> <p>Tidal (List<Hash>): The specifications of tidal kites.</p> <p>Geothermal (List<Hash>): The specifications of geothermal plants.</p> <p>Hydro (List<Hash>): The specifications of hydro plants.</p> <p>Incineration (List<Hash>): The specifications of fuel cells.</p>
Conventional	<p>PowerPlants (List<Hash>): The specifications of power plants.</p> <p>FuelCellPlants (List<Hash>): The specifications of fuel cells.</p>
	<p>TimeSeriesNames (List<String>): The names of the energy production time series to be requested by external tools each energy source.</p>
EnergyStorage	<p>Batteries (List<Hash>): The specifications of batteries.</p> <p>Flywheels (List<Hash>): The specifications of flywheels.</p>
PublicInfrastructure	<p>ChargingStations (List<Hash>): The specifications of electric vehicle charging stations.</p> <p>Transformers (List<Hash>): The specifications of transformers.</p> <p>Lighting (List<Hash>): The specifications of lighting infrastructure.</p> <p>TimeSeriesNames (List<String>): The names of the time series for the energy consumption of the components.</p>
Transport	<p>EVs (List<Hash>): The specifications of electric vehicles.</p>

An indicative example of the output JSON-response files that the VERIFY-D requests from INTEMA.grid and/or ESSIM is presented. The extended synthetic/estimated timeseries data are received through the JSON response file.

```
{
  "Project": {
    "Name": "Ameland",
    "GeneralInfo": {
      "Country": "Netherlands",
      "coordinates": [
        53.448,
        5.73
      ],
      "altitude": 4,
      "lifespan": 25
    },
    "CurrentScenario": {
      "Buildings": {
        "Building_1": {
          "id": 1,
          "type": "SingleHousehold",
          "envelope": {
            "target_temperature": {
              "winter": 22,
              "summer": 27
            },
            "FloorSurface": 120,
            "ExternalWallMaterial": "Brick",
            "Glazing": {
              "Opening": 50,
              "Layers": 2,
              "Thickness": 10,
              "GlassType": "NormalGlass",
              "Frame": "Aluminum"
            },
            "Insulation": {
              "Surface": 100,
              "Material": "StoneWool",
              "Thickness": 75
            }
          },
          "electrical": {
            "AnnualConsumption": 2500,
            "Generation": {
              "PVs": [
                {
                  "Type": "RoofFlat",
                  "InstalledPower": 10
                }
              ],
              "Wind": [
                {
```

```

        "Type": "Geared",
        "InstalledPower": 25
    }
],
"CHP": {
    "??": "??"
}
},
"Storage": {
    "Type": "Lilon",
    "Capacity": 80
}
},
"thermal": {
    "HeatSource": {
        "Type": "BoilerNGas",
        "InstalledPower": 25
    },
    "CoolSource": {
        "Type": "AirconditionBasic",
        "InstalledPower": 3.5
    }
}
},
"TimeSeriesNames": [
    "electricity_consumption",
    "boiler_ngas",
    "aircondition_basic",
    "temperature_indoor"
]
}
},
"Plants": {
    "Renewable": {
        "Wind": [
            {
                "Pinst": "300.0",
                "type": "geared",
                "number": "2",
                "column_name": "wind_farm0"
            }
        ],
        "Solar": [
            {
                "Pinst": "50.0",
                "type": "poly",
                "number": "1",
                "column_name": "solar_farm0"
            }
        ]
    }
},

```

```

    "Tidal": [],
    "Geothermal": [],
    "Hydro": [],
    "Incineration": []
  },
  "Conventional": {
    "PowerPlants": [],
    "FuelCellPlants": []
  },
  "TimeSeriesNames": [
    "electricity_production"
  ]
},
"EnergyStorage": {
  "Batteries": [],
  "Flywheels": []
},
"PublicInfrastructure": {
  "ChargingStations": [],
  "Transformers": [],
  "Lighting": [],
  "TimeSeriesNames": [
    "electricity_consumption"
  ]
},
"Transport": {
  "EVs": []
}
},
"PlannedScenario": {},
"FuelPrices": {
  "BuildingExport": 0.05,
  "BuildingImport": 0.12,
  "PlantExport": 0.1,
  "NaturalGas": 0.04,
  "Diesel": 0.2,
  "Biomass": 0.07
},
"TimeSeriesConfig": {
  "Timezone": "UTC",
  "Timestep": 60,
  "StartDatetimeCurrent": "2021-02-28T00:00:00.000+00:00",
  "EndDatetimeCurrent": "2022-02-28T00:00:00.000+00:00",
  "StartDatetimePlanned": "2022-02-28T00:00:00.000+00:00",
  "EndDatetimePlanned": "2023-02-28T00:00:00.000+00:00",
  "RequestFrom": "INTEMA.grid"
}
}
}

```

Table 13: Table of class and attributes for the JSON file that contains the timeseries data provided back to VERIFY-D tool from INTEMA.GRID and/or ESSIM tools.

Class	Attribute
Timeseries	<p>SentBy: (String): The platform that generated the requested time series.</p> <p>CompletedAt: (Timestamp): The timestamp that the time series generation was completed.</p> <p>CurrentScenario (Hash): The requested time series for the current state of the demonstrator.</p> <p>PlannedScenario (Hash): The requested time series for the planned scenario.</p>

Class	Attribute	
Buildings	Building_ID	<p>Unit (String): The unit in which the time series are returned.</p> <p>Values: (List<Float>): The requested time series for the building</p>

		with the specific ID.
Plants	Plant_ID	Unit (String): The unit in which the time series are returned. Values: (List<Float>): The requested time series for the plant with the specific ID.
PublicInfrastructure	Component_ID	Unit (String): The unit in which the time series are returned. Values: (List<Float>): The requested time series for the

		component with the specific ID.
--	--	---------------------------------

Here, we provide an indicative example of the output JSON file that the INTEMA.grid and/or ESSIM tool respond to VERIFY-D containing all the time series data.

```

{
  "TimeSeries": {
    "CurrentScenario": {
      "Buildings": {
        "1": {
          "electricity_consumption": {
            "unit": "kWh",
            "values": []
          },
          "boiler_ngas": {
            "unit": "kWh",
            "values": []
          },
          "aircondition_basic": {
            "unit": "kWh",
            "values": []
          },
          "temperature_indoor": {
            "unit": "kWh",
            "values": []
          }
        }
      },
      "Plants": {
        "1": {
          "electricity_production": {
            "unit": "kWh",
            "values": []
          }
        }
      },
      "PublicInfrastructure": {
        "2": {
          "electricity_consumption": {
            "unit": "kWh",

```



```
    "values": []  
  }  
}  
},  
"PlannedScenario": {},  
"SentBy": "INTEMA.grid",  
"CompletedAt": "2021-02-28T14:25:35.584+00:00"  
}  
}
```

3. CBA module

3.1 Overview

Smart grid technologies can enable higher levels of renewables in electricity systems by making the system more flexible, responsive, and intelligent. As more and more countries, particularly in the developing world, plan to increase their use of renewables, smart grid technologies provide the means to integrate these renewables in a cost-efficient and effective way. Smart grid projects are often evaluated and justified on an economic basis. The challenge for decision-makers (which can be utilities, policymakers, or building-level consumers) is to evaluate smart grid proposals rigorously, objectively, and with a well-defined and consistent methodology. Such analyses are critical for ensuring that scarce capital is invested wisely.

CBA is an ideal first tool for evaluating a smart grid investment. Its value lies not just in the provided outcome, but also in how it requires one to define and quantify the expected costs and benefits. Often it is this analytical discipline, rather than the result itself, that is most informative and offers the various stakeholders a clear path towards the integration of smart green solutions in the Business-as-Usual (BaU) operations. Before conducting a holistic CBA, one needs to consider several issues, such as the follows:

- First, different stakeholders will value the benefits of a smart grid differently. A societal perspective will account for all benefits; however, one may want to take a narrower perspective, such as that of the utility or of electricity users.
- Second, undertaking a CBA requires careful definition of a baseline, documenting what would happen in the absence of the smart grid project. This is a very tricky part where sometimes is ignored completely during the first stages of the analysis, rendering inadequate the proper evaluation of the interventions, and

- Third, CBA requires considerable judgment on the part of the analyst, particularly in estimating uncertain inputs and assessing qualitative benefits. CBA can support better decisions, but it should not be used to make decisions on its own.

The CBA methodology was first introduced for Transmission System Operators (TSOs). Transmission system development focuses on the long-term preparation and scheduling of reinforcements and extensions to the existing transmission grid. The identification of an investment need is followed by a project promoter(s) defining a project that addresses this need. Following Regulation (EU) 347/2013, these projects must be assessed under different planning scenarios, each of which represents a possible future development of the energy system [7].

Whilst their costs mostly depend on scenario independent factors like routeing, technology, material, etc., benefits strongly correlate with scenario-specific assumptions. Therefore, scenarios which define potential future developments of the energy system are used to gain an insight in the future benefits of transmission projects. The essence of scenario analysis is to come up with plausible pictures of the future.

3.2 Functionalities and Methodological Approach

The proposed CBA methodology, presented in Figure 5, is based on the both JRC's and ENTSO-E's methodologies [8], [9]. These are comprehensive frameworks to assess costs and benefits of Smart Grid Interventions inserted into the electricity infrastructure from the system planning perspective. The analysis accounts at same time for technical, economic, reliability, environmental, and security benefits. This framework aims at evaluating its effectiveness in the IANOS project demonstrators, i.e., LH islands of Terceira and Ameland, and the defined UCs.

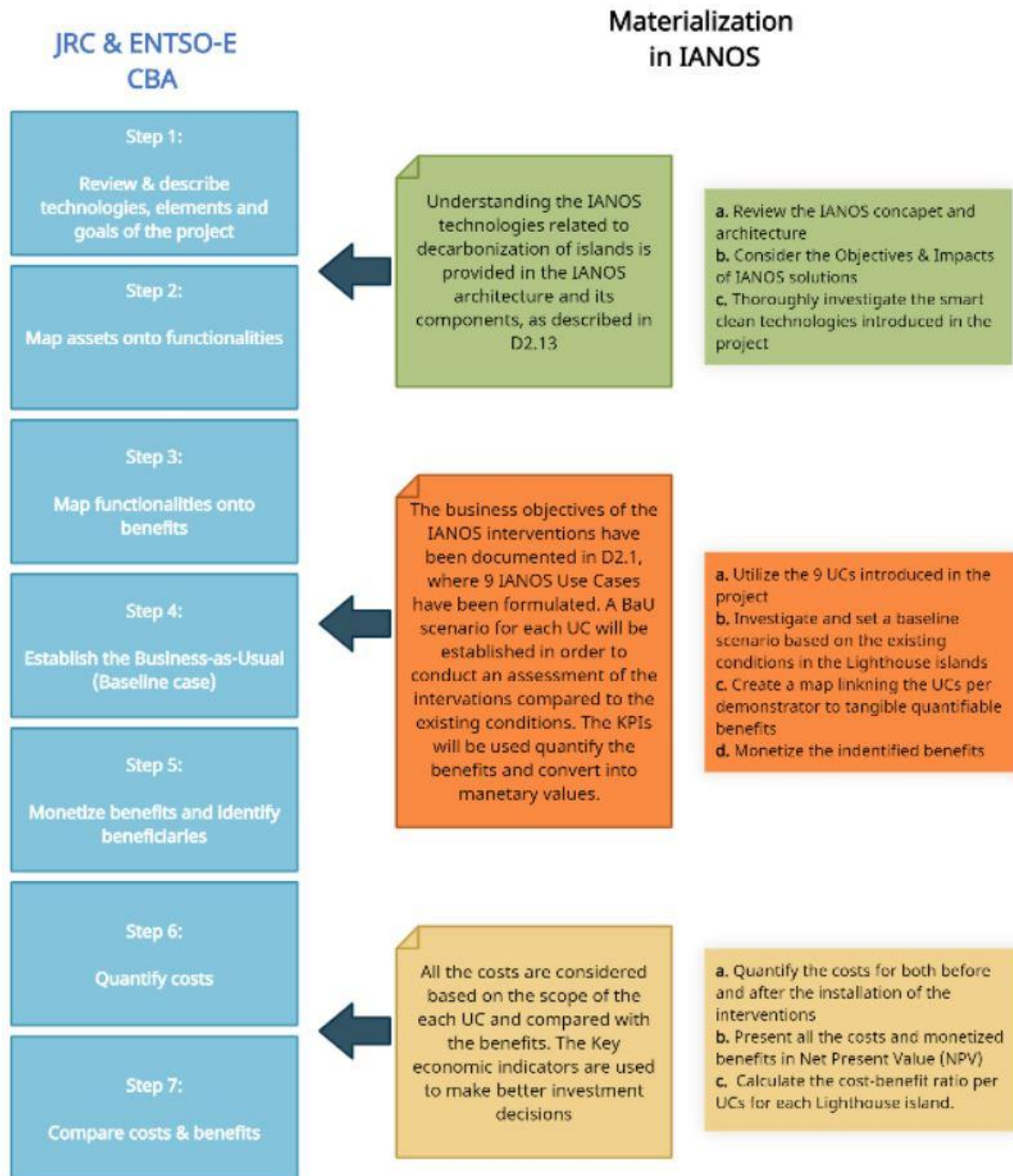


Figure 5: The CBA methodology and its materialization in the IANOS project interventions.

The economic indicators that are leveraged to perform the CBA are introduced. Firstly, the Discounted Cash Flow (DCF) model is introduced. This model is used to compute the present value of future cash flows, resulting from Smart Grid Interventions for each year of the analysed period. The DCF model is a basic evaluation model for an asset that is expected to generate cash payment in the

form of cash earnings, interest and principal payment, or dividends. The mathematical formulation of the DCF models is:

$$V_0 = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_n}{(1+r)^n} \quad (1)$$

where V_0 is the present value of the anticipated cash flows from the asset, $CF_{1,2,..,n}$ are the cash flows expected to be received up to n periods in the future, and r the discount rate, which is the required rate of return per period.

After the computation of the DCF for each year, the Net Present Value (NPV) for each benefit is computed. The NPV of a capital budgeting project is the monetary amount of the change in the value of the firms because of undertaking the project. For the case of the IANOS project, the NPV depicts the monetary amount of the change in the value of the energy infrastructure because of selecting and applying one or more Smart Grid Interventions, according to the business objectives of each introduced IANOS UCs. A positive NPV value showcases that the value of the infrastructure will increase if the new interventions will be adopted. On the other side, a negative NPV means that the infrastructures' value will decrease if the new interventions will be adopted. The specific formula for the NPV calculation is given by:

$$NPV = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_n}{(1+r)^n} - \text{Initial Investment} \quad (2)$$

where, $CF_{1,2,..,n}$ is the cash flow at the indicated times, r is the discount rate, and n is the life of the technology measured in number of years.

The discount rate r is the interest of rate that determines the present value of future cash flow. A low interest rate indicates promoting trend of development created by central banks. A high interest rate shows inflationary, riskier, and uncertain trends.

The selection of time horizon is of vital importance and has to be defined within the benefits and the costs of each intervention. The time horizon depends on the asset type of each installation, the investment scheme and the benefits for the overall electricity infrastructure (and in general energy infrastructure if benefits can be found in the rest energy carriers).

In order to conduct the assessment between the existing BaU condition and the benefits that the IANOS interventions will bring in the buildings, communities, regions and islands in total, the following indicator is introduced:

$$\textit{Benefit – cost ratio (BCR)} = \frac{\textit{NPV(Quantified Benefits)}}{\textit{NPV(Costs)}} \quad (3)$$

Table 14 provides a roadmap for the investors to assess whether a smart grid intervention for the specific setup that is described in the demonstration campaigns of the project, is recommended.

Table 14: Recommendation for investments based on BCR values.

BCR value	Investment recommendation
<<1	Not worth continuing the investment and potentially increased scalability will not benefit either
~<=1	Not worth continuing the investment with the existing setup
~>=1	Risky to continue the investment (this implies that relatively low IRR exists)
>>1	It is worth continuing the investment

According to ENTSO-E’s CBA methodology, the KPIs have been grouped in 3 distinctive categories, i.e., Benefits, Costs and Residuals, based on which type of impact each KPI can quantify. Each UC of the IANOS project is linked to specific KPIs that quantify the business impact of the interventions. The KPIs that will be used as the outcome of the Energy Planning & Transition Decision Support suite, will be computed using the functionalities of the components that constitute the

suite. Specific description is provided in Chapter 2 of this deliverable. Figure 6 provides the position of the CBA component in the suite, and how it uses the outcome of the rest components, i.e., the calculated KPIs values, in order to conduct CBA for the IANOS solutions. The benefits column represents the categories, as identified in the ENTSO-E’s CBA methodology. During the pre-validation and refinement activities of the IEPT tool (related to task 3.4), a cross-checking process will be conducted to provide a list of specific benefits for each UC, updating the illustrated ones.

The following chapters of this deliverable contain an extended description of the functionalities of the modules that are responsible for the KPIs calculation. Table 15 includes the KPIs list that contains the ones that will be used in the context of IEPT suite. The relation of those KPIs with the CBA methodology is presented in the last column of the Table. The role of the CBA component is to convert into monetary gains (if possible) all the impacts of those benefits for each UC, and to provide a holistic tool for investment planning for the different stakeholders. In case a benefit/residual cannot be directly converted into monetary gains, a scaler is introduced in order to provide an auxiliary tool to the decision-makers by showcasing the improvements/ positive impact that a specific IANOS intervention will make.

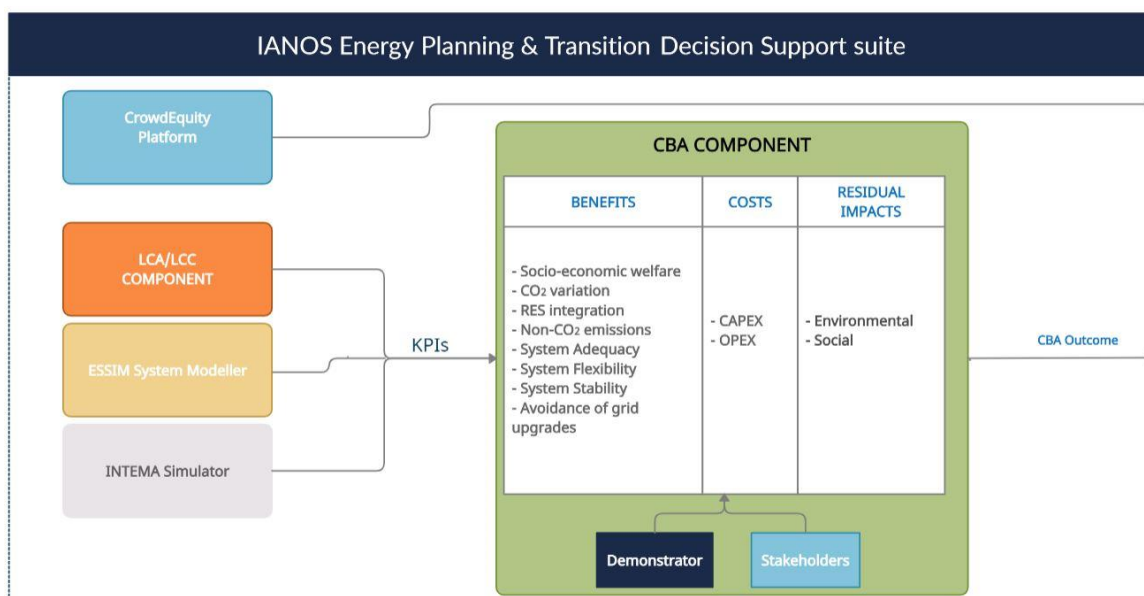

































Figure 6: Position of the CBA component in the IEPT suite and its interconnection with the rest components.

Table 15: Mapping of KPIs to the specific components of the IEPT suite.

KPIs Information		Calculated ³			Mapping to CBA
Categories in D2.7	KPI NAME	INTEMA	VERIFY	ESSIM	Categories
T1	RES Generation				<i>Benefits</i>
T2	Energy savings				<i>Benefits</i>
T5	Increase of degree of energetic self-supply by RES				<i>Benefits</i>
T7	Storage capacity of the energy grid per total island energy consumption				<i>Benefits</i>
T8	Reduced energy curtailment of RES and DER				<i>Benefits</i>
T9	Peak load reduction				<i>Benefits</i>

³ VERIFY will conduct the KPIs calculation for both LH islands of the IANOS project. INTEMA will conduct the KPIs calculation for TERCEIRA islands, and the ESSIM modeler for the AMELAND island. More information will be given in D3.7 and D3.8 (2nd version of D3.8).

T12	kWp photovoltaic installed per 100 inhabitants				<i>Benefits</i>
EN-1	Reduced Greenhouse Gas emissions				<i>Benefits</i>
EN-2	Reduced Fossil Fuels consumption				<i>Benefits</i>
EN-4	Air quality index (Air pollution)				<i>Residual</i>
EN-6	Primary Energy Demand and Consumption				
EC-1	Total investments				<i>Costs</i>
EC-2	ROI				<i>Costs</i>
EC-3	Total annual cost				<i>Costs</i>
EC-4	Payback period				<i>Costs</i>
EC-5	Total annual revenues				<i>Costs</i>

EC-8	Internal Rate of Return (IRR)				<i>Costs</i>
EC-10	Load purchasing from mainland				<i>Benefits</i>
I-4	Increased hosting capacity for RES, electric vehicles and other new loads				<i>Benefits</i>

3.3 Implementation and technology stack

The backend module of the CBA tool is deployed using open-source libraries in the Python language. This is responsible for sending API requests to other microprocesses, and both processing and analysing the received information in json format. This module sends the outcome of the CBA methodology to the IEPT suite user interface developed in HTML.

4. ESSIM module

4.1 Overview

The Energy System Simulator (ESSIM), as illustrated in Figure 7, is a discrete time simulation tool and collection of models that calculates energy flows in assets and the effects thereof, in an interconnected hybrid energy system over a period of time. With the help of the energy flows ESSIM calculates, one can get insights into how well the assets in a network are dimensioned, if there is overloading in any given transport asset (like pipe, cables, etc.) and what is the effect of storage in any part of the network.

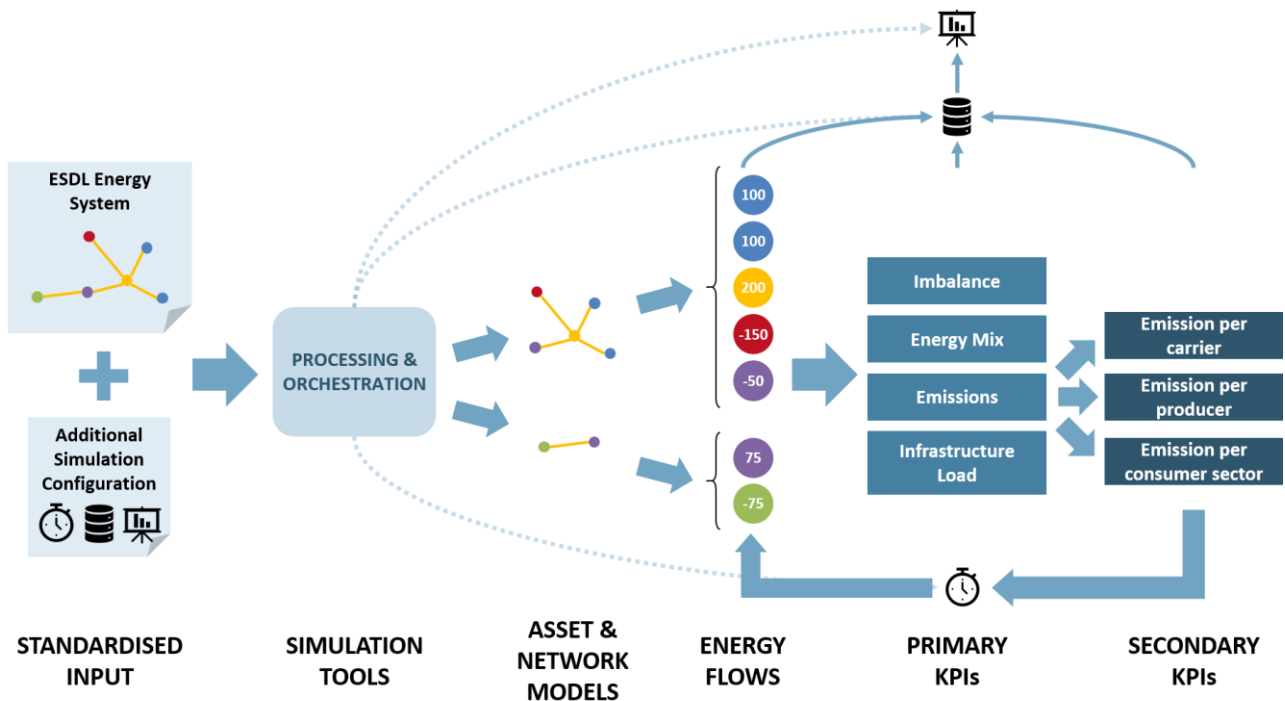


Figure 7: An overview of the functionalities of ESSIM.

As an input, ESSIM uses an energy system modelled using Energy System Description Language (ESDL) to get information about energy assets, carriers and commodities, infrastructure etc. An energy system is modelled in a map-based UI tool called MapEditor, that ultimately generates an ESDL. The following two subsections describe ESDL and MapEditor.

ESDL

ESDL is an open-source modelling language created for modelling the components in an energy system and their relations towards each other. Technically it is an XML schema definition (XSD) for formally describing energy assets in an XML format. This allows ESDL to be used as a formal specification of an energy grid for unambiguous interpretation by experts and tools. The language is machine readable so makers of energy transition calculation tools, simulations and GIS applications can support ESDL in order to enforce the interoperability of their products.

ESDL is capable of expressing the dynamic behaviour of components in the energy system. For instance, the power consumption of a neighbourhood. ESDL describes components by their basic functionality (Energy Capabilities), these are modelled in 5 abstract categories: Production, Consumption, Storage, Transmission and Conversion. Aggregation and composition principles of ESDL enables energy modelers to model a complex energy system in a generic way.

ESDL can be used in various ways, for example:

- By energy transition calculation tools. ESDL acts as a common language for different energy transition calculation tools, specifying the format of the inputs and outputs of such tools. This allows for integration of multiple tools.
- In an Energy Information System. ESDL can be used as a basis for a central energy information system where the energy system of a certain region is registered.
- As a language for (local) governments to model, reason about and share their (local) energy system.
- To monitor the evolution of an energy system: multiple ESDL snapshots of a certain area over time provide insight in the evolution of an energy system.
- As a format to share data relevant to energy systems or the energy transition. Examples:
 - CO₂ emissions per energy carrier

- o Technology factsheets for specific components, brands, types (e.g., a heat pump factsheet that describes its typical parameters)
- o Cost information of assets, or expected cost developments in future
- o Standard configurations or templates of typical parts of the energy system (e.g., a house with a heat pump, solar panels and an EV charging station)

A fully detailed description of ESDL, both technical and pragmatic, can be found as an on-line gitbook on [8].

ESDL MapEditor

ESDL MapEditor is a map-based energy system editor. With the MapEditor ESDL based energy system descriptions are defined, that can be simulated with a growing number of ESDL capable simulators, among which is ESSIM (section 2.3). The editor allows to define the system on a map, thus placing assets in their real-life location. These assets can be anything from production, consumption, infrastructure (transmission), conversion and storage for every imaginable energy carrier. The editor provides features to intuitively construct the system, work with Geographic Information System (GIS) components (WMS layers, shapefiles and more) to assist in visualization of the system. Also, the editor is connected to external data sources (on buildings for example) and to external models (e.g., spatial analysis models). The editor further supports configuring the assets in the system with energy profiles of energy demand, consumption for every applicable asset or any other data that is relevant for further processing/simulating the ESDL energy system. When ESSIM is used for simulation, the results can be visualized in the MapEditor by selecting specific assets and viewing the simulation results in the form of charts and graphs which makes analysis of the system possible. An open-source version of the ESDL MapEditor can be found on [9].

4.2 Functionalities

ESSIM calculates energy flows per time step for a simulation period. It takes as inputs the energy system defined in ESDL and calculates optimal schedule of flexible producers and the effect of this schedule in terms of emissions, costs, load on the network, etc. Thanks to the easy configurability of the energy system with the help of the ESDL MapEditor, the user can use ESSIM to perform “what if?” scenario analyses on current and future energy systems.

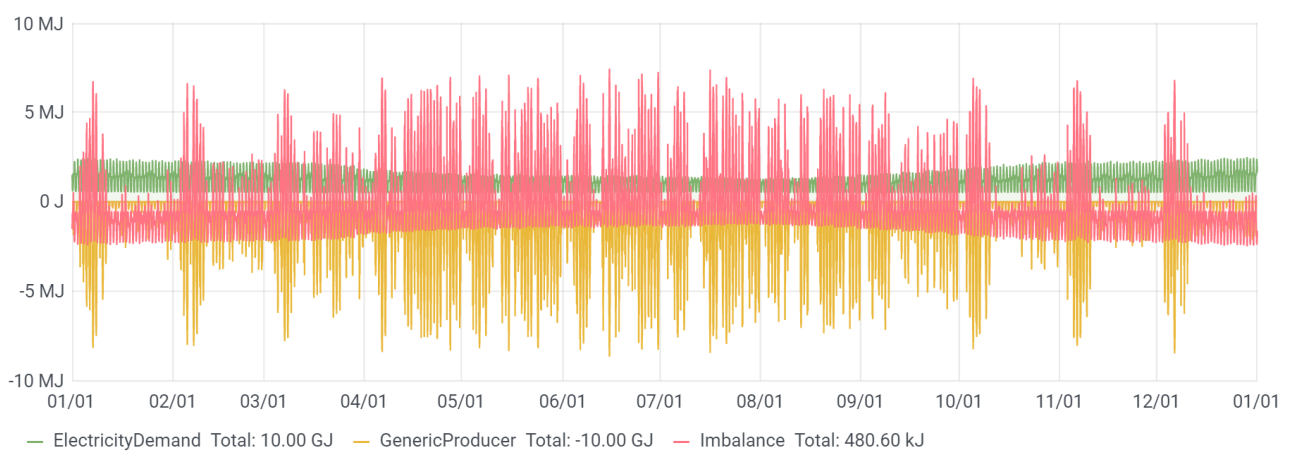


Figure 8: ESSIM output: Hourly data showing imbalance.

Along with the primary KPIs that ESSIM generates (Energy mix, network imbalance, emissions, etc.), external KPI modules connected to ESSIM also allow for post-processing ESSIM data to get measurable insights into the energy system variations. Results of KPI modules are in JSON format and as such can be communicated with external tools.

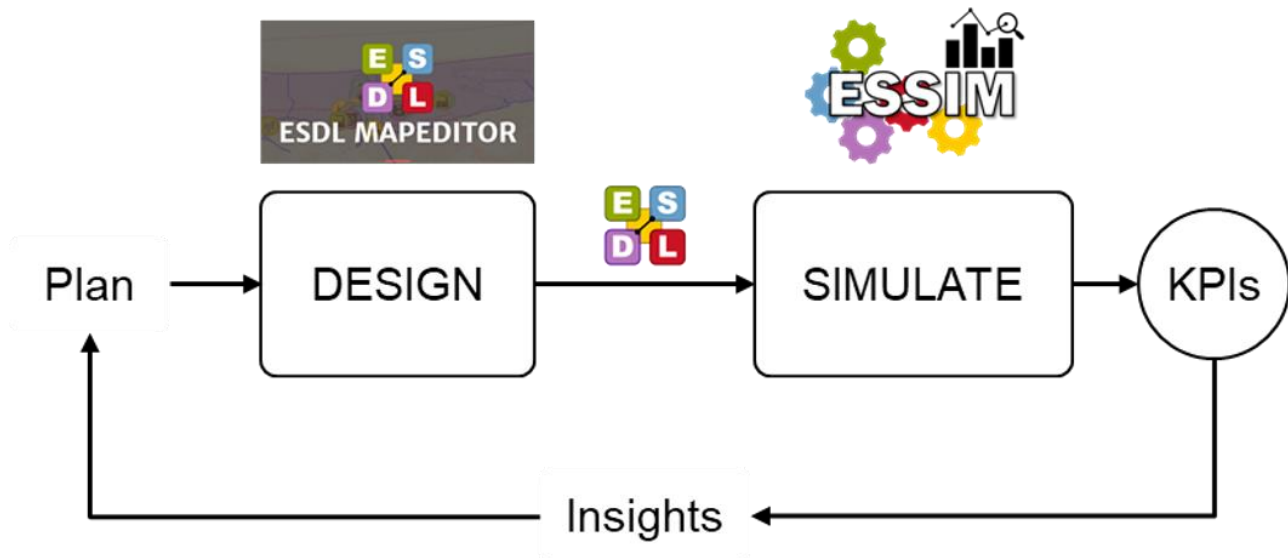


Figure 9: ESSIM used in the planning-design phase of Energy Transition.

Energy Assets

ESSIM follows the ESDL principle of classifying energy system assets into Producers, Consumers, Storages, Conversions and Transmission. Each asset (except for Transport assets) can either have a pre-determined behaviour (inflexible) programmed into it with the help of a profile or let ESSIM calculate its energy allocation (flexible) based on its flexibility, some control strategy and the behaviour of other assets in its network. ESSIM contains models for each of these five classes of assets and thanks to ESDL's hierarchical data structure, model behaviour can also be inherited from parent models. E.g., with a generic Consumer behaviour implementation, all existing ESDL Consumers such as ElectricityDemand, HeatingDemand, etc., and any ESDL Consumers added in the future can be supported within ESSIM. Additionally, implemented within ESSIM are also some specific asset models that have certain peculiarities. E.g., a co-generation plant is a conversion asset with two output ports with one output effecting the other.

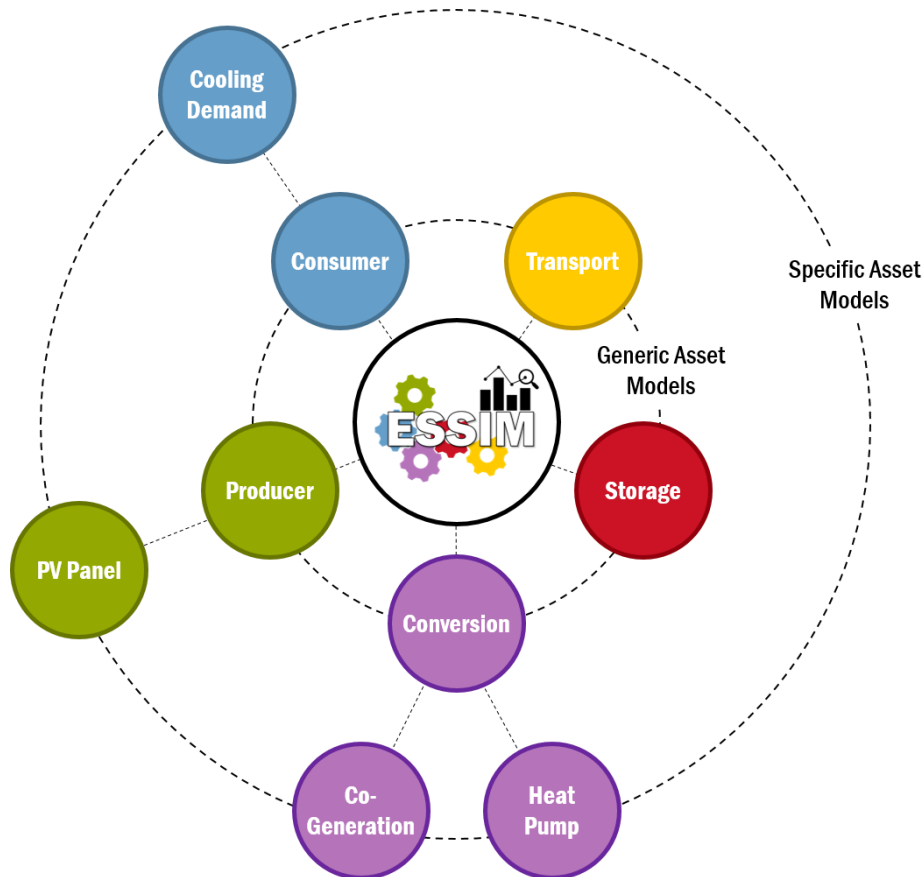


Figure 10: All implemented asset models in ESSIM.

Transmission Network

In ESSIM, a transmission network is an atomic network of connected energy assets using the same energy carrier. This means ESSIM treats isolated assets physically connected only to each other but using the same energy carrier as separate transport networks. Internally ESSIM creates a tree of such a network where the Producer/Consumer/Conversion/Storage assets are the leaf nodes, and the Transport assets are the branches. Conversion assets appear in multiple transport networks as consumers of some energy carriers and producers of some others. Based on the provided ESDL description and configured behaviour, each transport network attempts to balance itself in each time step.

The transport network trees are created in the pre-processing step in ESSIM and cannot be changed during the simulation. In addition to creating the trees, ESSIM also pre-determines the order and parallelisation in computing the network tree balances.

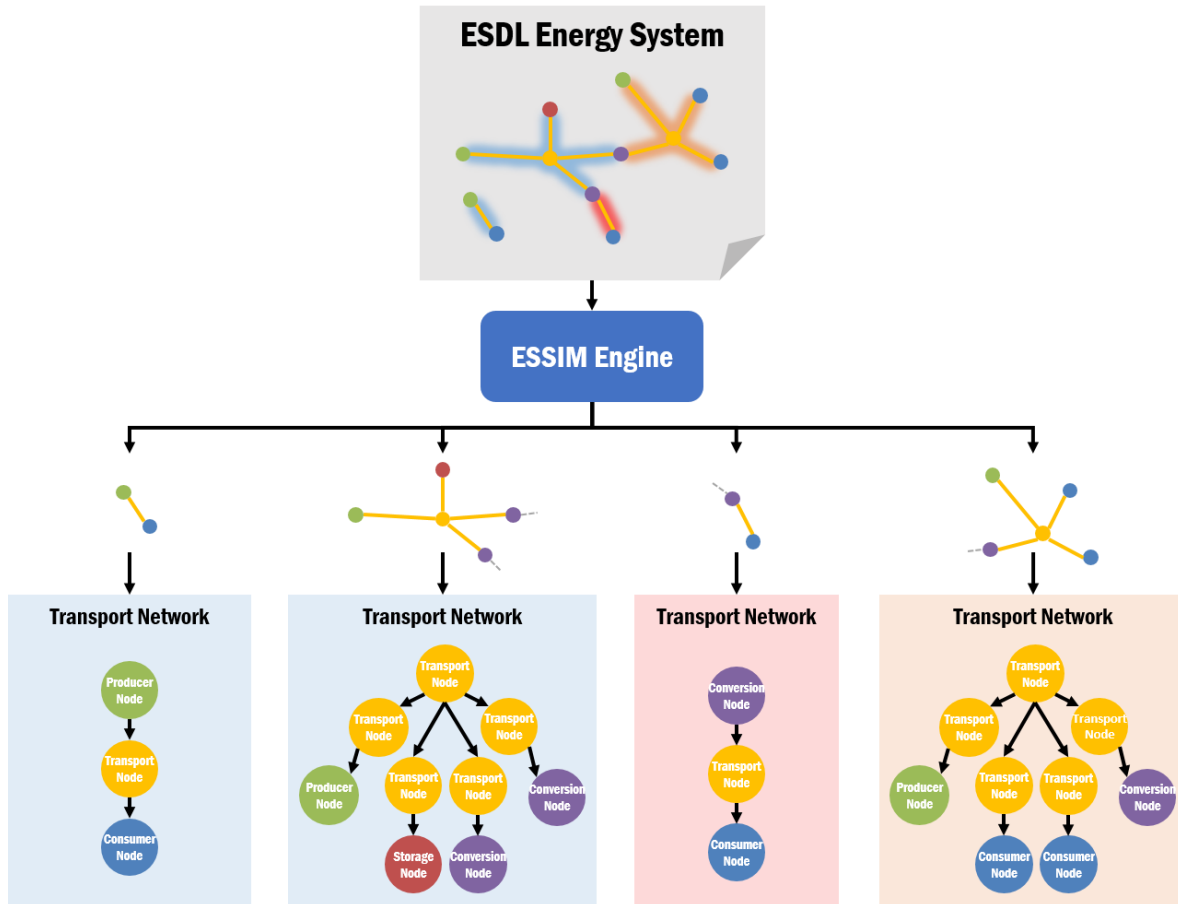


Figure 11: Splitting of an energy system into constituent transport (transmission) networks.

4.3 Implementation and technology stack

ESSIM is implemented in Java. At the heart of the ESSIM tool are:

- A simulation engine that orchestrates a fixed discrete timestep evaluation of each commodity network's balance in a pre-determined order,
- A flexibility-based demand-supply matching algorithm that uses marginal costs of energy production as a means to grade desirability of producers,

- A tree-based transport network solver that calculates the load on various transport elements based on the demand-supply solution determined above.

The tool outputs the data provided and generated during the course of the simulation into a timeseries database (InfluxDB) and generates a dashboard (Grafana) to visualise the same. ESSIM allows for connecting external asset models (via an MQTT interface) and external network (solver) models (via a REST interface), alongside its internal models and while using its own orchestration mechanism. This makes ESSIM a viable candidate for a co-simulation orchestrator.

Figure 12 shows the technology stack of ESSIM, including KPI Modules that calculate and communicate KPI results with ESSIM and the underlying database. As seen in Figure 12, each interacting component is Dockerized.

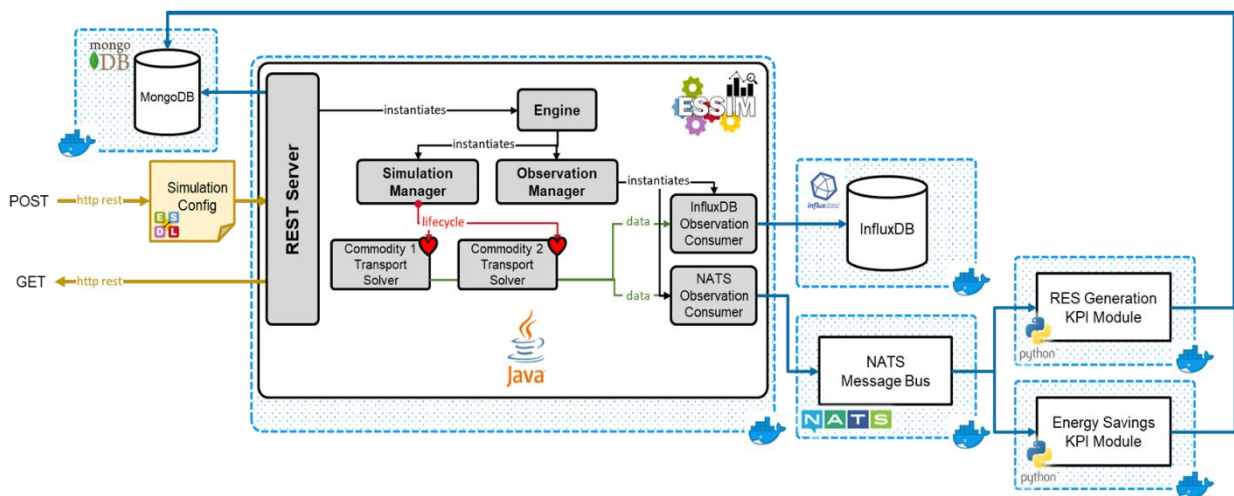


Figure 12 ESSIM Technology stack

The KPI Modules subscribe to ESSIM to receive simulation results at each time step. This subscription and message communication is performed via NATS message bus. Once the simulation is finished and all the messages (results at each timestep) are received, KPI Modules perform their calculation and write the result in MongoDB. Using a KPI ID and a simulation ID, an application can send a GET request to ESSIM to retrieve KPI results for a specific simulation. ESSIM fetches

these results from MongoDB and sends it back to the requesting application. The format of the GET request is:

essim/simulation/<simulation-id>/kpi/<kpi-id>,

where *<simulation-id>* and *<kpi-id>* are the ID of an ESSIM simulation and the desired KPI ID, respectively.

With respect to the message request specification presented in Table 9, a lookup Table should be implemented to perform the mapping between the desired IANOS KPI IDs (e.g., T1) and the ESSIM KPIs (e.g., RES Generation), as well as the Use Case specification and ESSIM simulation IDs.

5. INTEMA.grid module

5.1 Overview

CERTH has been developing its own Suite of software Tools for the energy sector under the name INTegrated Energy Management (INTEMA). INTEMA.grid is part of the INTEMA Suite, with specific implementations and tools for grid-level simulations, able to simulate multi-vector energy systems, integrated, accounting also the grid topologies and interconnections among variable systems. INTEMA.grid aims at helping engineers to address challenges towards a sustainable energy transition, while is being developed to be fully customizable by energy experts, rendering it in a position to include any type of system simulation (mature or high innovative), on multiple spatial and temporal scales (both steady and transient simulations, with a user-defined timestep). The tool offers a set of functionalities for an energetic grid assessment, each one covering different needs of the decision-making process.

Since the launch of IANOS project, CERTH has concentrated its efforts in two main directions:

- i) To be capable of fully supporting the dynamic simulation of the LH islands, by developing the corresponding component models for the technologies (mature and innovative) that are present.
- ii) The development of a web-based GUI that will be supporting the scenario setup, simulation and assessment. Under this view, a back-end automated engine is still under development, able to automatically generate the corresponding system model to be simulated, accounting also for user-friendliness and customizability, covering all typical grid cases.

The following paragraphs report in detail the developments conducted so far and highlight the specific advancements occurred in the context of IANOS.



5.2 Functionalities

The present section lists the main functionalities of INTEMA.grid along with a short description and some implementation info. Although specific functionalities can be used in sequence (e.g., optimal power flow, substantiated by a dynamic simulation), the functionalities are independent of each other. Table 16 lists all the available functionalities of the INTEMA.grid Suite of Tools. Furthermore, it describes the functionalities that are scheduled to be automated in the web interface until the end of the project.

Table 16: Functionalities attributes and development timeframe for IANOS.

Functionality	Free and open-source tools utilization	Developed by CERTH		Automation through the web-interface
		Developed in previous projects	Developed during IANOS	
Power Flow	✓	-	-	-
Optimal Power Flow	✓	-	-	-
Dynamic Grid Analysis	-	-	✓	✓
Forecasting	-	✓	-	-
Web Interface	-	-	✓	✓
IEEE Common Data Format	✓	-	-	-

- Power Flow: Power Flow (PF) analysis is a fundamental study necessary in any power systems configuration, able to provide an analysis of the most important and essential variables in the power system operating phase. It calculates all major quantities (e.g., active and reactive power, voltage angle etc.) at each node (bus) of the system. INTEMA.grid offers simple PF functionality with the integration of open-source Python modules PyPSA [12] and Pandapower [13].

- Optimal Power Flow: While energy forecasts are the first step to minimizing the cost, particular decisions must be made regarding the coordination of the utilized power plants. Such decisions involve solving an optimal resource allocation problem, while considering the power plants' operating costs. The control and coordination of the grid assets can either be centralized into a single decision-maker or distributed [14]. INTEMA.grid offers an efficient and reliable solution to the optimal power flow problem. Taking advantage of modern convex optimization methods [15], the tool is able to address the problems of unit commitment, i.e., generator start-up and shut-down, and economic dispatch, i.e., determining the power output of each generator, in order to meet the power requirements at minimum cost, within the constraints of the network [16]. Optimization can be carried out for both pure or mixed DC and AC networks on the basis of linearized power flow equations. The optimization method assumes that the loads are non-dispatchable and load requirements must be met at all time snapshots.
- Dynamic Grid Analysis: INTEMA.grid's power grid simulation engine leverages Modelica language and offers detailed dynamic simulations considering variables such as: a) grid assets (lines, transformers, generators, capacitor banks, loads etc.), b) conventional and renewable generation and c) energy storage units. The tool is capable of estimating with high accuracy all relevant quantities regarding energy management, voltage/frequency stability and power quality. At the same time, the high order dynamic representation enables stability assessment.
- Forecasting: The stability of the electricity grid requires the electricity supply to constantly meet demand. Thus, forecasting energy production and consumption have always been of great interest. INTEMA.grid offers in-house developed power forecasting modules for load and RES generation (wind and solar energy) based on machine learning algorithms [17]. The models have been developed in the context of the Horizon projects SMILE [18] and RENAISSANCE [19].

➤ Web Interface: A convenient web-based graphical user interface is being developed, during this reporting period of IANOS, to support the case definition and results visualization. The interface is based on the Single Page Application (SPA) [20] approach, which eliminates page reloads and enhances the usability in more complex applications where multiple interactions between the user and the system must take place. The implementation is based on the Vue.js JavaScript framework consuming the RESTful API implemented in Python with the Django web framework. Utilizing the web interface, the user is able to define, for the network topologies of interest, its key components and interconnections among them and perform steady or transient simulations (Figure 13), with a user defined timestep, according to the objectives of the simulation run. A network can be defined either manually or by uploading a properly formatted file, describing it. To define a topology manually, the user has to designate the various components involved. Specifically, the components that can be defined by the user are the network's buses (Figure 14), lines (Figure 15), loads (Figure 16) and generators (Figure 17). The components can be edited or deleted, aiming to carry out many simulations with similar topologies and various parameters. Depending on the simulation type, different kinds of generator components can be defined. For steady simulations, a generic generation type is used. For dynamic simulations, thermal plants, batteries, photovoltaics and wind turbines are available (Figure 18, Figure 19, Figure 20, Figure 21). Table 17 lists all the implemented components in the current version of user interface and the key input

parameters that are used to describe them

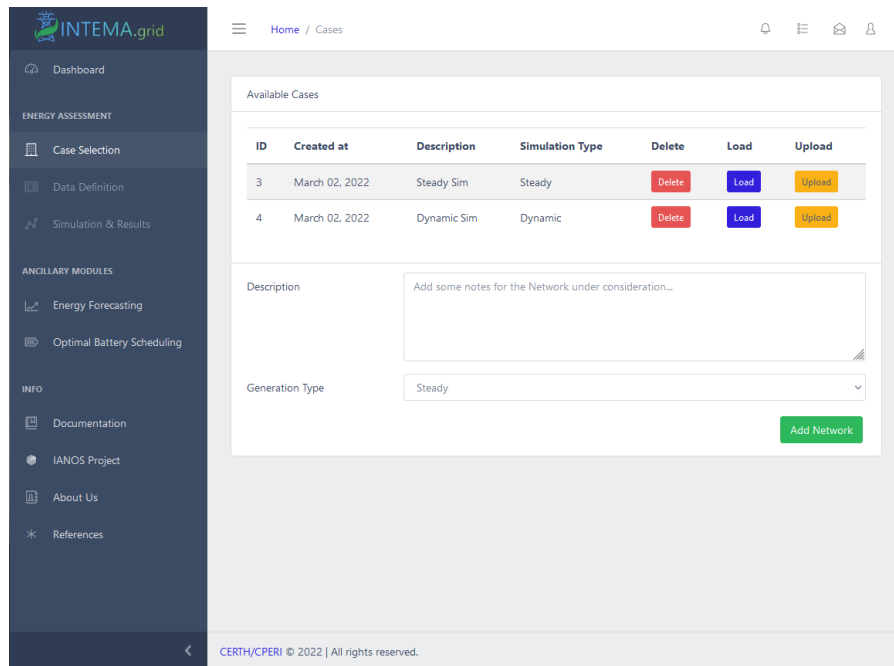


Figure 13: INTEMA.grid frontend- network selection page.

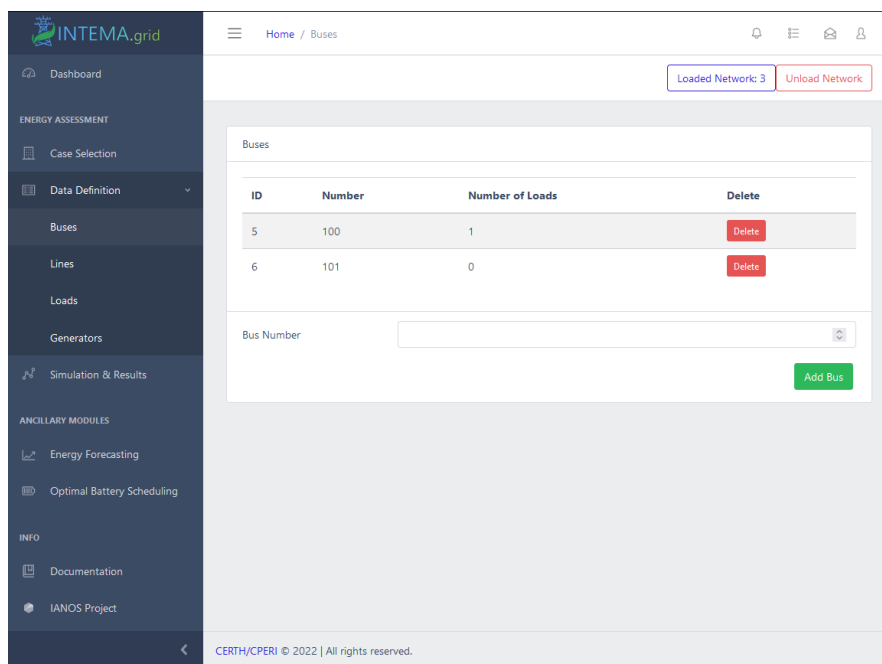


Figure 14: INTEMA.grid frontend - buses definition page.



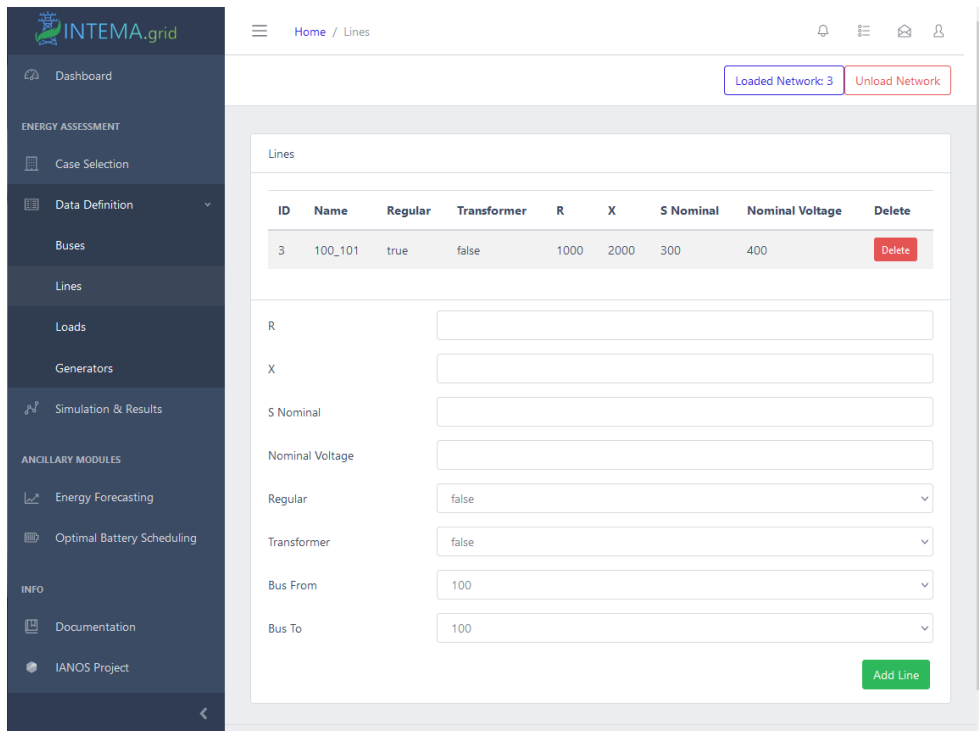


Figure 15: INTEMA.grid frontend - lines definition page.

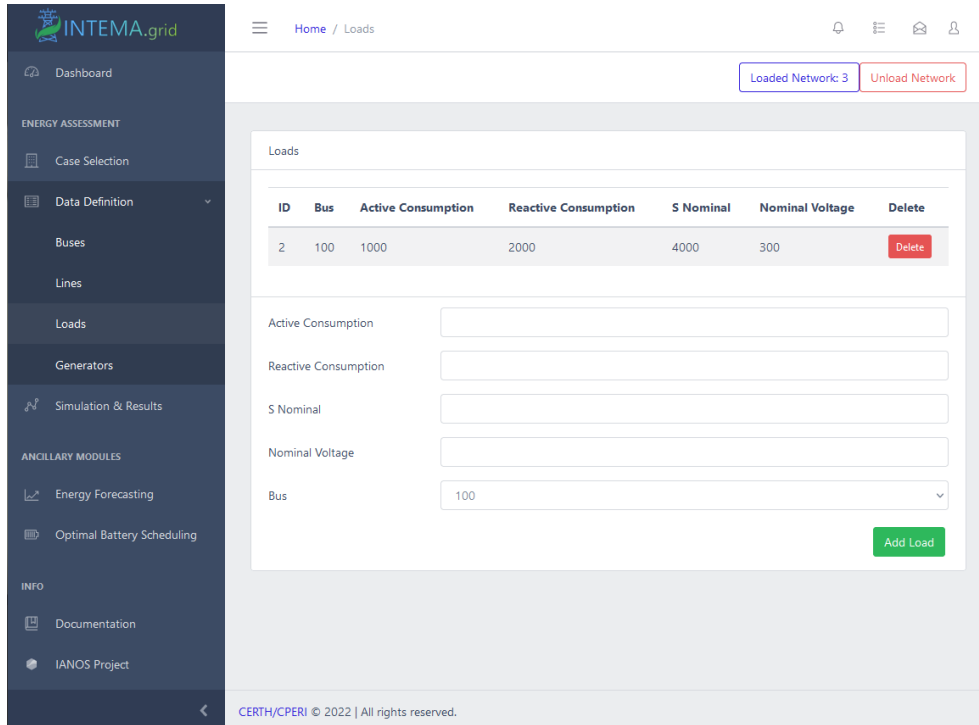
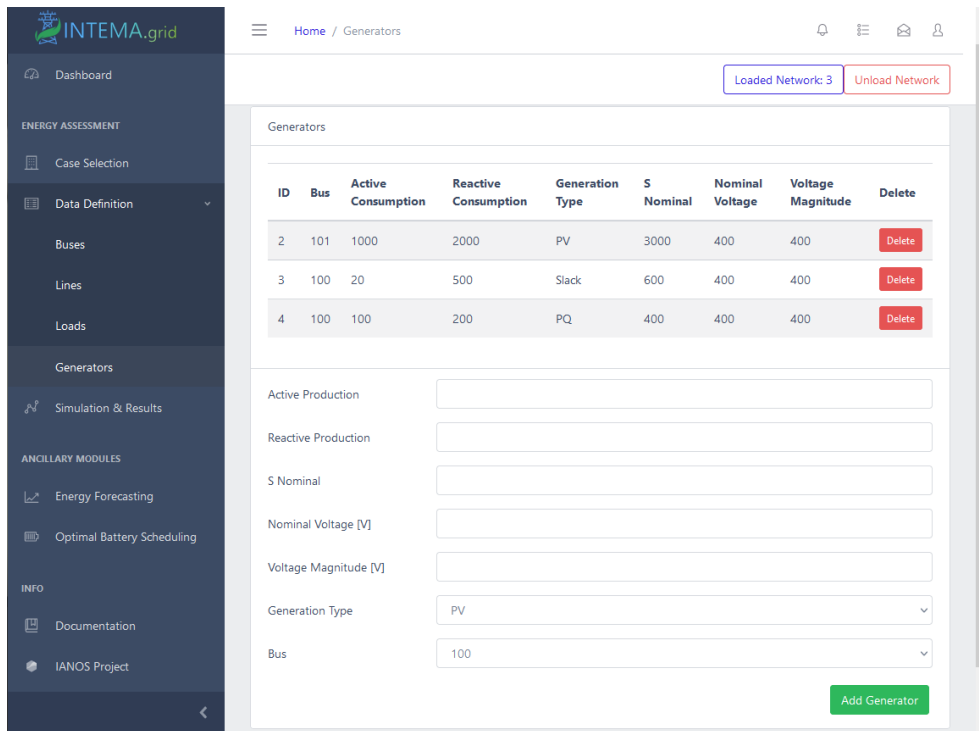


Figure 16: INTEMA.grid frontend - loads definition page.



Home / Generators

Loaded Network: 3 Unload Network

Generators

ID	Bus	Active Consumption	Reactive Consumption	Generation Type	S Nominal	Nominal Voltage	Voltage Magnitude	Delete
2	101	1000	2000	PV	3000	400	400	Delete
3	100	20	500	Slack	600	400	400	Delete
4	100	100	200	PQ	400	400	400	Delete

Active Production:

Reactive Production:

S Nominal:

Nominal Voltage [V]:

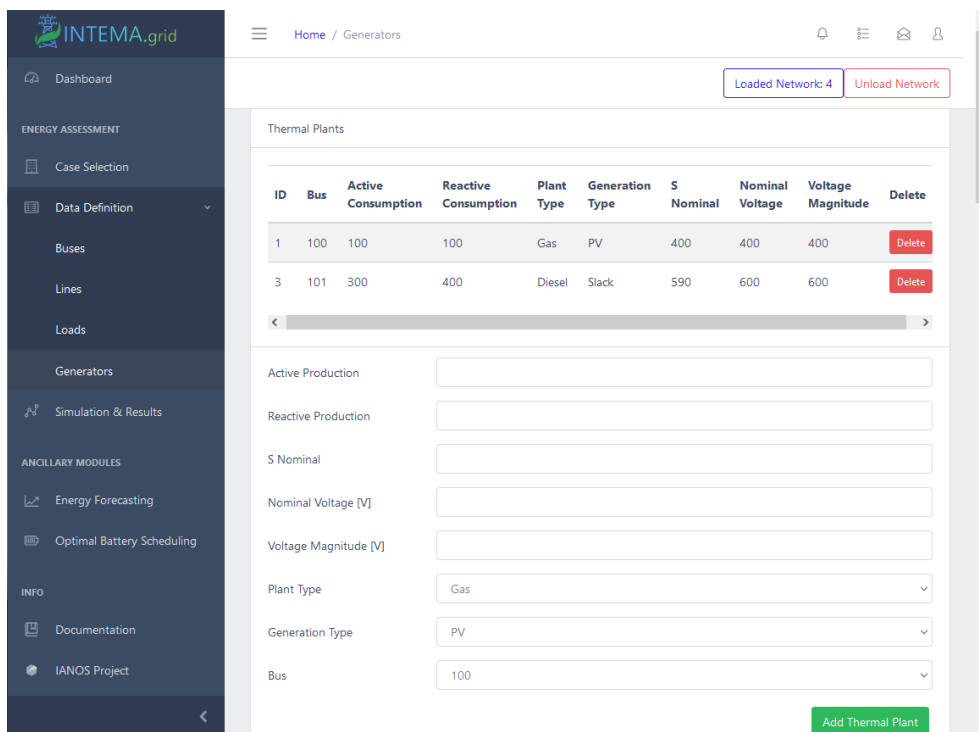
Voltage Magnitude [V]:

Generation Type: PV

Bus: 100

Add Generator

Figure 17: INTEMA.grid frontend - generators definition.



Home / Generators

Loaded Network: 4 Unload Network

Thermal Plants

ID	Bus	Active Consumption	Reactive Consumption	Plant Type	Generation Type	S Nominal	Nominal Voltage	Voltage Magnitude	Delete
1	100	100	100	Gas	PV	400	400	400	Delete
3	101	300	400	Diesel	Slack	590	600	600	Delete

Active Production:

Reactive Production:

S Nominal:

Nominal Voltage [V]:

Voltage Magnitude [V]:

Plant Type: Gas

Generation Type: PV

Bus: 100

Add Thermal Plant

Figure 18: INTEMA.grid frontend - thermal plants definition.

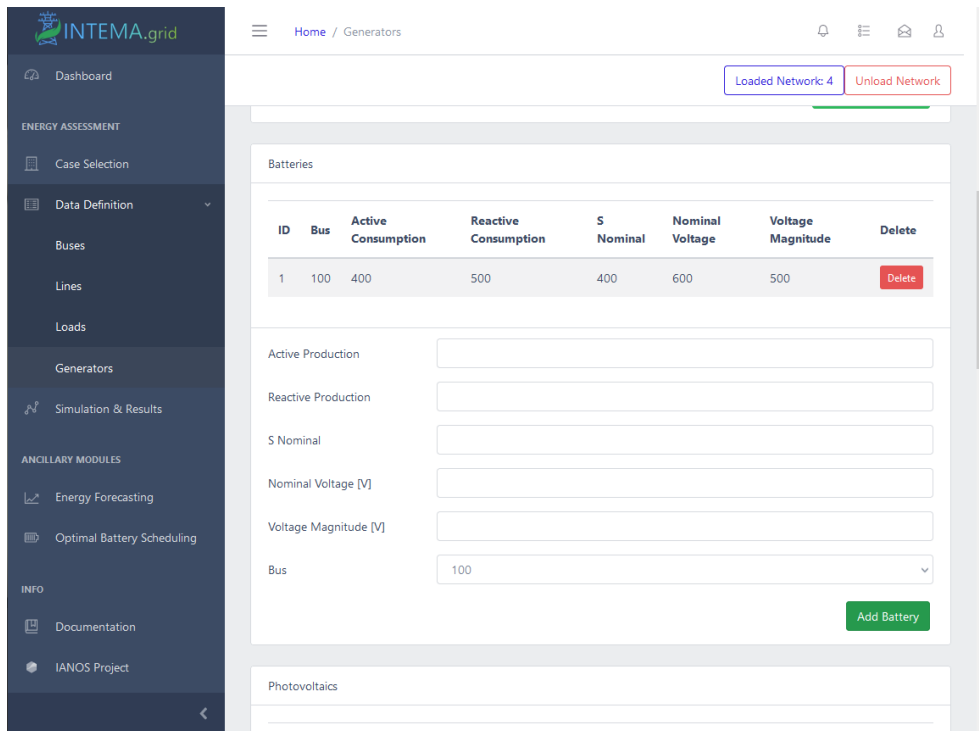


Figure 19: INTEMA.grid frontend - batteries definition.

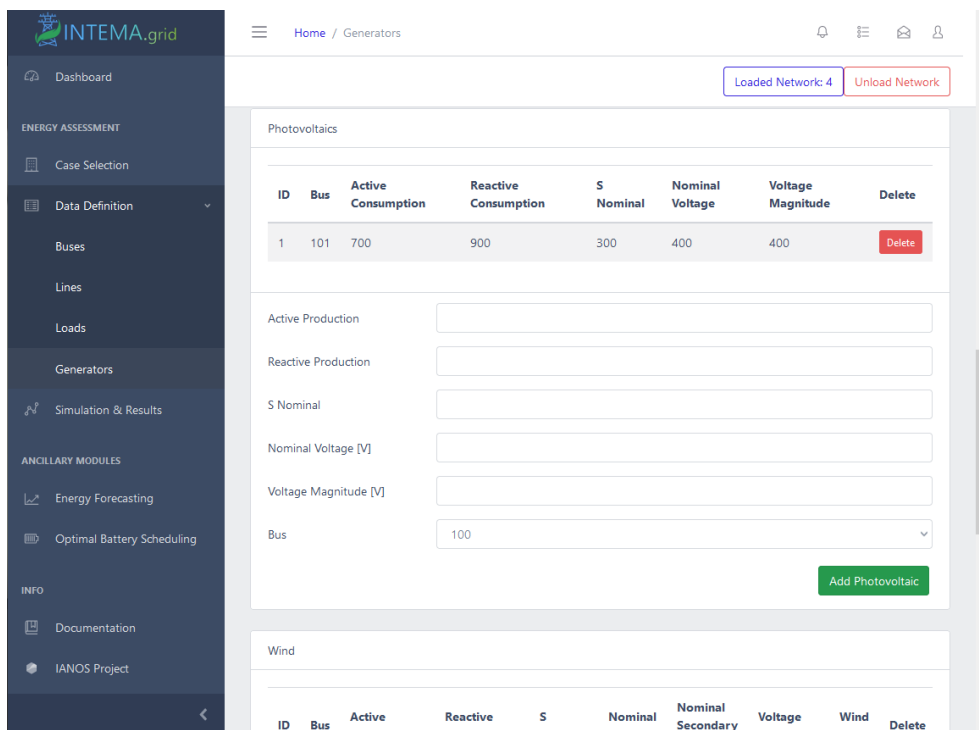


Figure 20: INTEMA.grid frontend - photovoltaics definition.

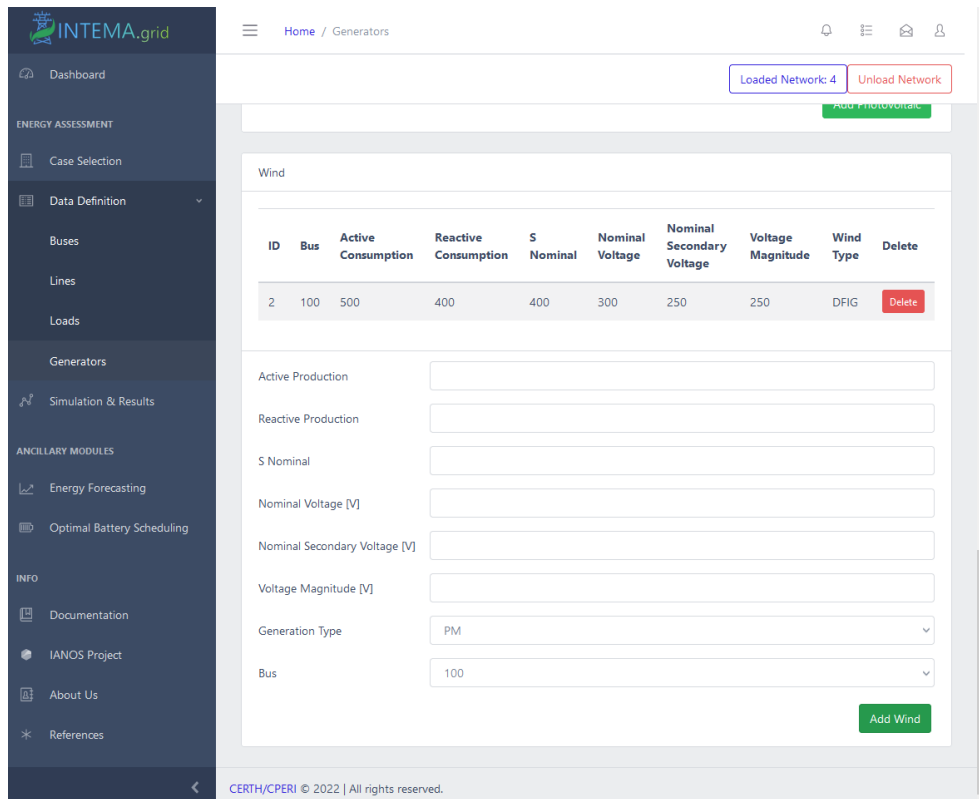


Figure 21: INTEMA.grid frontend - wind turbines definition.

Table 17: INTEMA.grid frontend – components and required parameters.

Component	Parameters required
Buses	Unique name
Lines	Resistance, Reactance, Nominal Apparent Power, Nominal Voltage, Line type (Regular or Transformer), Starting Bus, End Bus
Loads	Active Consumption, Reactive Consumption, Nominal Apparent Power, Nominal Voltage, Bus
Thermal Plants	Active Production, Reactive Production, Nominal Apparent Power, Nominal Voltage, Voltage Magnitude, Plant Type (Gas, Hydro, Diesel, Steam), Generation Type (PV, PQ or Slack), Bus
Batteries and Photovoltaics	Active Production, Reactive Production, Nominal Apparent Power, Nominal Voltage, Voltage Magnitude, Bus

Wind Turbines	Active Production, Reactive Production, Nominal Apparent Power, Nominal Voltage, Nominal Secondary Voltage, Voltage Magnitude, Generation Type (PM or DFIG), Bus
---------------	--

IEEE Common Data Format

The scenario definition for a grid scale simulation involves the import of a large set of information. An automated data import is supported based on the IEEE Common Data Format (CDF) [21], which is a well-accepted and frequently used, format by the industry and academia. The user can upload a .cdf file containing all bus, lines, transformers and generation/load definitions. An important note is that its standard format regards mainly steady state information; thus, if the user aims to perform dynamic simulation, additional data should be defined.

5.3 Implementation and technology stack

Sequence diagram

INTEMA.grid offers two available interfaces for the data definition and simulation. The first one is provided through the web interface and is presented in Figure 22. After the user logs-in to his/her account, the data definition process is initiating. The user is able to import all necessary data for the case under consideration in corresponding forms. As a next step INTEMA.grid processes the available defined input data, constructs the Modelica code and sends it to the Dymola environment to be simulated. Subsequently, the simulation results return to the platform for post processing and the last step involves the visualization of the results, using figures and Tables.

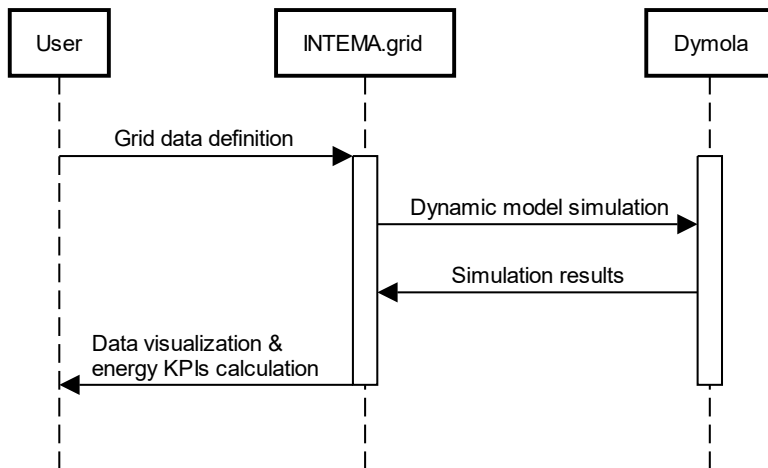


Figure 22: INTEMA.grid sequence diagram using the web interface.

The second option regards the REST API interface, which enables the integration of the tool with the rest of IEPT suite. In this case, the sequence diagram is presented in Figure 23. As the simulation has already been performed, the IEPT can access the specific case using its id and can retrieve the required energy related KPIs (key result of INTEMA.grid platform).

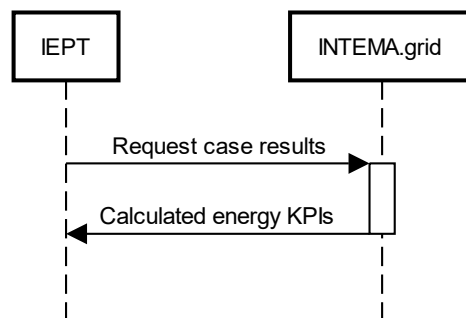


Figure 23: INTEMA.grid sequence diagram for data retrieve.

Data exchange model and synergy with the rest of IEPT tools

INTEMA.grid requires a large set of input data including main grid assets parameters and design points, their topology, and the corresponding loads. The tool utilizes mainly static/historical data for its simulations; thus, there is no need for any real-time connection, minimizing the risks for any security issues. Output of the tool, includes the list of calculated KPIs listed in Table 15 and generally regard:

- production of conventional and renewable generation units,
- energy exchange with the grid,

- storage assets integration (batteries, heating batteries, pumped hydro storage, etc.), and
- aggregated values for the performance assessment of the grid.

The calculated indicators will be considered by the CBA tool for the holistic scenario assessment. CERTH generates and stores in its own storage disks the detailed simulations results. Since these files can become large (several GB), the most important variables calculated are stored in a JSON formatted file. The following naming convention is used “INTEMA_’case_id’_run’run_id’.json”.

An additional data exchange model is under development for the integration of INTEMA.grid and VERIFY. The purpose of this integration is the provision of simulated operation data to the VERIFY platform in the form of hourly-based timeseries. This enables higher granularity of the LCA and LCC calculations performed by VERIFY. The data exchange format is described in detail in subsection 2.2.

Integration: exposed services/ API

Simulation results will be exposed to the IEPT platform using the RESTful API described in subsection 2.2. This way the calculated energy KPIs will be utilized by the rest of the platform for the continuation of the analysis. Additionally, a specific service will be exposed to the VERIFY platform which will provide simulated timeseries for the grid operation and is also described in detail in subsection 2.2.

Model development

INTEMA.grid takes advantage of the extensive Modelica code repository and builds upon well-validated open-source libraries in the domain of energy generation, distribution and storage. The tool uses the PowerSystems (PS) library [22], as well as in-house developed models. Despite its highly technical nature, the present section aims to give an overview of the most important models utilised for the dynamic simulations. Table 18 lists all the main components utilized

in INTEMA.grid dynamic simulation engine, categorizing them on whether they were developed by CERTH or not. Appendix A provides an extensive description for each component. The models will be parameterized with the corresponding grid data provided by the relative partners.

Table 18: Dynamic models development timeframe.

Category	Component	Open-source component	Developed by CERTH	
			Developed in previous projects	Developed during IANOS
Passive grid components	Lines	✓	-	-
	Transformers	✓	-	-
	Loads	✓	-	-
Conventional power plants	Steam power plant	✓	✓	-
	Gas power plant	✓	✓	-
	Diesel power plant	✓	✓	-
Renewable power plants	Photovoltaics	✓	-	-
	Wind turbines	-	✓	-
	Hydroelectric power plants	✓	✓	-
Energy storage	Battery systems	-	✓	-
IANOS technologies	Biobased Saline	-	-	✓
	Hybrid heat pump	-	-	✓
	Flywheel	-	-	✓
	Hybrid Power Electronic Transformer	-	-	✓

	Solid Oxide Fuel Cell	✓	-	✓
	Proton Exchange Membrane Electrolyzer Cell	-	✓	-
	Geothermal Power Plant	-	-	✓
	MicroCHP	✓	-	-
	PCM storage	-	✓	-
	Autogenerative High Pressure Digestion	-	-	✓

Future work for the next reporting period

The previous paragraphs presented the current status of the development for INTEMA.grid. At the same time, the main tool functionalities were defined, and a roadmap has been drawn for the next necessary steps of implementation.

In this context, future work regards two main aspects, partially complementary to each other:

- i) To conduct dynamic simulations for the evaluation of the use cases for the Terceira Island, supporting their dimensioning and their assessment
- ii) The completion of the web application development (including both front and back-end) will assist the automation of the simulation procedure and enable rapid scenario definitions and assessment, primarily for the case of the Fellow islands.

6. VERIFY-D module

6.1 Overview

VERIFY-D is a web-based platform that provides a holistic methodology and evaluation for the LCA and LCC analysis. The platform provides extensive analysis moving beyond the inventory level computations, by assessing the flows in terms of environmental and costing impacts of the city infrastructure elements.

Environmental and costing analysis will cover multiple time periods (25 to 45 years ahead). The VERIFY-D methodology can be further applied at district/island level to model and perform multi-domain LCA analysis, considering the impacts of 1) private and public buildings, 2) transportation infrastructure elements, 3) produced energy of RES and non-RES technologies, 4) energy storage systems.

6.2 Functionalities

The main objective of the platform is to assist in achieving the desired energy transition targets, as they are proposed by the EC [23]. For obtaining more accurate results almost all stages of the value chain are considered (e.g., production, use phase). VERIFY-D as a software tool combines the static LCA-LCC analysis with the dynamic use phase of system components set during the specified lifetime. Input data (either real-time, near real-time or synthetic) from multiple external sources or tools (specifically for synthetic type of data), will be supported through custom API implementation. A large variety of innovative technologies will be included and demonstrated as main scope of IANOS. The operation and environmental assessment of which, in terms of LCA and LCC terms, will be analysed using VERIFY-D. In addition, data repositories will assist the platform functionality, by storing large amount of data in specific ontology frames (e.g., SAREF [24]).

6.3 Implementation and technology stack

In contrast with other LCA-LCC applications, VERIFY-D is based on open-source libraries, frameworks and databases (e.g., Python, Ruby on rails, PostgreSQL etc.) eliminating the dependencies with closed code tools. Extended description for the VERIFY-D platform architecture, functionalities and capabilities is available in IANOS **Deliverable D3.1**⁴.

⁴ The deadline for D3.1 is the same as for this deliverable. Hence, a link cannot be provided.



7. Conclusions

This report presents the overview, architecture, and functionalities of the IEPT suite. The IEPT suite is a holistic tool for the decision-makers in the energy value chain to assess quantitatively from an economic, technical and environmental perspective whether the smart grid interventions provide benefits that exceed the existing BaU operational scenarios. This will diminish the barriers for RES acceptance of the stakeholders, unleashing the decarbonization potential for the islands in the European region.

The backbone of this suite is the CBA component, which receives the input from the LCA/LCC, and the energy and power system modellers, offering quantifiable investment insights. On top of that, the IEPT suite contains a platform that offers crowdfunding services to the investors, thus providing an end-to-end experience for the stakeholders that willing to upgrade their existing energy assets and power system infrastructure, towards a sustainable future. The integral components of the IEPT suite are:

- CBA Component
- VERIFY-D LCA/LCC Platform
- INTEMA.grid System Modeller
- ESSIM Modeller
- CrowdEquity Platform

The IEPT suite will be employed by the LH in order to evaluate the demonstration activities, through the calculation of a set of KPIs, as well as for the CBA of the smart grid interventions in both LH and FI. Finally, the IEPT suite will be used for the scalability and replicability studies of the IANOS solutions in the three FI. The second version of this deliverable (with a due date of M30) will identify and resolve any issues that will emerge during the integration process of the different modules. In addition, it will provide an extensive description of the User Interfaces and will finalize the data exchange format between the IEPT microprocesses.

8. Appendix A- Description of the INTEMA.grid model components

1. Passive grid components

Transmission/distribution lines

The “ π -equivalent” or “T-equivalent” circuit [25] is used to represent the distribution and transmission line with the discretized telegrapher equation. The models are available in PS.

Transformers

The PS library contains models for transformers in different abstraction levels, with the choice of Y-topology or Δ -topology at primary and secondary windings. The impedance values are determined ‘as seen from the terminals’, so that the same parameter values lead to equivalent networks, independently of the choice of the primary and secondary topology. A phase-shift parameter may be used in order to account for the phase difference between the primary and secondary sides, due to the applied winding and polarity scheme. The models provided by the PS library include:

- Ideal magnetic coupling, i.e., zero magnetization current, no stray-impedance.
- Ideal magnetic coupling, but with stray-impedance
- Ideal magnetic coupling, with stray-impedance, but with two secondary windings.
- Stray-impedance and resistance, with non-ideal magnetic coupling, i.e., non-zero magnetisation current and magnetic losses.
- Stray-impedance and resistance, with non-ideal magnetic coupling, but including effective “time-averaged” saturation.

- Stray-impedance and resistance, with non-ideal magnetic coupling, but using a more realistic and computation-intensive model for the magnetic saturation.

All aforementioned models are valuable for the grid representations. Their choice depends on several factors, such as level of detail, grid scale (distribution or transmission), transient phenomenon under consideration etc.

Loads

PS library offers a set of load models, each one corresponding to well documented models in standard literature [26],[27] providing different levels of control on the consumed active and reactive power. In all cases, the user may control the load response by means of an input signal, which may be constant or vary dynamically. Depending on the model, the input signal has the meaning of either the “consumed power” or the “consumed power at nominal voltage”. The response of the loads to varying input signals falls into two categories: either “instantaneous”, where the loads instantaneously change their internal state to meet the specified power requirements, or “asymptotic”, where the loads meet the specified power requirements asymptotically at steady state. Loads with asymptotic response accept as parameter a characteristic response time constant. The following list gathers the most useful load models:

- The dynamic impedance load models a load with impedance and instantaneous response that consumes the specified active and reactive power at nominal voltage. It may induce transient effects.
- The steady-state PQ load adjusts instantaneously its internal impedance so that it consumes the specified active and reactive power, independently of the input voltage. The specified power can vary dynamically. Since it requires the solution of a nonlinear problem at each simulation step, it should only be used for small to medium-scale simulations.
- The PQ inductive or capacitive load dynamically change their internal state to asymptotically meet the power requirements specified by the input signal at all voltages.

- The ZIP load model is an inductive nonlinear load with a characteristic that is a second-degree polynomial of voltage and current. The effective load asymptotically relaxes to the input signal at steady state and nominal voltage

2. Conventional power plants

Steam power plant

Steam turbines of fossil-fuel power plants make up the most of generation capacities of the industrially developed countries [28]. Such plants use coal, lignite, peat, natural gas or diesel as their fuel and produce superheated (approximately 600 °C) and high pressurized steam (approximately 28 MPa) supplying the steam turbine [18]. High-capacity power plants often use multiple stages of steam turbines, i.e., high, intermediate and low-pressure turbines.

A steam power plant model is implemented by CERTH using PS and Modelica standard libraries and is presented in Figure 24. The model receives the active and reactive power setpoints and injects the power to the grid accordingly. In Figure 24, the main components can be identified, namely the turbine-governor subsystem, the automatic voltage regulator and exciter subsystem, the power system stabilized and the synchronous generator. In general, standardised models for the synchronous generation components have been favoured to ensure the validity of the responses.

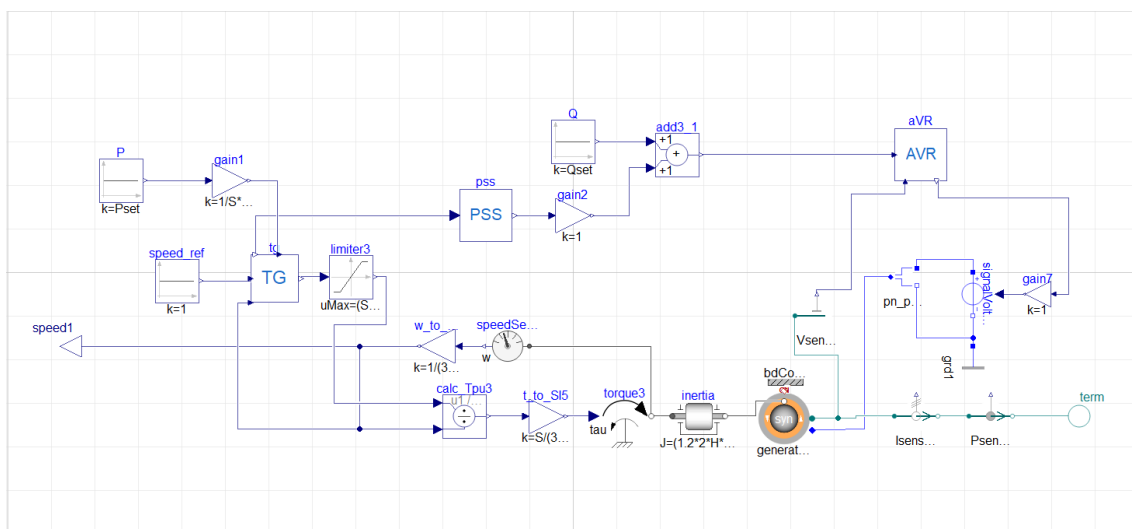


Figure 24: CERTH developed steam power plant model.

The required torque is set and controlled by the turbine's governor. The model of the standardized steam turbine-governor system IEEE-TGOV1 and its parameters are depicted in Figure 25. The model receives as an input the angular velocity of the turbine and outputs the torque that is needed to remain synchronised. Firstly, the speed control ($1/R$) regulates the torque output as ω (grid frequency) oscillates slightly due to load changes. Therefore, the steam flow varies depending on the position of the steam (control valves) introducing time constants/delays to the model. Lastly, a damping coefficient (DT) must be considered as part of the mechanical power dissipated, turning into thermal energy, mainly due to friction. The important parameters that define system's response include the permanent droop R , the time constants T_1 , T_2 , and T_3 , as well as the turbine's damping coefficient DT .

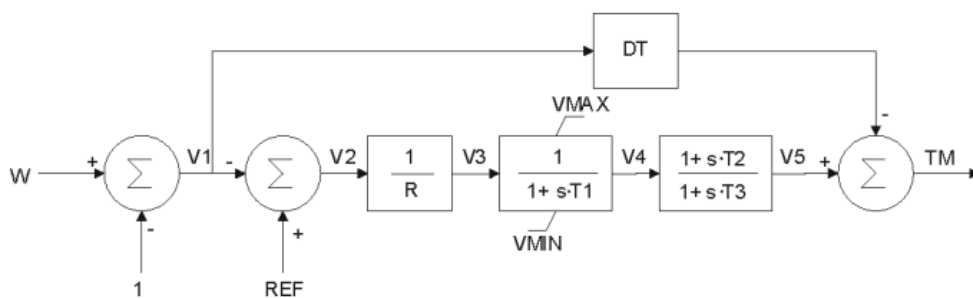


Figure 25: Steam turbine governor IEEE-TGOV [30].

In the generator's side, the terminal voltage is regulated by the automatic voltage regulator, as shown in Figure 26. The model receives as input the generator terminal voltage and outputs the required field voltage. The basic components of an exciter control system comprise three main components, namely the amplifier, the sensor and the exciter. Parameters K_A , K_E , K_F and T_A , T_E , T_F are gains and time constants of the amplifier, the exciter and the sensor, respectively.

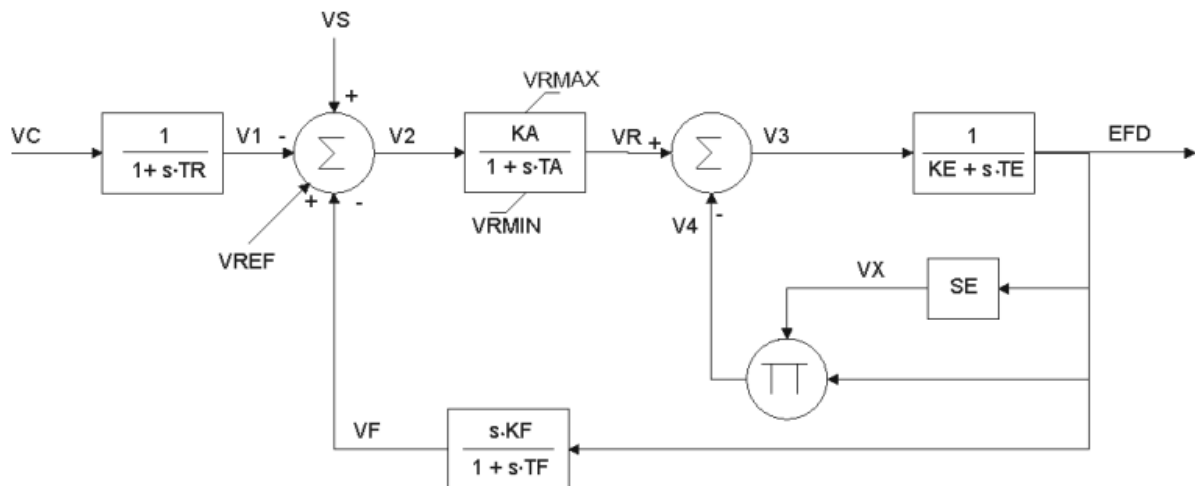


Figure 26: Automatic voltage regulator (AVR) IEEE T1 [31].

Power system stabilizers are responsible for the damping of electromechanical oscillations caused by small disturbances due to load changes. The utilized stabilizer model is depicted in Figure 27. The model consists of the KPSS gain, the wash-out filter (TW time constant), provided to eliminate steady-state bias in the output and a phase compensation block/lead-lag filter (T1 and T2 time constants). The output is limited by VPSSMAX and VPSSMIN voltage limits.

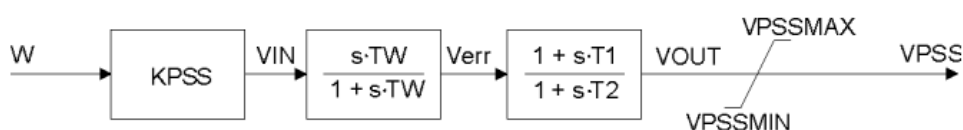


Figure 27: Simple PSS model [32].

Important parameter of this model is TW, known as washout time constant.

Gas power plant

A gas turbine power plant produces a great amount of energy for its size and weight. It comprises of three primary sections, i.e.: the compressor, the combustion chamber and the turbine. The new gas turbines have inlet temperatures close to 1500 °C, pressure ratios of approximately 40:1 and

efficiencies that surpass 45% [33]. A gas turbine model with type GAST governor is depicted in Figure 28.

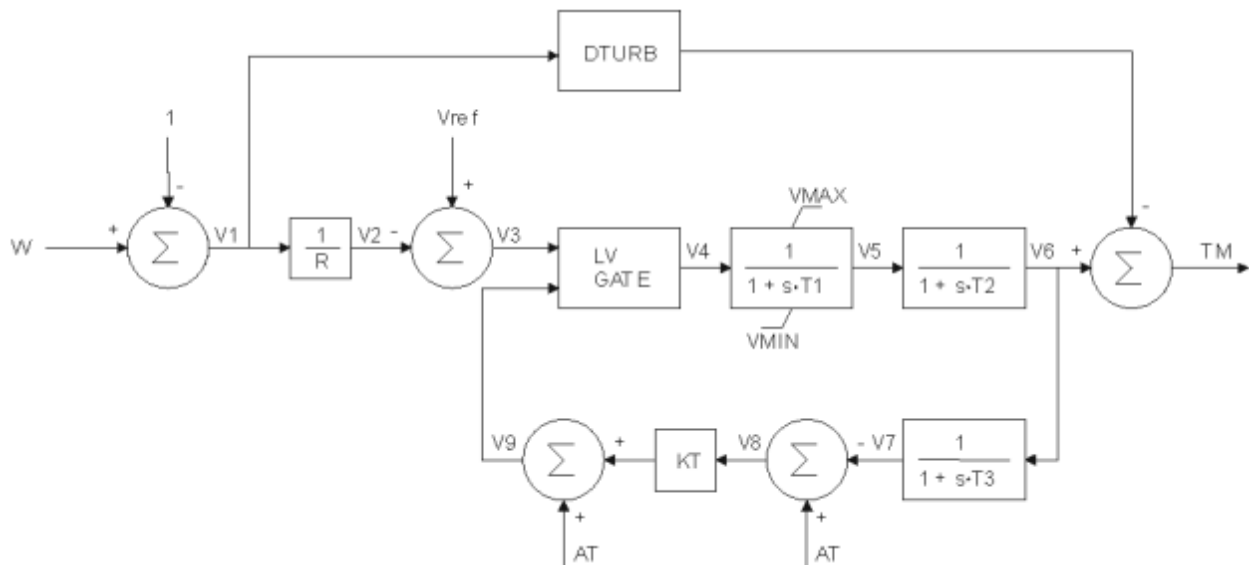


Figure 28: Gas turbine model type GAST [32].

As in all turbine-governors, the permanent droop control ($1/R$) automatically adjusts the produced power (TM) on synchronous units as the grid frequency changes. The lowest value gate (LV) determines how much fuel is to be admitted to the turbine and introduces the time constant $T1$ representing the natural valve positioning time constant of the governor for small disturbances. $T2$ represents the delay due to internal energy storage of the gas turbine engine. Furthermore, there are limits to the rise of exhaust temperatures caused by increasing loads. Thus, the loop with the ambient temperature load limits (AT), the turbine exhaust temperature time constant $T3$ and the temperature limiter gain KT is included in the model. The $DTRUB$ factor must be introduced as well, as the energy extracted from the high temperature, high pressure gas produced by the combustor on the turbine blades is limited.

Diesel power plant

Power plants with reciprocating generators run on cheap heavy fuel oil and have proven to be a reliable and economical means of power generation worldwide. A Modelica diesel power plant model is integrated by CERTH with the synchronous

generator of PS library. The modelling of the diesel power plant follows the one shown in Figure 24, but with a different turbine governor, presented in Figure 29.

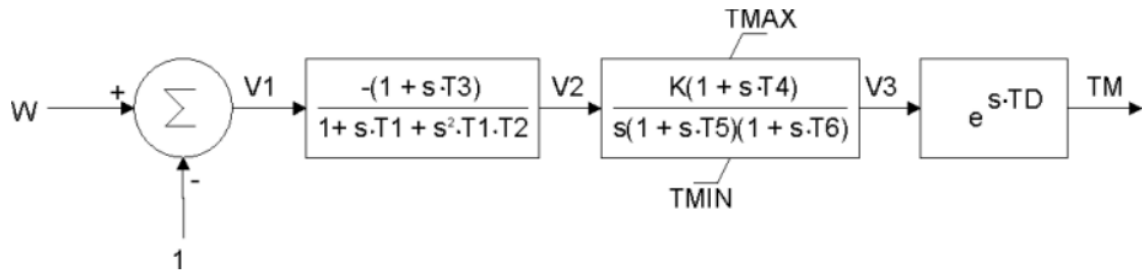


Figure 29: Diesel turbine governor DEGOV [30].

The DEGOV model is employed to simulate torque produced by the diesel engine based on the speed signal from the governor. This model consists of an electric control box with time constants T_1 , T_2 , T_3 , an actuator with T_4 , T_5 , T_6 , and a diesel engine with time delay (TD).

3. Renewable power plants

Photovoltaics

Constituting a popular generation technology, a set of well-validated photovoltaic models have already been developed. The most suitable model for grid level simulations is included in BuildingSystems library. The model applies the Lagrange multipliers method for the calculation of the Maximum Power Point (MPP) at each time. This approach avoids the need for a MPP tracking algorithm (e.g., perturbation and observation, incremental conductance) which introduce discrete (clocked) decision making and burden simulation time.

Wind turbines

Wind turbines use generators to transform kinetic energy into electricity. INTEMA.grid library includes two different types of wind turbine models. One is modeled with a doubly fed induction generator (slip ring), as shown in Figure 30, while the other model presented in Figure 31 is of a direct-driven generator with permanent magnet excitation [34].

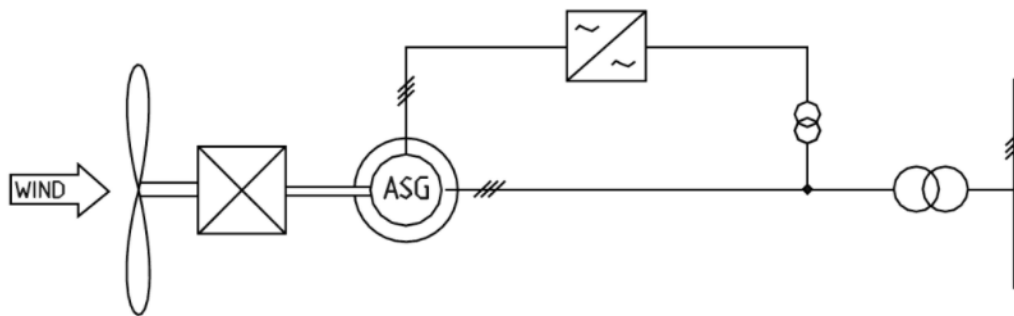


Figure 30: Doubly-fed induction generator with cycloconverter of the experimental Growian wind turbine.

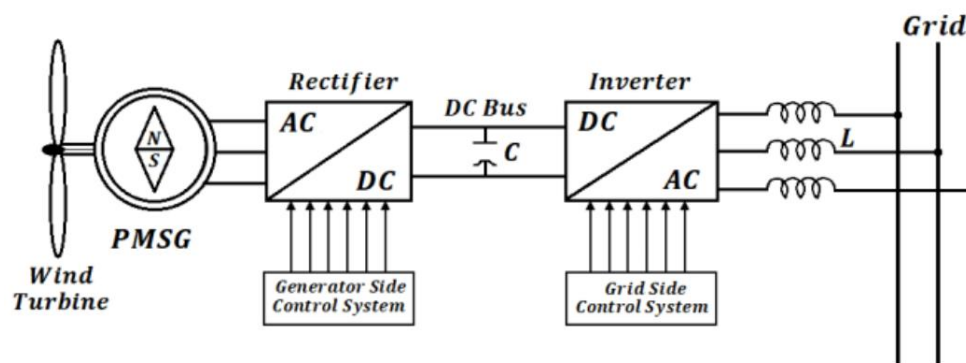


Figure 31: Direct drive permanent magnet synchronous generator wind turbine energy conversion principle scheme.

The models consider for the ambient air velocity profile and calculates the injected power to the grid, according to the following arithmetical expression:

$$P = \frac{1}{2} \times \rho \times A \times v^3 \times C_p$$

where ρ is the density of air, A the area swept by the rotor, C_p is the power coefficient and v is the windspeed at hub height. The power coefficient is expressed by the equation:

$$C_p = c_1 \times (c_2 \times \lambda - c_3 \times \beta - c_4) \times e^{-c_5 \times \lambda} + c_6 \times \lambda$$

$$\lambda = \frac{1}{\lambda + 0,008 \times \beta} - \frac{0,035}{\beta^3 + 1}$$

$$\lambda = \frac{\omega \times R}{v}$$

, where β is the pitch angle, λ is the tip speed ratio, ω the angular velocity, R the radius, v the velocity of the air, and λ_{dai} an auxiliary variable.

Hydroelectric power plants

Hydropower is considered to be the best option for electric power generation, because of its economic and environmental merits. Hydroelectric stations can either be pumped-storage plants, an impoundment facility with a reservoir in upland or mountainous region, or a run-of-river plant [35]. The general model of a hydroelectric turbine-governor system is presented in Figure 32.

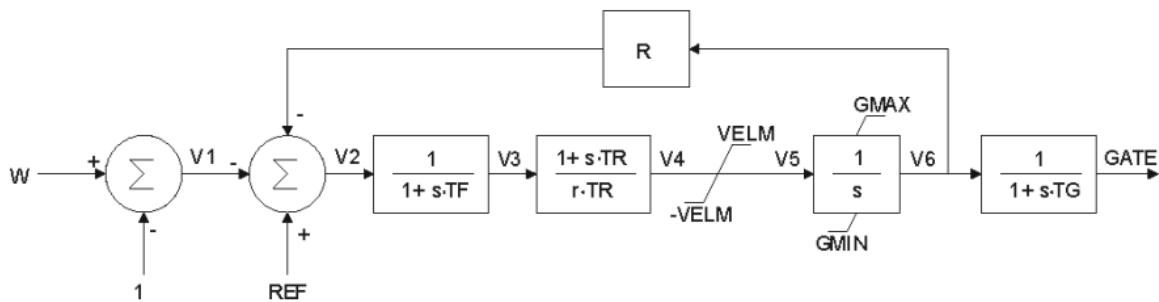


Figure 32: HYGOV hydro turbine-governor model [19]

The input and output of the model are the reference rotor speed (w) and the gate opening (GATE) in p.u.. Parameters R and r represent the permanent and temporary droop, respectively. The model includes a deadband and a lead/lag filter (TF) on the primary speed input. The velocity limit (VELM) is the reciprocal of the time taken for the wicket gates to move from fully open to fully closed. The parameter TG is the representation of the time lags within the governor hydraulic servo system. GMAX is the maximum gate limit setting as established by the operator at the governor console. The minimum gate position (GMIN) is normally zero.

4. Energy storage

Battery systems (Lithium-ion, Lead-acid)

Dynamic models for two types of battery cells have been developed to support the representation of small, medium and large-scale Battery Energy Storage

Systems (BESSs). The two types of batteries are lithium-ion (Li-ion) and lead-acid, which are the most widely used in energy applications. Both have been modelled following the widely approved modelling technique of the Equivalent Circuit Method (ECM), presented in the literature for both Li-ion and Lead-acid batteries [36], [37], [38]. The generalised topology of ECM is depicted in Figure 33.

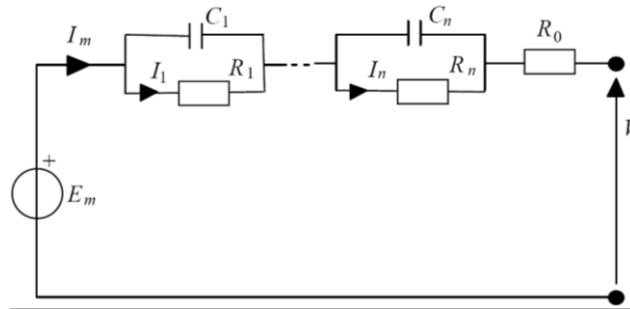


Figure 33: The generalized Equivalent Circuit Model (ECM) [26].

The model focuses on calculating accurately the terminal voltage and state-of-charge (SoC) of each cell of the BESS configuration, based on the instantaneous power extracted to (discharging) or received by (charging) the connected electrical grid. Battery voltage response evolves with a nonlinear behaviour when electric charge is transferred through battery terminals, and this is due to complex electrochemical phenomena (polarisation – diffusion, double layer). These transient phenomena, related to the nonlinearity of voltage response, are captured by a number n of parallel resistor-capacitor (RC) branches. This number is decided by the specific battery application, required accuracy and available computational resources. A resistance connected in series (R_0) is equivalent to instantaneous voltage drop, while open-circuit voltage (OCV or E_m) reflects the available internal energy. All of the above model parameters are dependent on SoC, temperature, current and therefore their values are extracted for varying external conditions from look-up Tables made available from CERTH datasets for many types of battery chemistries. The set of equations solved by the model:

$$\text{SoC}(t) = \text{SoC}(t_0) - \frac{1}{C_{\text{bat}}} \int I_m(t) dt$$

$$I_{C,i} = C_i \frac{dV_i}{dt}$$

$$I_m = I_{C,i} + I_i = C_i \frac{dV_i}{dt} + \frac{V_i}{R_i}$$

$$V_t = E_m - \sum_{i=1}^n V_i - I_m R_0$$

, where C_{bat} denotes battery cell capacity and V_t is the cell terminal voltage. The battery cell model developed in Dymola with 1 RC branch and thermal dependence is presented in Figure 34. The model receives the charge/discharge power setpoint based on specific operation strategy. Then, based on the battery's power balance, the SoC is estimated, and the terminal voltage is given as an output.

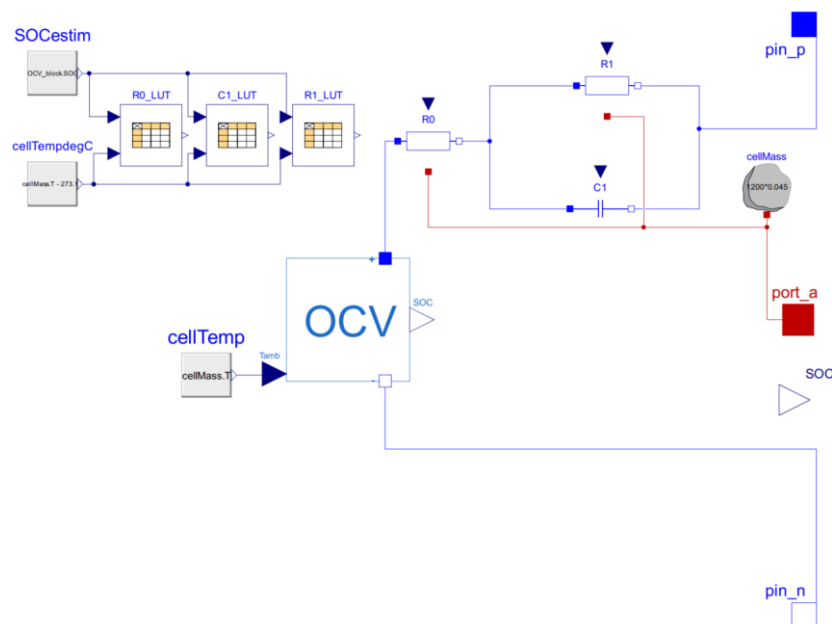


Figure 34: CERTH battery cell model with 1 RC branch and thermal dependence

IANOS technologies

The technologies presented up until now can be considered common in the context of grid modelling, covering the majority of simulation cases. The present section presents the development of specialized dynamic models for the novel IANOS technologies that are installed in the lighthouse islands, i.e., Terceira and

Ameland. In this manner, special effort has been made to properly represent these assets in the INTEMA.grid tool. Focus will be placed on the models developed by CERTH, while adopted open-source models from will be described in brief.

Biobased Saline

SuWoTec energy storage system consists of a sustainable recyclable saltwater gel battery (chemical compound without any lithium or cobalt). Among other novel features, it supports deep discharge without any effect on aging mechanisms, both AC and DC charging/discharging options, as well as guaranteed safety. Technical specifications are available in Table 19.

Table 19: Suwotec battery specifications as provided by the manufacturer

Parameter	Value
Nominal voltage	552 V
Nominal capacity	120 Ah
Maximum charging power capacity	12 kW
Maximum discharging power capacity	15 kW
Charge efficiency	>97% at 20 °C
Discharge efficiency	>96% at 20 °C
Weight	3600 kg

The model used in Dymola software, is based on the battery model of Buildings open-source library, is depicted in Figure 35. As it can be also noticed graphically, the model receives the battery power exchange (P) as an input for each time step and integrates an electrical conductor with the equivalent electrical behaviour in the broader system model, through the positive terminal (at the left of the figure). SoC is also calculated and provided as an output.

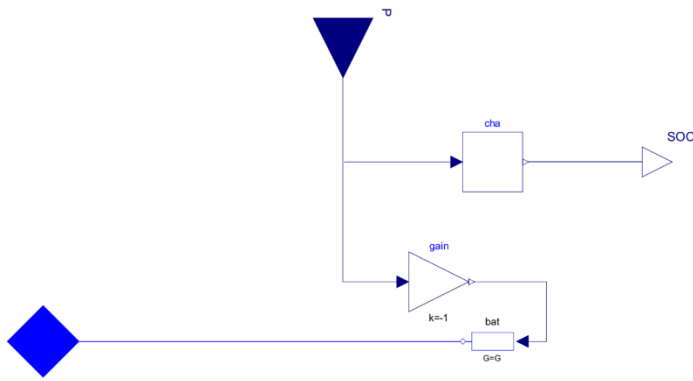


Figure 35: Saline battery model

Hybrid heat pump

This type of heat pump (HP) is supported by a complementary boiler combining the advantages of both technologies to provide the necessary heat to the heating system supply water in the most profitable way. For example, at extremely low ambient temperature the coefficient of performance (COP) of the HP is of really low values and therefore boiler contributes exclusively for load coverage. The model developed for the Hybrid Heat Pump (HHP) is presented in Figure 38. As can be seen, the model receives as input values the temperature setpoint of the heating system and weather conditions. The opportunity to switch HP mode from heating to cooling is also given. Through its terminal ports, integration within other water and air circuits is made possible. On top of the above, a control system adjusts the heat pump and boiler heat contribution depending on the ambient temperature value.

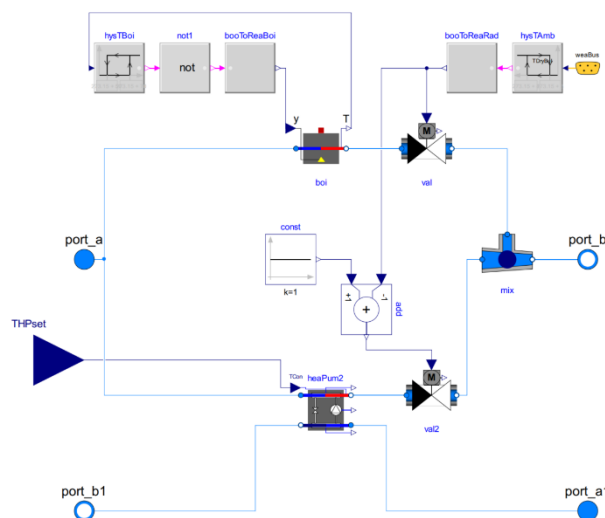


Figure 36: CERth model of hybrid heat pump

The 135 HHPs installed in Ameland involve 7 different manufacturer models, which are listed in Table 20.

Table 20: Number of installed HHP units in 135 Ameland apartments per manufacturer model

HHP model	Number of installed units
Remeha Elga Ace	82
Remeha Tzerra HP 40-5c	37
DAIKIN EHYHBH05AV32	8
DAIKIN Altherma	6
Remeha Tzerra HP 390-5c	1
Mitsubishi Ecodan	1
Vaillant	1

Parameters of the developed model are modified for each application to meet the design specifications of each model. However, since most of the installed units are Elga Ace HHPs, a verification process has been setup for the particular machine. Available technical data from the manufacturer are given in Table 21.

Table 21: Technical specifications of Elga Ace HHP

Parameter	Value
HP heating capacity	4.14 kW _{th}
HP cooling capacity	2.78 kW _c
Nominal COP	4.5
Nominal EER	4.28
Boiler capacity	24 kW _{th}
Boiler fuel type	Natural gas
External unit water operating temperature range (heating)	18 °C/ 55 °C
External unit water operating temperature range (cooling)	17 °C/ 25 °C
External unit air operating temperature range (heating)	-15 °C/ 20 °C
External unit air operating temperature range (cooling)	10 °C/ 45 °C
Nominal water volume flow rate	0.71 m ³ /h

Nominal air volume flow rate

1800 m³/h

To move forward with HHP verification the Elga Ace HP performance in heating mode has been compared against values given by the manufacturer datasheet under varying operating conditions [39]. These conditions are listed in Table 22.

.Table 22: Elga Ace HHP nominal COP and heating power values for varying outdoor air temperature

Outdoor air temperature (°C)	Nominal COP	Nominal Power (kW _{th})
-7	2.77	2.8
2	4.04	2.7
7	6.48	1.7
12	9.09	2

Through this procedure the HP model results have been verified since the output thermal power and COP values have been compared against specified data at multiple points throughout the entire allowed operating range.

Figure 37 shows the obtained simulation results of COP value against all possible ambient temperatures. To evaluate the model accuracy, the sum squared error between simulated and measured values expressed as a percentage of nominal COP (4.50) has been calculated and is equal to 1.96 %. Detailed results are listed in Table 23.

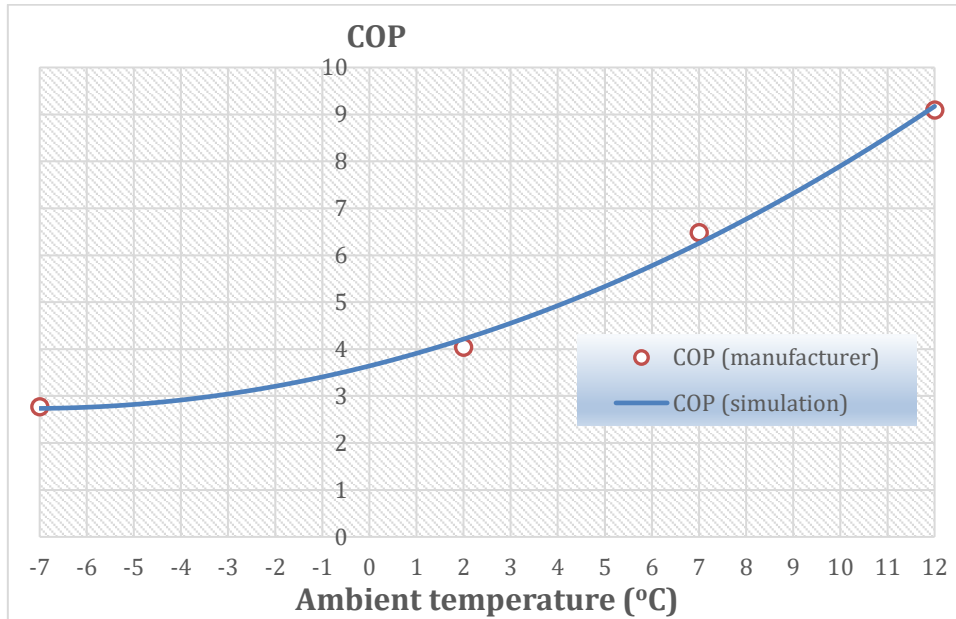


Figure 37: COP simulation results against data provided by manufacturer

Table 23: Elga Ace HP COP results comparison against available manufacturer data

Ambient air temperature in °C	COP (measured)	COP (simulated)	Error	Squared Error
-7	2.770	2.737	0.033	0.001
2	4.040	4.214	-0.174	0.030
7	6.480	6.257	0.223	0.050
12	9.090	9.172	-0.082	0.007
Sum squared error - SSE				0.088
SSE/(Nominal Power) %				1.96%

Figure 38 shows the extracted simulation results of heating power value against all possible ambient temperatures. The sum squared error as a percentage of nominal heating power (4.14 kW_{th}) has also been calculated and is equal to 7.25 %. Detailed results are listed in Table 24.

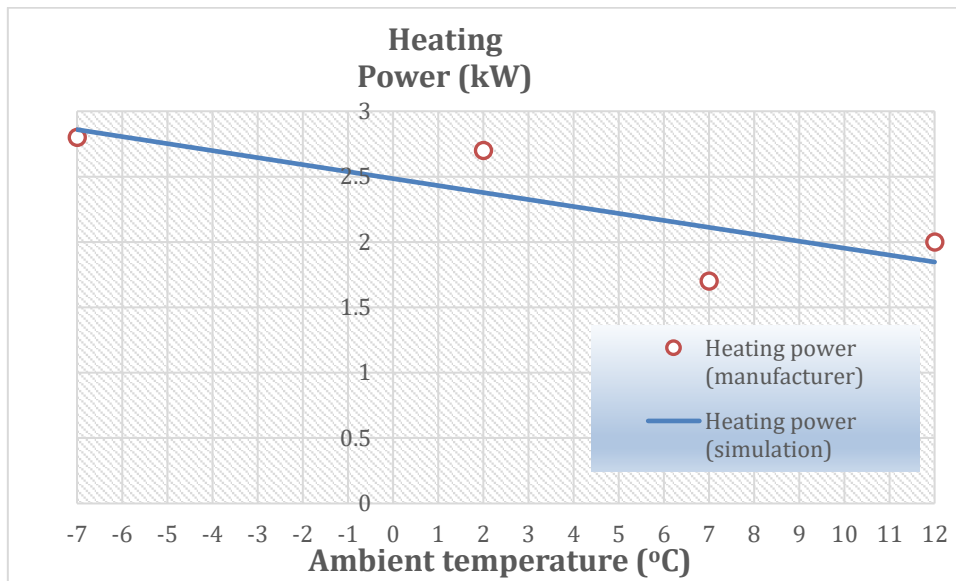


Figure 38: Heating power simulation results against data provided by manufacturer

Table 24: Elga Ace HP heating power results comparison against available manufacturer data

Ambient air temperature in °C	Heating power in kW (measured)	Heating power in kW (simulated)	Error	Squared Error
-7	2.800	2.859	-0.059	0.004
2	2.700	2.378	0.322	0.104
7	1.700	2.112	-0.412	0.170
12	2.000	1.847	0.153	0.023
Sum squared error - SSE				0.300
SSE/(Nominal Power) %				7.25%

Flywheel

Flywheel Energy Storage Systems (FESS) store energy in rotating masses. The inertia and speed of the rotating mass, dictate the amount of kinetic energy that is stored as rotational energy [40]. The stored rotational energy is given by

$$E = \frac{1}{2} J \omega^2,$$

where J is the moment of inertia and ω is the angular velocity of the flywheel.

Flywheel models can be integrated with asynchronous machines, for large



and relatively slow flywheels, whereas synchronous permanent magnet motors are more suitable for small and fast-turning flywheels. The implemented FESS model is presented in Figure 39 and includes the rotor, a permanent magnet generator and two inverters in a back-to-back configuration.

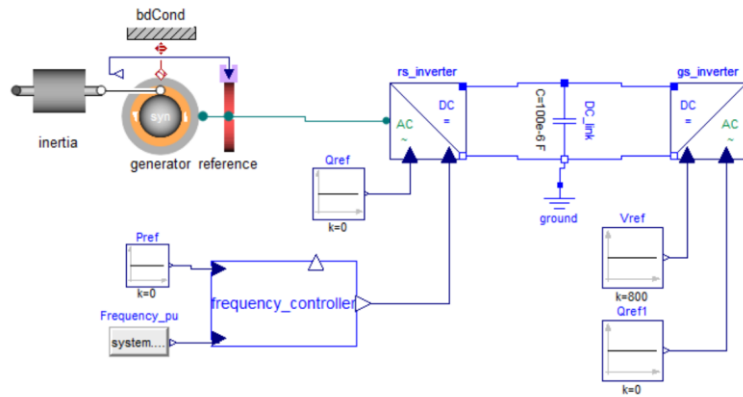


Figure 39. Developed flywheel energy storage model.

FESSs are used in grid stability applications, as they can provide large power for a short duration, usually during a contingency event (e.g., loss of generation, short-circuit). The novel FESS of Teraloop will be installed in Terceira. Table 25 lists the main parameters of the particular system. Currently, a verification process is undergoing to ensure that the developed model represent accurately Teraloop system.

Table 25: Teraloop flywheel system parameters.

Parameter	Value
Capacity (kWh)	3 kWh
Power rating (kW)	100 kW
Roundtrip efficiency (%)	97 %
Depth of discharge (%)	100 %
Discharge duration (minutes)	1,8 minutes
Installation type	Array - containerized or other.
Capital cost / unit	€100,000 + installation fees.

Hybrid Power Electronic Transformer

The Hybrid PET (HPET) is a special type of transformer that combines a conventional Low-Frequency Transformer (LFT) with a Back-to-Back (BtB) AC to AC electronic converter. The BtB converter is able to modulate the voltage on the low field side (LFS), acting on each phase independently in order to improve the

quality of the voltage at the LFS. Although the efficiency of a typical BtB converter is considerably lower than that of the LFT transformer, the overall efficiency of the HPET transformer is minimally affected since the electronic converter is designed to operate at a fraction of the LFT rated power.

The HPET Modelica model, developed by CERTH, uses the PS Library and is mainly kept at a medium to high level of abstraction, in order to mitigate the computational cost of simulations, in line with the assumptions adopted in [41]. The internal controller acts towards minimizing the error between the voltage at an external setpoint, defined by the user and an ideally balanced signal (in dq0 representation):

$$V_{\text{ref}} = \begin{bmatrix} \sqrt{3/2}V_0 \cos(\phi(t)) \\ \sqrt{3/2}V_0 \sin(\phi(t)) \\ 0 \end{bmatrix}$$

Phase locking between the controller internal phase and the phase at the reference point guarantees that overcorrection by the BtB converter is avoided, in order to maximize the HPET efficiency. Figure 40 presents an example of HPET usage. A three-phase generator is used to drive a three-phase asymmetric load. A relay controls the dispatch of an additional asymmetric load. The BtB converter located in the middle of the figure regularizes the voltage at the load terminal by controlling each phase independently. Table 26 presents the parameters for the HPET provided by EFACEC following IEC 60076 standard. A verification procedure has been initiated, the results of which will be included in the next reporting period.

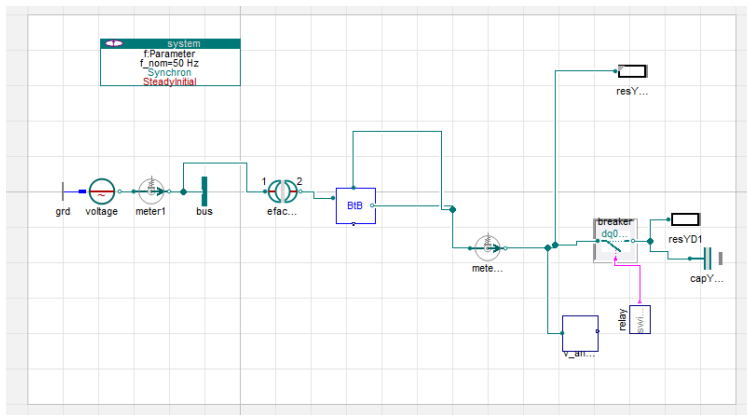


Figure 40: Modelica example of a hybrid power electronic transformer driving a dynamically changing asymmetric load.

Table 26: Parameters of the hybrid transformer according to IEC 60076.

Parameter	Value	
Nominal power	400 kVA	
# Phases	3	
Frequency	50 Hz	
Connection	Dyn5	
Short Circuit Impedance	0.04	
Cooling type	KNAN	
Fluid	ESTER	
Transformer losses	TIER 2 ECODESIGN	
	High Voltage Side	Low Voltage Side
(Off circuit tap changer)	15750 V	400 ±12 % V on load continuous voltage regulation (independently for each phase) with power electronics. The voltage is adjusted by an external setpoint provided by the DSO.
	15375 V	
Nominal Voltage	15000 V	
	14625 V	
	14250 V	
Nominal Current	15.4 A	550 A
Insulation Level:	LI 95 AC 38	LI 30 AC 10

Solid Oxide Fuel Cell

A Modelica model of a domestic Solid Oxide Fuel Cell (SOFC) with heat recovery has been developed based on the TransiENT and ClaRa libraries.

Typical SOFCs are based on the electrochemical reaction of hydrogen (H₂) oxidation on the anode with oxygen ions (O₂⁻). A minimal operational temperature of approximately 600 °C is required for the O₂⁻ transport through the electrolyte. Instead of using H₂ as fuel, CH₄ can also be used after being reformed with steam to produce H₂ and CO:



Reforming can take place in an external component or internally on the anode [42].

CERTH has developed a Modelica model for the “BlueGen” (BG) residential SOFC system generator, with a maximum of 2 kW electrical output which is modulated by the residential load demands [43]. Any load demands beyond 2 kW are assumed to be met by the grid. The system is fuelled by a mixture of steam and methane, which is internally reformed on the anode, utilizing the heat generated by the electrochemical reaction to produce the required hydrogen. Waste heat from the SOFC operation can be recovered as hot water, while the heat generated from the anode exhaust gas afterburner is used to preheat the fuel and generate steam.

The developed model has been based on components provided by the TransiENT and ClaRa libraries, while special care has been taken to guarantee that the model is compatible with components of the PS library (Figure 41). Internal reforming is modeled by bringing the “SteamReformer” model provided by the TransiENT library in thermal contact with the anode of the FC component, which is used to model the SOFC electrochemical reaction. The SOFC is represented by the block of components on the left and the load driven by the SOFC by the block of components on the right. Internal reforming is modelled by bringing the SteamReformer model provided by the TransiEnt library in thermal contact with the anode of the FC component, which is used to model the SOFC electrochemical reaction. The SOFC is used to drive a dynamically changing load (middle right). A power controller (bottom left) drives the SOFC in order to minimize the power flow from the external grid to the load.

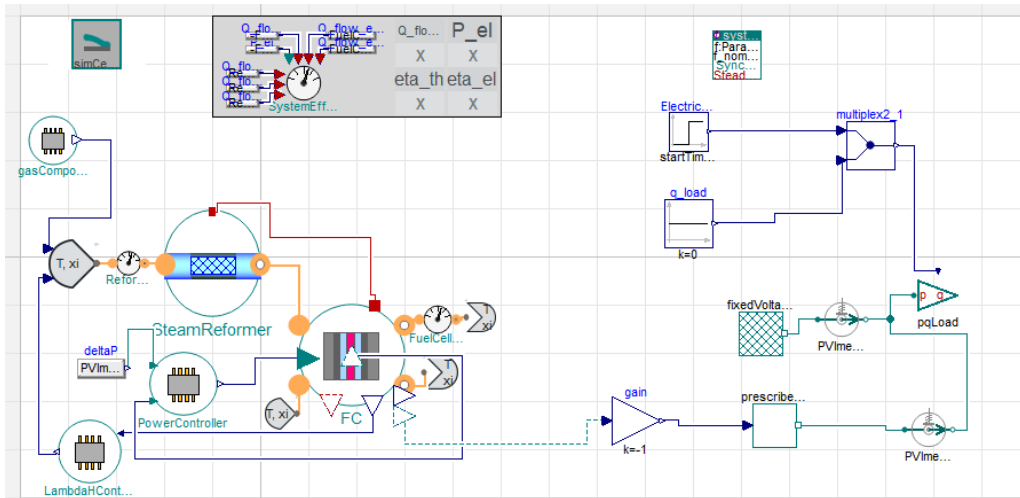


Figure 41: Modelica example featuring a SOFC model operating in conjunction with components of the PowerSystems library.

At the moment, all major modules of the BG system have been accounted for in the Modelica model, with the exception of the exhaust gas afterburner. With this module missing, the calculated efficiencies for the model are lower than the efficiencies reported for the BG system (Figure 42).

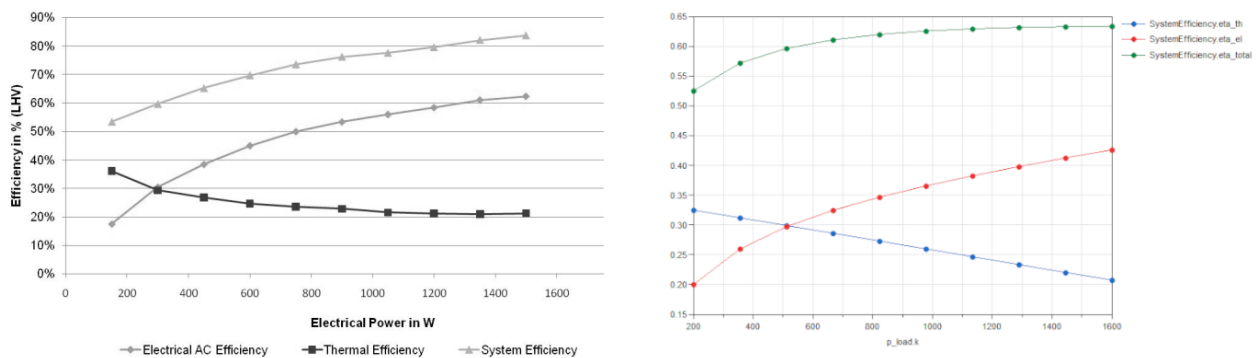


Figure 42: Comparison of the Modelica efficiencies with the experimental data. Left: BG efficiencies as a function of the generated power in W (adapted from [32]). Right: As in left, but for the efficiencies calculated for the Modelica model.


Proton Exchange Membrane Electrolyzer Cell

Electrolyzers are devices able to produce almost pure hydrogen and oxygen with very small traces of contaminants that can be used to serve the requirements of

renewable energy systems. Among the other alternatives PEMs have the advantage of being compact and simple in operation, free of hazardous chemicals, and able to produce hydrogen with high levels of purity [44].

A standalone Modelica model of a Proton Exchange Membrane (PEM) electrolyzer cell has been developed by CERTH. The model depends only on the Modelica standard library. The developed model is based on a one-dimensional, semi-static description, where the transient electrical response is ignored, following the modelling approach in [44], [45]. This approach is justified by the experimentally established fast transient electrical response of existing PEM cells.

Geothermal Power Plant

A thermodynamic model for the Pico Alto geothermal binary cycle power plant located in Terceira [46] has been developed. The plant's binary cycle consists of high enthalpy (over 150 °C) geothermal heat source in steam and brine phases. The secondary cycle is an Organic Rankine Cycle (ORC) with a capacity of 3.5 MW. The plant operates in a binary cycle for the utilization of the geothermal heat source. The first cycle refers to the geothermal fluid (steam & brine) and begins with the fluid entering the system from the production wells and ends with the fluid entering the reinjection well. The second cycle is the Organic Rankine Cycle (ORC) with cyclopentane (C₅H₁₀-) as the working fluid.

The flow diagram of the binary cycle is shown in Figure 43. In each hot well, the geothermal fluid mixture is separated into two discrete phases (steam & brine) and enters the power plant shell and tubes heat exchangers (two brine preheaters and one steam preheater in parallel and one evaporator in series with the preheaters). The nominal operating conditions of the geothermal cycle are presented in Table 27. Furthermore, both steam and brine enter the reinjection well with a temperature value over 95 °C managed by the plant's control system.

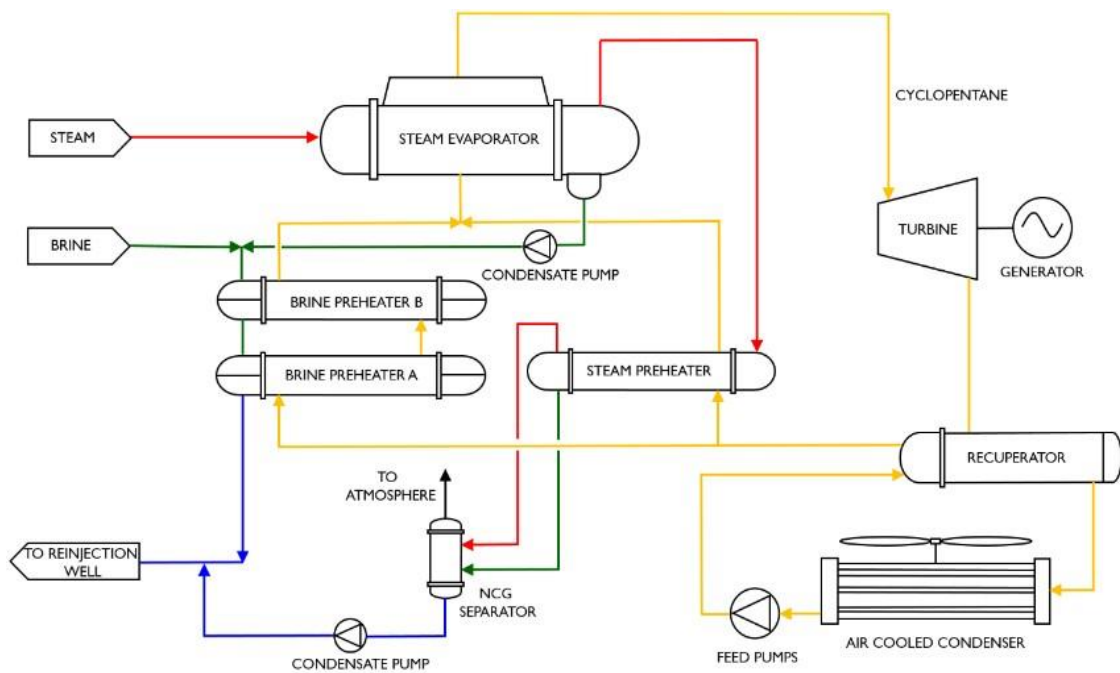


Figure 43: Two-phase recuperated ORC flow diagram [46].

Table 27: Operating conditions of the geothermal plant [46].

	Mass flow rate (kg/s)	Inlet Temperature (°C)	Absolute Pressure (bar)
Steam	9.6	160	5.5
Brine	14	175	10

The liquid cyclopentane is pressurized and driven from the air-cooled condenser to the recuperator tube side, where it will be initially heated by the cyclopentane vapour stream from the turbine outlet. Then it will flow through steam and brine preheaters, where it will be heated until it reaches saturation conditions and then it will enter the steam evaporator where vapour cyclopentane will be produced. Then the saturated vapour will be expanded in the axial inflow - radial outflow turbine. Afterwards, the cyclopentane vapour will flow into the recuperator shell side and finally to the condenser where it will be air-cooled and condensed, reinitiating the cycle. As operation parameters and the thermodynamic states throughout the ORC cycle were not available, the dynamic model was tuned in accordance to the operating data available in the literature (for the specific plant)

[47]–[51], changed parameters iteratively until numerical and physical stability was reached.

The model of the plant is shown in Figure 44. The bottom half of the model represents the ORC with cyclopentane as the working medium. At the upper side of the figure, the geothermal cycle is shown, consisting of the brine and steam flow circuits.

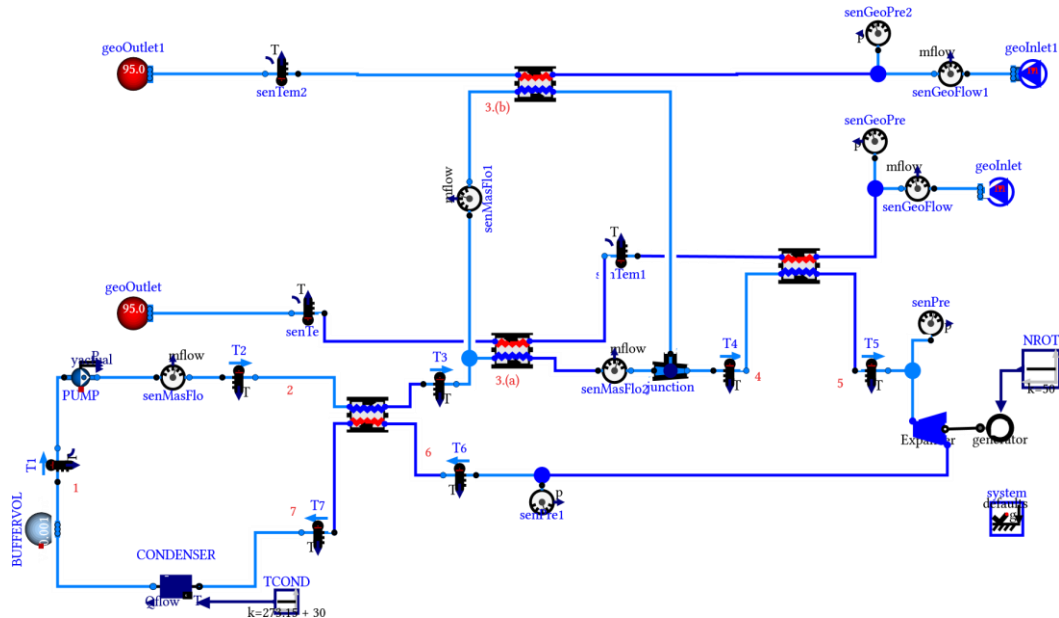


Figure 44: Developed dynamic model for the geothermal power plant in Pico Alto.

The detailed thermodynamic model enables the transient analysis of the plant under consideration. A low order model will be developed based on the insights gained for the integration in the overall island power system model to avoid computational barriers.

MicroCHP

To proceed with micro – Combined Heat and Power (micro-CHP) representation the CHP model from the open-source library AixLib has been used. This model supports the calculation of both thermal and electrical output power of the unit based on two possible strategies. The first is to satisfy the thermal comfort constraint of a specific temperature setpoint and the second is to cover an electrical load demand profile provided as model input. For both control strategies, the necessary unit capacity is calculated and through Table-based

analysis, all CHP variables are given as outputs. These include electrical power, thermal power and fuel consumption. Advanced control algorithms make sure that operation takes place considering the design and operating constraints of the unit, such as maximum available or minimum allowed capacity.

PCM storage

Phase-change Material (PCM) storage technology has been modelled with the utilisation of CERTH in-house custom models. These models have undergone evaluation in three EU projects (AMADEUS [52], Plug-N-Harvest [53], and SMILE [18]) and can therefore be considered validated and reliable. A graphical representation of the model is available in Figure 45.

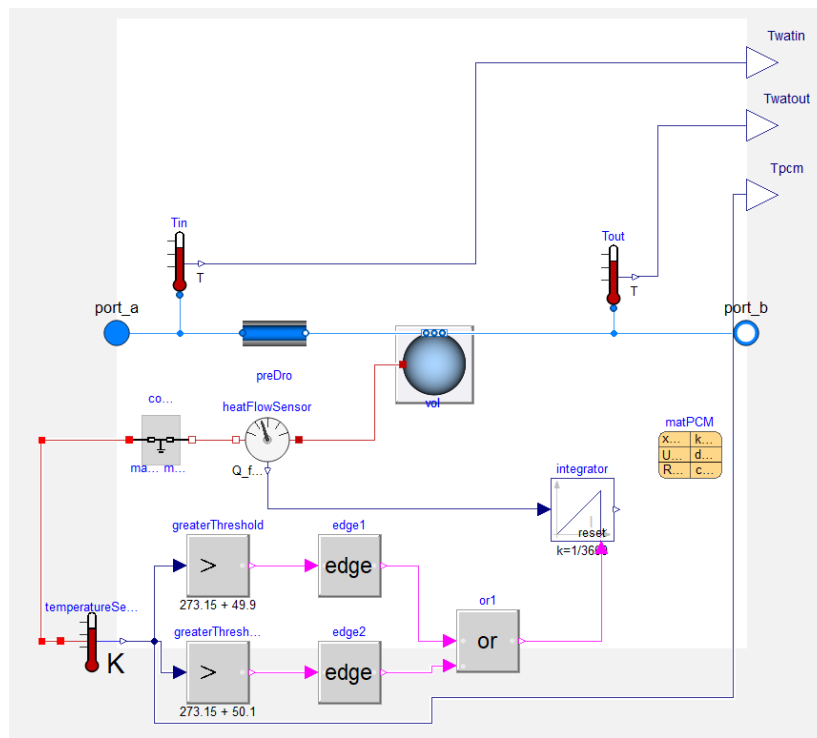


Figure 45: CERTH PCM model

Autogenerative High Pressure Digestion

An Autogenerative High Pressure Digestion (AHPD) model has been developed by CERTH in Aspen Plus. The AHPD model is an adaptation of Rajendran et al. (2013) process model for anaerobic digestion [54]. Figure 46 presents the nominal operation point of the developed model in a diagram form.

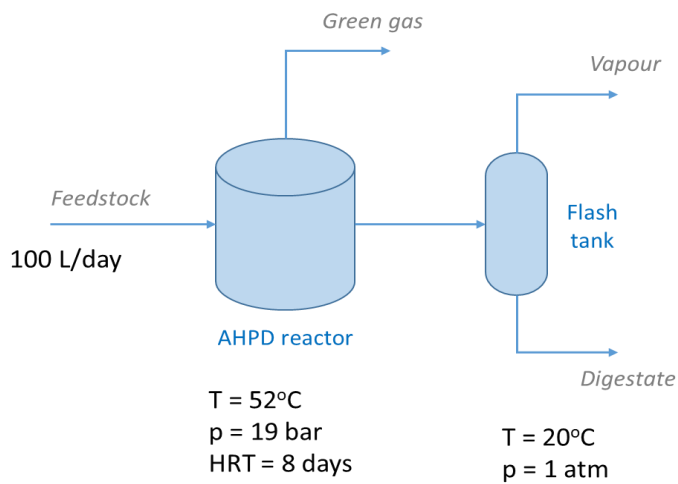


Figure 46: Flow diagram of the Autogenerative High Pressure Digestion process

The feedstock composition was extracted from literature [55] (secondary sludge composition) adapted accordingly and presented in Table 28.

Table 28: Feedstock composition

Substance	Composition (wt%)
Water	99.2
Total solids	0.08
Cellulose	23.59
Hemicellulose	10.72
Soluble proteins	16.22
Insoluble proteins	9.73
Triolein	0.48
Tripalmitin	0.48
Sn-1-Palmito-2-Linolein (C ₃₇ H ₆₈ O ₅)	0.48
Dextrose	10.72
NH ₃	1.07
Inerts	26.50

The reactor volume was considered 858.3 L (Vapor/Liquid volume ratio= 1/16).

Table 29 presents the stream results in mass fractions. Vapor streams are also presented in mol fractions.

Table 29: Simulation results for the Autogenerative High Pressure Digestion

	Feedstock	Green Gas		Vapour		Digestate
	Mass fraction	Mass fraction	Mole fraction	Mass fraction	Mole fraction	Mass fraction
WATER	0.992	0.00812	0.008368	0.015244	0.024004	0.992784
CO ₂	0	0.208051	0.087765	0.661297	0.426248	0.000761
CH ₄	0	0.778651	0.901081	0.300306	0.531007	1.37E-05
GLYCEROL	0	0	0	0	0	7.63E-06
DEXTRROSE	0.000858	0	0	0	0	7.19E-07
PROPIONIC ACID	0	4.06E-06	1.02E-06	5.42E-06	2.08E-06	0.000332
ISOBUTYRIC ACID	0	1.22E-06	2.57E-07	4.44E-06	1.43E-06	0.000351
ISOVALERIC ACID	0	1.24E-06	2.25E-07	1.77E-06	4.91E-07	6.20E-05
NH ₃	8.58E-05	2.88E-07	3.14E-07	1.76E-06	2.93E-06	5.83E-07
NH ₄ ⁺	0	0	0	0	0	0.00031
ETHYL-CYANOACETATE	0	0	0	0	0	0.000165
HYDROGEN	0	1.35E-05	0.000124	4.36E-06	6.14E-05	0
H ₂ S	0	0.004643	0.002529	0.021832	0.018171	7.51E-05
BENZENE	0	0.000459	0.000109	0.001187	0.000431	8.02E-06
HCO ₃ ⁻	0	0	0	0	0	0.000988
HS ⁻	0	0	0	0	0	1.90E-05
CELLULOSE	0.001887	0	0	0	0	0.000567
HEMICELLULOSE	0.000858	0	0	0	0	0.000344
TRIOLEIN	3.84E-05	0	0	0	0	3.85E-06
TRIPALMITIN	3.84E-05	0	0	0	0	3.85E-06
SN-1-PALMITO-2-LINOLEIN (C ₃₇ H ₆₈ O ₅)	3.84E-05	0	0	0	0	3.85E-06
XYLOSE	0	0	0	0	0	9.76E-05
ETHANOL	0	5.54E-05	2.23E-05	0.000115	7.10E-05	0.00043
SOLUBLE PROTEIN (C ₁₃ H ₂₅ O ₇ N ₃ S)	0.001298	0	0	0	0	0.00013
INSOLUBLE PROTEIN (C _{4.39} H ₈ NO _{2.1})	0.000779	0	0	0	0	0.00039
ACETATE	0	0	0	0	0	2.45E-05
INERT	0.00212	0	0	0	0	0.002123
Total Mass flow (kg/day)	99.88	0.0799		0.0807		99.72

The green gas Yield is 109.1 Nm³ green gas / tons dry input and the CH₄ content in green gas is 70.8% of the total CH₄ produced. A parametric investigation has been performed on the developed model in ASPEN plus, sweeping key parameters across the range of values the plant is designed to operate. The resulted operation “maps” were imported in Modelica, adequately encapsulating the system’s behaviour while also avoiding computational burdens.



9. References

- [1] "(5) Software Systems Architecture: Working With Stakeholders Using Viewpoints and Perspectives | Request PDF." https://www.researchgate.net/publication/233747780_Software_Systems_Architecture_Working_With_Stakeholders_Using_Viewpoints_and_Perspectives (accessed Feb. 22, 2022).
- [2] "ISO - ISO/IEC/IEEE 42010:2011 - Systems and software engineering — Architecture description." <https://www.iso.org/standard/50508.html> (accessed Feb. 22, 2022).
- [3] "Welcome To UML Web Site!" <https://www.uml.org/> (accessed Feb. 22, 2022).
- [4] "API Documentation & Design Tools for Teams | Swagger." <https://swagger.io/> (accessed Feb. 22, 2022).
- [5] "What are microservices?" <https://microservices.io/> (accessed Feb. 23, 2022).
- [6] "Use Cases | Docker." <https://www.docker.com/use-cases> (accessed Feb. 23, 2022).
- [7] "EUR-Lex - 32013R0347 - EN - EUR-Lex." <https://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex%3A32013R0347> (accessed Feb. 25, 2022).
- [8] "Cost Benefit Analysis." <https://tyndp.entsoe.eu/cba> (accessed Mar. 01, 2022).
- [9] "Smart grid cost-benefit analysis | JRC Smart Electricity Systems and Interoperability." <https://ses.jrc.ec.europa.eu/smart-grid-cost-benefit-analysis> (accessed Mar. 01, 2022).
- [10] "ESDL Documentation - ESDL." <https://energytransition.gitbook.io/esdl> (accessed Feb. 28, 2022).
- [11] "ESDLMapEditorESSIM/docker-toolsuite: All information to install, setup and run the ESDL MapEditor and ESSIM toolsuite on your local machine." <https://github.com/ESDLMapEditorESSIM/docker-toolsuite> (accessed Feb. 28, 2022).
- [12] T. Brown, J. Hörsch, and D. Schlachtberger, "{PyPSA}: {Python} for {Power} {System} {Analysis}," *Journal of Open Research Software*, vol. 6, Jan. 2018, doi: 10.5334/jors.188.
- [13] L. Thurner *et al.*, "pandapower - an {Open} {Source} {Python} {Tool} for {Convenient} {Modeling}, {Analysis} and {Optimization} of {Electric} {Power} {Systems}," *IEEE Transactions on Power Systems*, vol. 33, no. 6, pp. 6510–6521, Nov. 2018, doi: 10.1109/TPWRS.2018.2829021.
- [14] A. D. Dominguez-Garcia, S. T. Cady, and C. N. Hadjicostis, "Decentralized optimal dispatch of distributed energy resources," in *2012 {IEEE} 51st {IEEE} {Conference} on {Decision} and {Control} ({CDC})*, Dec. 2012, pp. 3688–3693. doi: 10.1109/CDC.2012.6426665.
- [15] J. A. Taylor, *Convex {Optimization} of {Power} {Systems}*; 1st ed. Cambridge University Press, 2015. doi: 10.1017/CBO9781139924672.



- [16] A. J. Conejo and L. Baringo, "Unit {Commitment} and {Economic} {Dispatch}," in *Power {System} {Operations}*, Cham: Springer International Publishing, 2018, pp. 197–232. doi: 10.1007/978-3-319-69407-8_7.
- [17] P. Iliadis, S. Ntomalis, K. Atsonios, A. Nesiadis, N. Nikolopoulos, and P. Grammelis, "Energy management and techno-economic assessment of a predictive battery storage system applying a load levelling operational strategy in island systems," *International Journal of Energy Research*, vol. 45, no. 2, pp. 2709–2727, Oct. 2020, doi: 10.1002/er.5963.
- [18] "{SMILE} {H2020}." Accessed: Feb. 15, 2022. [Online]. Available: <https://www.h2020smile.eu/>
- [19] "Renaissance {H2020} project towards sustainable energy communities." Accessed: Oct. 02, 2022. [Online]. Available: <https://www.renaissance-h2020.eu/>
- [20] E. Molin, "Comparison of {Single}-{Page} {Application} {Frameworks} - {A} method of how to compare {Single}-{Page} {Application} frameworks written in {JavaScript}," Stockholm, Sweden, 2016.
- [21] W. Group, "Common {Format} {For} {Exchange} of {Solved} {Load} {Flow} {Data}," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-92, no. 6, pp. 1916–1925, Nov. 1973, doi: 10.1109/TPAS.1973.293571.
- [22] R. Franke and H. Wiesmann, "Flexible modeling of electrical power systems -- the {Modelica} {PowerSystems} library," Mar. 2014, pp. 515–522. doi: 10.3384/ecp14096515.
- [23] "A European Green Deal | European Commission." https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed Mar. 08, 2022).
- [24] "SAREF: the Smart Applications REFerence ontology." <https://saref.etsi.org/core/v3.1.1/> (accessed Mar. 08, 2022).
- [25] M. E. El-Hawary, *Electrical power systems: design and analysis*, Rev. print. New York: Institute of Electrical and Electronics Engineers, 1995.
- [26] P. Kundur, N. J. Balu, and M. G. Lauby, *Power system stability and control*. New York: McGraw-Hill, 1994.
- [27] A. Arif, Z. Wang, J. Wang, B. Mather, H. Bashualdo, and D. Zhao, "Load {Modeling} – {A} {Review}," *IEEE Transactions on Smart Grid*, p. 1, 2017, doi: 10.1109/TSG.2017.2700436.
- [28] A. S. Leizerovich, *Steam turbines for modern fossil-fuel power plants*. Lilburn, GA : Boca Raton, FL: Fairmont Press ; Distributed by Taylor & Francis/CRC Press, 2008.
- [29] X. Wu, J. Shen, Y. Li, and K. Y. Lee, "Steam power plant configuration, design, and control," *WIREs Energy and Environment*, vol. 4, no. 6, pp. 537–563, Nov. 2015, doi: 10.1002/wene.161.

- [30] NEPLAN, “Standard {Dynamic} {Turbine}-{Governor} {Systems} in {NEPLAN} {Power} {System} {Analysis} {Tool}.” [Online]. Available: https://www.neplan.ch/wp-content/uploads/2015/08/Nep_TURBINES_GOV.pdf
- [31] NEPLAN, “Standard {Dynamic} {Excitation} {Systems} in {NEPLAN} {Power} {System} {Analysis} {Tool}.”
- [32] NEPLAN, “Standard {Dynamic} {Power} {System} {Stabilizers} in {NEPLAN} {Power} {System} {Analysis} {Tool}.”
- [33] M. P. Boyce, *Gas turbine engineering handbook*, 4th ed. Amsterdam ; Boston: Elsevier/Butterworth-Heinemann, 2012.
- [34] E. Hau, *Wind {Turbines}*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013. doi: 10.1007/978-3-642-27151-9.
- [35] G. A. Munoz-Hernandez, S. P. Mansoor, and D. I. Jones, *Modelling and {Controlling} {Hydropower} {Plants}*. London: Springer London, 2013. doi: 10.1007/978-1-4471-2291-3.
- [36] M. Chen and G. A. Rincon-Mora, “Accurate {Electrical} {Battery} {Model} {Capable} of {Predicting} {Runtime} and {I}-{V} {Performance},” *IEEE Transactions on Energy Conversion*, vol. 21, no. 2, pp. 504–511, Jun. 2006, doi: 10.1109/TEC.2006.874229.
- [37] M. Ceraolo, “New dynamical models of lead-acid batteries,” *IEEE Transactions on Power Systems*, vol. 15, no. 4, pp. 1184–1190, Nov. 2000, doi: 10.1109/59.898088.
- [38] T. Huria, M. Ceraolo, J. Gazzarri, and R. Jackey, “High fidelity electrical model with thermal dependence for characterization and simulation of high power lithium battery cells,” in *2012 {IEEE} {International} {Electric} {Vehicle} {Conference}*, Mar. 2012, pp. 1–8. doi: 10.1109/IEVC.2012.6183271.
- [39] Elga Ace, “Installatie-, gebruikers- en servicehandleiding {Hybride} ‘split’ warmtepomp lucht / water.” Dec. 2020. [Online]. Available: <https://tools.remeha.nl/wp-content/uploads/sites/3/2020/06/IOM-Elga-Ace-NOT-7745647-05.pdf>
- [40] B. Bolund, H. Bernhoff, and M. Leijon, “Flywheel energy and power storage systems,” *Renewable and Sustainable Energy Reviews*, vol. 11, no. 2, pp. 235–258, Feb. 2007, doi: 10.1016/j.rser.2005.01.004.
- [41] F. Prystupczuk, V. Rigoni, A. Nouri, R. Ali, A. Keane, and T. O’Donnell, “Hybrid {Power} {Electronic} {Transformer} {Model} for {System}-{Level} {Benefits} {Quantification} in {Energy} {Distribution} {Systems},” *Frontiers in Electronics*, vol. 2, p. 716448, Sep. 2021, doi: 10.3389/felec.2021.716448.
- [42] S. A. Saadabadi, N. van Linden, A. Heinsbroek, and P. v Aravind, “A solid oxide fuel cell fuelled by methane recovered from groundwater,” *Journal of Cleaner Production*, vol. 291, p. 125877, Apr. 2021, doi: 10.1016/j.jclepro.2021.125877.

- [43] K. Föger and T. Rowe, "Ceramic fuel cells Ltd residential generator [BlueGen], ultra-efficient distributed power generation in smart grid," 2011, p. 12.
- [44] Z. Abdin, C. J. Webb, and E. MacA. Gray, "Modelling and simulation of a proton exchange membrane ({PEM}) electrolyser cell," *International Journal of Hydrogen Energy*, vol. 40, no. 39, pp. 13243–13257, Oct. 2015, doi: 10.1016/j.ijhydene.2015.07.129.
- [45] H. Gorgun, "Dynamic modelling of a proton exchange membrane ({PEM}) electrolyzer," *International Journal of Hydrogen Energy*, vol. 31, no. 1, pp. 29–38, Jan. 2006, doi: 10.1016/j.ijhydene.2005.04.001.
- [46] A. Franco, N. Vieira, C. Ponte, and E. Renováveis, "Geothermal {Developments} in {Pico} {Alto}, {Terceira} {Island}, {Portugal}," in *Geothermal {Resources} {Council} {Transactions}*, 2017, vol. 41, p. 13.
- [47] S. Frick, S. Kranz, G. Kupfermann, A. Saadat, and E. Huenges, "Making use of geothermal brine in {Indonesia}: binary demonstration power plant {Lahendong}/{Pangolombian}," *Geothermal Energy*, vol. 7, no. 1, p. 30, Dec. 2019, doi: 10.1186/s40517-019-0147-2.
- [48] G. Andritsos, A. Desideri, C. Gantiez, and V. Lemort, "Steady state and dynamic modelling of a 1 {MWel} commercial waste heat recovery {ORC} power plant," 2016, p. 12.
- [49] M. Imran, R. Pili, M. Usman, and F. Haglind, "Dynamic modeling and control strategies of organic {Rankine} cycle systems: {Methods} and challenges," *Applied Energy*, vol. 276, p. 115537, Oct. 2020, doi: 10.1016/j.apenergy.2020.115537.
- [50] H. Zhai, L. Shi, and Q. An, "Influence of working fluid properties on system performance and screen evaluation indicators for geothermal {ORC} (organic {Rankine} cycle) system," *Energy*, vol. 74, pp. 2–11, Sep. 2014, doi: 10.1016/j.energy.2013.12.030.
- [51] A. F. Altun and M. Kilic, "Thermodynamic performance evaluation of a geothermal {ORC} power plant," *Renewable Energy*, vol. 148, pp. 261–274, Apr. 2020, doi: 10.1016/j.renene.2019.12.034.
- [52] "{AMADEUS} {Project} - {Electric} {Thermal} {Energy} {Storage}." Accessed: Feb. 15, 2022. [Online]. Available: <https://amadeus-project.eu/>
- [53] "Plug-{N}-{Harvest} {H2020} {\textbar} {Plug}-{N}-{Harvest} {H2020}." Accessed: Feb. 15, 2022. [Online]. Available: <https://www.plug-n-harvest.eu>
- [54] K. Rajendran, H. R. Kankanala, M. Lundin, and M. J. Taherzadeh, "A novel process simulation model ({PSM}) for anaerobic digestion using {Aspen} {Plus}," *Bioresource Technology*, vol. 168, pp. 7–13, Sep. 2014, doi: 10.1016/j.biortech.2014.01.051.
- [55] T. A. Marcinkowski, "Effect of alkalization process on changes in the chemical composition of secondary sludge," *Environment Protection Engineering*, vol. 36, no. 2, pp. 153–160, 2010.