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## Design of Scenarios for eNeuron toolbox simulations

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### WP5, Task 5.1, Task 5.2

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## Executive summary

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This deliverable is the first one in a series of three reports that will be developed under Work Package 5 (WP5) "Validation of energy hub solutions through simulation and testing in a lab environment" from the H2020 project eNeuron.

In this work, several technology components have been modelled for their use in the future WP5 simulations, including distributed generation units, energy storage systems, and flexibility components from all energy carriers with the objective of designing hybrid models of the energy hubs. To this extent, several distribution grids have been also built for validation purposes in the next tasks.

Moreover, a set of scenarios for simulation have been defined with the aim of covering a wide spectrum of energy carriers (i.e., gas, hydrogen, water, electricity, heating, and cooling) and locations on the future simulations. These scenarios envision their implementation in the medium term, and their definition will allow a precise simulation prior to its real implementation within the project. Some of the scenarios are grounded on the four pilots of the eNeuron project, and its possible implementation within the project time frame. Other are more general, with the aim of providing a wider vision of technologies not restricted to pilots' characteristics.

Nonetheless, an important objective of the deliverable is to characterize every scenario with a set of specific time series associated with the generation, consumption and storage. For the generation of those time series, real data or synthetic models have been used.

Therefore, the main outcomes of this deliverable are to provide a description of:

- the models for the flexibility assets of the various energy carriers identified in the project along with the representative grids,
- time series of technologies for generation, consumption, and storage, for its inclusion in the future simulation of the selected scenarios. These time series are obtained from real data acquired from the partners monitoring systems, from other open-source databases and from synthetic data extracted from the models developed,
- twelve general scenarios in several locations of Europe with different energy carriers for their possible future simulation, and
- four specific scenarios based on the four pilots existing in the eNeuron consortium (Portugal, Norway, Poland, and Italy).



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## Abbreviations and acronyms

Acronym	Meaning
<b>AMI</b>	Advanced Metering Infrastructure
<b>BESS</b>	Battery Energy Storage System
<b>BEMS</b>	Building Energy Management Systems
<b>BMS</b>	Building Management System
<b>B/HEMS</b>	Building/Home Energy Management Systems
<b>CEC</b>	Citizen Energy Community
<b>CCHP</b>	Combined Cooling, Heat and Power
<b>CHP</b>	Combined Heat and Power
<b>CNG</b>	Compressed Natural Gas
<b>CSP</b>	Concentrated Solar Power
<b>DB</b>	Database
<b>DAFI</b>	Directive Alternative Fuel Initiative in Italy
<b>DER</b>	Distributed Energy Resource
<b>DSO</b>	Distributed System Operator
<b>DHC</b>	District Heating and Cooling
<b>DHW</b>	Domestic Hot Water
<b>EV</b>	Electric Vehicle
<b>ETS</b>	Emission Trading Scheme
<b>ECCs</b>	Energy Efficiency Certificates
<b>EER</b>	Energy Efficiency Ratio
<b>EH</b>	Energy Hub
<b>EU</b>	European Union
<b>GHG</b>	Greenhouse Gas
<b>HEMS</b>	Home Energy Management Systems
<b>ICE</b>	Internal Combustion Engine
<b>KPI</b>	Key Performance Indicator
<b>LEC</b>	Local Energy Community
<b>LV</b>	Low Voltage
<b>MV</b>	Medium Voltage
<b>MGT</b>	Micro Gas Turbine
<b>μEHs</b>	micro-Energy Hubs
<b>P2P</b>	Peer-to-peer
<b>REC</b>	Renewable Energy Community



Acronym	Meaning
<b>RESs</b>	Renewable Energy Systems
<b>ROI</b>	Return of investment
<b>SS</b>	Secondary Substations
<b>PV</b>	Solar Photovoltaic
<b>SOC</b>	State of Charge
<b>UTC</b>	Universal time Coordinated
<b>UPM</b>	Universidad Politécnica de Madrid
<b>UnivPM</b>	Università Politecnica delle Marche
<b>UCY</b>	University of Cyprus
<b>UCs</b>	Use Cases
<b>V2G</b>	Vehicle-to-Grid
<b>WT</b>	Wind Turbine
<b>WP</b>	Work Package



# 1 Introduction

---

Deliverable D5.1 starts a series of three reports that will be developed under Work Package 5 (WP5) "Validation of energy hub solutions through simulation and testing in a lab environment" from the H2020 project eNeuron. The deliverable is the result of two specific tasks:

- Task 5.1: Modelling of flexibility elements and distribution grids. In this task, several components are modelled for use in the simulations, including distributed generation units (such as PV facilities), energy storage systems (such as electric vehicles), and thermal components (heat pumps, CHPs, etc.) to be able to design hybrid models of the energy hubs (EHs). Representative grids have been also built and modelled.
- Task 5.2: Design of scenarios for simulation. In this task, scenarios for the simulation of different technologies and energy carriers are designed.

Therefore, this report will formulate the baseline for the next activities of WP5 that are namely:

- Task 5.3. Simulation of energy hub solutions in selected scenarios. In this task, simulations of the eNeuron toolbox functionalities will be run and analysed for the different representative grids selected in T5.1 and the scenarios of T5.2.
- Task 5.4. Validation of the operation of energy hubs in a lab environment. This task will focus on the validation of the simulated scenarios of T5.2 and the solutions proposed in Work Package 4 - Analysis, design and operation optimisation of the local energy systems: emergence of energy hubs.

## 1.1 Purpose and scope of the document

The main purpose of deliverable D5.1 is to define a set of possible scenarios for the future validation of the eNeuron toolbox. The scenarios have been designed considering the pilots involved in the eNeuron project and the technologies analysed in Work Package 2 - Limitations and shortcomings for optimal use of local resources. Every scenario includes a description and diagram together with its location and technical characteristics. Moreover, every scenario describes different energy management strategies and regulatory and economic aspects.

Furthermore, different technologies and distribution grid models have been selected and included in this deliverable as an outcome of Task 5.1. Nonetheless, a time series database, the eNeuron Database, has also been created as an output of Task 5.2.

All scenarios developed are therefore linked to the eNeuron Database with the aim of providing all necessary tools for the future scenarios' simulation.

## 1.2 Structure of the document

The document is structured in six main sections. The first two ones, Section 1 and Section 2, introduce the purpose and structure of the document and the methodology followed for its elaboration.



Section 3 provides the mathematical models of different technologies elaborated under Task 5.1. The main objective of this section is to offer several technology models that can be represented in any optimisation software and be the building blocks of the optimisation problems for the scenarios' simulations.

Section 4 introduces the eNeuron Database, a time series database of real and synthetic data that, together with the models, will support the simulation of the scenarios in future tasks.

Section 5 is the core of the deliverable, describing all the scenarios created during Task 5.2 execution. Sixteen scenarios, twelve of them general and four based on the specific pilots of the consortium, are detailed.

Finally, Section 6 concludes the document.



## 2 Methodology

Deliverable D5.1 describes the main outcomes developed under Task 5.1 and Task 5.2 of WP5.

### 2.1 Task 5.1 - Modelling of flexibility elements and distribution grids

The main objectives of the activities under Task 5.1 were:

- to develop the model of the technologies and flexibility elements of the multi-carrier energy systems,
- to develop flexible electrical distribution models that would allow the validation to be performed in the next tasks upon the scenario's formulation,
- to provide a pathway for the integration process of the technologies into the electrical grid.

So, as far as the activities under T5.1 are concerned, the following methodology has been established:

- **As far as the technologies' models are concerned:**

The mathematical models for generation, conversion and storage technologies and flexibility assets for the multi-carrier energy systems already in the partners' inventory have been identified. The technologies considered for all carriers are shown below.

Heat pump	Absorption chiller	Backup Diesel Generator	Thermal storage
Natural gas boiler	Solar Photovoltaic (PV)	Electrolyser	Electric boiler
Combined Heat and Power (CHP)	Wind Generator	Electricity storage (Battery), including EV	Solar thermal systems, including Concentrated Solar Power (CSP)
Micro-CHP	Micro-hydro	Thermal energy storage	Fuel cells

These models were simulated into two software package solutions that will be the basis for validation of the eNeuron scenarios. These are IBM ILOG CPLEX Optimization Studio commercial software environment (hereinafter referred to as CPLEX) and PowerFactory® of DIGSILENT. CPLEX is going to be used for the validation of the optimisation algorithms. DIGSILENT PowerFactory® software was chosen to technically validate the stability of the electrical grid due to the accuracy of the models provided, its internal library, its compatibility with Python and its accessibility for modelling both large networks with hundreds of components, as well as small-scale installations. It is important to mention that only technologies that have at least one electricity interconnection (input or output or both) have been modelled in PowerFactory®. For the technology models that do not involve both electrical output and electrical input, the interaction with the CPLEX environment is foreseen for the interconnection with other energy carriers and thus the interaction with the other carriers is captured.



- **As far as the grid selection is concerned:**

This objective is only relevant to the PowerFactory® software package. The objective is to find a set of grids with a trade-off between size, accuracy, and tractability, while also considering which topologies are more suitable for representing local energy communities (LEC) that can behave as EHs, being residential/commercial, urban/rural, etc. The accuracy should be high enough to provide significant results in terms of grid status (power flows, losses, voltage, etc.) without over-penalising the computational cost. The specifications considered are shown in Figure 1.

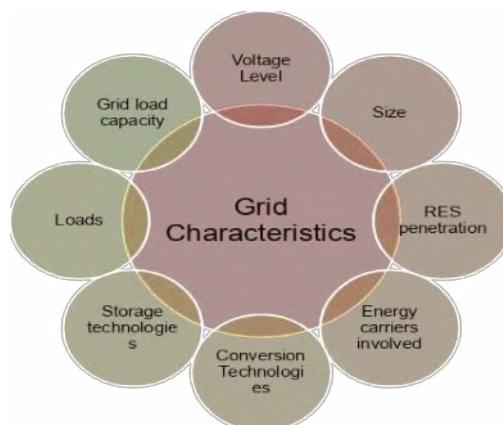


Figure 1. The grid specifications that were considered

For this reason, data profiles from the Low Voltage Network Solutions project [1] have been retrieved. This enabled to structure different Low Voltage (LV) network models in the PowerFactory® software framework capable of hosting new low carbon technologies and analysing them in the next eNeuron strategies to increase the penetration level of low carbon technologies within the energy communities. From the different 25 LV networks, the following feeders are selected to meet the needed specifications:

Network 1	Feeders 1,2,3
Network 6	Feeders 2
Network 10	Feeders 1,2,3,4,5,6

The different networks are interconnected with Medium Voltage (MV) overhead links. More details will be given in the dedicated section.

- **As far as the integration of models into grids is concerned:**

A Python module has been developed with the main objective to automate the process of the user retrieving data and integrating technologies' models in the grids simulated in PowerFactory®.

## 2.2 Task 5.2 - Design of scenarios for simulation

The main objectives of activities under T5.2 were:

- to design a set of scenarios for the eNeuron toolbox simulations,



- to create a time series database based on i) synthetic models and ii) real data acquired by the partners involved in the tasks, to be used as input data for the validation of the eNeuron toolbox in the defined scenarios.

These objectives were developed across four subtasks for the definition, compilation, and homogenization of both time series databases and scenarios. So, as far as the activities under T5.2 are concerned, the following methodology has been established:

- **Database creation:**

The eNeuron Database creation has followed an iterative process according to the real data and models available by the partners and the requisites raised by the scenarios. Therefore, two subtasks were assigned to this objective, one devoted to the time series definition and the other one for the compilation, processing, and homogenization. In the first subtask, partners involved defined which time series were available. In the second subtask, the time series were extracted and described. The complete eNeuron Database can be found on the eNeuron Website<sup>1</sup>. These two subtasks were defined to be revisited during the scenario's creation to fulfil the needs for the scenario's definition. Therefore, if any input data was missing for any scenario, it had to be created and included in the eNeuron Database. Hence, these two subtasks lasted for the complete T5.2 period. Nonetheless, it is important to note that the eNeuron Database is an open outcome of the eNeuron project, which will grow and evolve during the project execution.

- **Scenario's creation:**

The scenarios definition has been divided into two sequential subtasks. The first subtask was devoted to the definition of twelve General Scenarios designed with the aim of covering a wide spectrum of energy carriers (i.e., gas, hydrogen, water, electricity, heating, and cooling). The second subtask was devoted to the creation of four pilot scenarios which focus on the pilots available at the eNeuron consortium. Every scenario, independently of being general or based on a pilot, must cover the following requisites:

- A description and location of the scenario.
- A general diagram of the scenario that could be divided into different diagrams to allow the understanding of the energy carriers and interconnections between all elements in the scenario.
- A description of the technical characteristics of the technologies included.
- Energy management strategies envisioned for the scenario.
- Regulatory aspects to be taken into account for the scenario creation.
- Economic costs and benefits. If possible, to quantify either the costs needed to start the pilot or to maintain it. Some of the scenarios leave this analysis for a future task to be done with the help of the eNeuron toolbox.
- Impacts that the scenario will achieve.

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<sup>1</sup> <http://eneuron.eu/wp-content/uploads/2022/06/Time-series-summary.pdf>



- A link to the eNeuron Database times series that could be used for the scenario simulation.

Selected scenarios will be used to validate the eNeuron toolbox and its functionalities in the next tasks of WP5. Therefore, the scenarios created within task T5.2 are provided as a deliverable for its future simulation under the eNeuron toolbox with all inputs described and available.



### 3 Optimisation and simulation models

#### 3.1 Mathematical models of energy conversion technologies and flexibility assets

In this section, the mathematical models of the 15 technologies including generation and storage developed under T5.1 are presented. The main objective of this section is to offer the models that can be represented in the CPLEX software or any other optimisation software and be the building blocks of an optimisation problem in the next future. As mentioned in previous section, these mathematical models will be used as a basis also in the PowerFactory® software to represent the technologies that have at least one electrical input or output and are not already developed in the software library. This way the physical representation of these technologies shall be secured, as PowerFactory® is focused only on the electrical grids and components. So, the technologies that will be represented in this latter software is a subset of the 15 technologies and are listed in Table 1.

Table 1. Technologies evaluated for the PowerFactory® models.

Technology	Type			Characteristics		Other carriers
	Generation	Consumption	Storage	Flexible	Shiftable	
BESS			X	X	X	
Electric vehicle		X	X (V2G)	X	X	
Photovoltaics	X					
Wind turbine	X					
Micro-hydro	X			X		
CHP and $\mu$ CHP	X			X	X	Heating-cooling, gas.
Back-up diesel generator	X			X	X	
Fuel cell	X			X	X	Heating-cooling, Hydrogen
Electrolyser		X		X	X	Hydrogen
Heat pump		X		X	X	Heating-cooling.
Electric boiler		X			X	Heating.

For the technologies whose input and output are both electrical, the modelling with using only the PowerFactory® software suffices. But for the technologies that their input or output is other than electrical, CPLEX software collaboration is foreseen to capture the interaction with the other carriers.



## 3.1.1 Heat pump

Energy Technology	Reversible heat pump
Application level	The application is at level of EH and $\mu$ EH
Mathematical model	<p>The capacity constraint formulated below, ensures that for each time step hour <math>t</math> of day <math>d</math>, the heating (cooling) rate provided by the heat pump is limited by its minimum part load and the size, if the technology is on, i.e., the binary decision variable <math>x_{HP,d,t}^{HM}</math> is equal to 1:</p> $H_{HP}^{min} \cdot x_{HP,d,t}^{HM} \leq H_{HP,d,t}^{HM} \leq H_{HP}^{max} \cdot x_{HP,d,t}^{HM} \forall d, t \quad (1)$ <p>The reversible heat pump may be involved to meet the thermal and cooling demand in heating and cooling mode, respectively. The related operation constraint valid for the heating mode is formulated as:</p> $E_{HP,d,t}^{HM} = H_{HP,d,t}^{HM} / COP_{HP}^{HM} \quad \forall d, t \quad (2)$ <p>which links the electricity required by the heat pump to the heat rate provided through its coefficient of performance. The constraint is similar for the heat pump operating in cooling mode.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{HP,d,t}^{HM}</math>: heating rate provided by the heat pump [kW]</li> <li>▪ <math>E_{HP,d,t}^{HM}</math>: power required by the heat pump [kW]</li> </ul> <p>The binary decision variable <math>x_{HP,d,t}^{HM}</math> is that indicates the on/off status of the heating pump in heating mode.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{HP}^{min}</math>: minimum thermal part load of the heat pump [kW]</li> <li>▪ <math>H_{HP}^{max}</math>: maximum thermal load of the heat pump [kW] / capacity</li> <li>▪ <math>COP_{HP}^{HM}</math>: coefficient of performance of the heat pump in heating mode.</li> </ul>

## 3.1.2 Natural gas boiler

Energy Technology	Natural gas boiler
Application-level	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The capacity constraint formulated below ensures that for each step <math>t</math> of day <math>d</math>, the heating rate provided by the boiler is limited by its lower and upper bond. If the technology is on, i.e., the binary decision variable <math>x_{boil,d,t}</math> is equal to 1:</p> $H_{boil}^{min} \cdot x_{boil,d,t} \leq H_{boil,d,t} \leq H_{HP}^{max} \cdot x_{boil,d,t} \forall d, t \quad (3)$



	<p>The related operation constraint is formulated as:</p> $G_{boil,d,t} = \frac{H_{boil,d,t}}{\eta_{th,boil} \cdot LHV^{NG}} \quad \forall d, t \quad (4)$ <p>where <math>G_{boil,d,t}</math> is the amount of natural gas consumed by the boiler and <math>\eta_{th,boil}</math> is the thermal efficiency of the boiler.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{boil,d,t}</math>: heating rate provided by the boiler [kW]</li> <li>▪ <math>G_{boil,d,t}</math>: natural gas volumetric flow rate required by the boiler [Nm<sup>3</sup>/h]</li> </ul> <p>The binary decision variable is <math>x_{boil,d,t}</math> that indicates the on/off status of the boiler.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{boil}^{min}</math>: minimum thermal part load of the boiler [kW]</li> <li>▪ <math>H_{boil}^{max}</math>: maximum thermal part load of the boiler [kW]</li> <li>▪ <math>\eta_{th,boil}</math>: thermal efficiency of the boiler [%]</li> <li>▪ <math>LHV^{NG}</math>: lower heat value of natural gas [kWh/Nm<sup>3</sup>]</li> </ul>

### 3.1.3 CHP or Micro-CHP

Energy Technology	CHP or Micro-CHP
Application-level	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents a CHP or a micro-CHP (with MGT or the ICE as the prime mover) and relates the power produced with natural gas consumed and the heat rate recovered with the power produced on an hourly basis. The energy networks involved are gas, electricity, and heat networks. The cooling network can also be included in case there is an absorption chiller.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the power provided by the <math>\mu</math>CHP is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{\mu CHP,d,t}</math> is equal to 1:</p> $E_{\mu CHP}^{min} \cdot x_{\mu CHP,d,t} \leq E_{\mu CHP,d,t} \leq E_{\mu CHP}^{max} \cdot x_{\mu CHP,d,t} \quad (5)$ <p>The operation constraints for the micro-CHP (<math>\mu</math>CHP) are formulated below:</p> $G_{\mu CHP,d,t} = \frac{E_{\mu CHP,d,t}}{\eta_{e,\mu CHP} LHV_{gas}} \quad (6)$ <p>that allows calculating the amount of natural gas required by the <math>\mu</math>CHP to provide power, <math>E_{\mu CHP,d,t}</math>.</p> <p>The heat rate recovered by the <math>\mu</math>CHP is formulated below:</p>



	$H_{\mu\text{CHP},d,t} = \frac{E_{\mu\text{CHP},d,t} \cdot \eta_{th,\mu\text{CHP}}}{\eta_{e,\mu\text{CHP}}} \forall d, t \quad (7)$ <p>The equation below allows linking the amount of heat recovered by the <math>\mu\text{CHP}</math> to the shares used to meet the thermal demand and to meet the cooling demand through the absorption chiller.</p> $H_{\mu\text{CHP},d,t} = H_{\mu\text{CHP},d,t}^{Th} + H_{\mu\text{CHP},d,t}^{SC} \forall d, t \quad (8)$
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{\mu\text{CHP},d,t}</math>: power provided by the <math>\mu\text{CHP}</math> [kW]</li> <li>▪ <math>G_{\mu\text{CHP},d,t}</math>: gas consumed by the <math>\mu\text{CHP}</math> (dependent variable) [<math>\text{Nm}^3/\text{s}</math>]</li> <li>▪ <math>H_{\mu\text{CHP},d,t}</math>: heat rate recovered by the <math>\mu\text{CHP}</math> (dependent variable) [kW]</li> <li>▪ <math>H_{\mu\text{CHP},d,t}^{Th}</math>: heat rate for thermal purposes [kW]</li> <li>▪ <math>H_{\mu\text{CHP},d,t}^{SC}</math>: heat rate for cooling purposes [kW]</li> </ul> <p>The binary decision variable is <math>x_{\mu\text{CHP},d,t}</math> that indicates the on/off status of the <math>\mu\text{CHP}</math>.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{\mu\text{CHP}}^{\min}</math>: minimum part load of the <math>\mu\text{CHP}</math> [kW]</li> <li>▪ <math>E_{\mu\text{CHP}}^{\max}</math>: maximum part load of the <math>\mu\text{CHP}</math> [kW]</li> <li>▪ <math>\eta_{e,\mu\text{CHP}}</math>: electrical efficiency of the <math>\mu\text{CHP}</math> [%]</li> <li>▪ <math>\eta_{th,\mu\text{CHP}}</math>: thermal efficiency of the <math>\mu\text{CHP}</math> [%]</li> <li>▪ <math>LHV_{gas}</math>: lower heat value of natural gas [<math>\text{kWh}/\text{Nm}^3</math>]</li> </ul>

### 3.1.4 Absorption chiller

Energy Technology	Absorption chiller
Application-level	The application is at the level of EH and $\mu\text{EH}$
Mathematical model	<p>The model represents an absorption chiller and relates the cooling rate produced by the absorption chiller with the heat rate used to power the absorption chiller on an hourly basis. The energy networks involved are heat and cooling networks.</p> <p>The capacity constraint formulated below ensures that for each step <math>t</math> of day <math>d</math>, the cooling rate provided by the absorption chiller (Abs) is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{Abs,d,t}</math> is equal to 1:</p> $C_{Abs}^{\min} \cdot x_{Abs,d,t} \leq C_{Abs,d,t} \leq C_{Abs}^{\max} \cdot x_{Abs,d,t} \quad (9)$ <p>The operation constraint for the absorption chiller is formulated below:</p> $C_{Abs,d,t} = \frac{H_{Abs,d,t}}{COP_{Abs}} \forall d, t \quad (10)$
Decision variables	In the mathematical model, the continuous decision variables are:



	<ul style="list-style-type: none"> <li>▪ <math>C_{Abs,d,t}</math>: the cooling rate provided by the absorption chiller [kW]</li> <li>▪ <math>H_{Abs,d,t}</math>: the heat rate used to power the absorption chiller [kW]</li> </ul> <p>The binary decision variable is <math>x_{Abs,d,t}</math> that indicates the on/off status of the absorption chiller.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>C_{Abs}^{min}</math>: minimum part load of the absorption chiller [kW]</li> <li>▪ <math>C_{Abs}^{max}</math>: maximum load of the absorption chiller [kW] / capacity</li> <li>▪ <math>COP_{Abs}</math>: coefficient of performance of the absorption chiller.</li> </ul>

### 3.1.5 Solar photovoltaic generator

Energy Technology	Solar photovoltaic generator
Application-level with type(s)	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents a PV generator and relates the electric power produced with solar irradiance on an hourly basis. The energy network involved is the electricity network.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the power provided by the PV generator is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{PV,d,t}</math> is equal to 1:</p> $E_{PV}^{min} \cdot x_{PV,d,t} \leq E_{PV,d,t} \leq E_{PV}^{max} \cdot x_{PV,d,t} \quad (11)$ <p>The operation constraints for the PV are formulated below:</p> $SI_{PV,d,t} = \frac{E_{PV,d,t}}{\eta_{e,PV} \cdot PR_{PV} \cdot A_{PV}} \forall d, t \quad (12)$ <p>that allows calculating the solar irradiance level required by the PV generator to provide power, <math>E_{PV,d,t}</math>.</p>
Decision variables	<p>In the mathematical model, the continuous decision variable is:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{PV,d,t}</math>: power provided by the PV generator [kW]</li> </ul> <p>The binary decision variable is <math>x_{PV,d,t}</math> that indicates the on/off status of the PV generator.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{PV}^{min}</math>: minimum part load of the PV generator [kW]</li> <li>▪ <math>E_{PV}^{max}</math>: maximum load of the PV generator [kW]</li> <li>▪ <math>A_{PV}</math> total PV panel area [m<sup>2</sup>]</li> <li>▪ <math>\eta_{e,PV}</math>: PV panel efficiency</li> </ul>



	<ul style="list-style-type: none"> <li>▪ <math>PR_{PV}</math>: “performance ratio” equivalent to the overall conversion efficiency, including inverter losses, temperature losses, cable losses, shading losses, dirtiness losses, and others, if desirable, can be included in the <math>\eta_{e,PV}</math></li> <li>▪ <math>SI_{PV,d,t}</math>: solar irradiance impacting the PV generator [kW/m<sup>2</sup>] over the tilted PV surface (considering the tilt angle over the horizontal surface)</li> </ul>
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### 3.1.6 Wind generator

Energy Technology	Wind turbine generator
Application-level with type(s)	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>For a typical wind turbine, it is assumed that it starts generating at the cut-in wind speed <math>v_c</math>, the electricity output increases linearly as the wind speed increases from <math>v_c</math> to the rated wind speed <math>v_R</math>, the rated electricity output is provided when the wind speed varies from <math>v_R</math> to the cut-out wind speed <math>v_F</math> at which the wind turbine will be shut down for safety considerations (all the variables are known based on weather and type). Then, the electricity output from the wind turbine can be defined as:</p> $E_{d,t}^{WT} = \begin{cases} E^{WT} \frac{v_{d,t}-v_c}{v_R-v_c} & v_c \leq v_{d,t} \leq v_R \\ E^{WT} & v_R \leq v_{d,t} \leq v_F \\ 0 & v_{d,t} < v_c, v_{d,t} > v_F \end{cases} \quad (13)$
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{d,t}^{WT}</math>: power provided by the wind turbine generator [kW]</li> </ul>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E^{WT}</math>: rated power of the turbine generator [kW]</li> <li>▪ <math>v_{d,t}</math>: wind velocity impacting the wind turbine generator [m/s]</li> <li>▪ <math>v_c</math>: cut-in wind speed [m/s]</li> <li>▪ <math>v_R</math>: rated wind speed [m/s]</li> <li>▪ <math>v_F</math>: cut-out wind speed [m/s]</li> </ul>

#### Notes for Power Factory

This model is already included in the PowerFactory library. The power obtained from the wind turbines (WT) is related to the following equation:

$$P = \frac{\rho}{2} A_r v^3 \eta_e$$



where  $A_r$  is the rotor area,  $\rho$  is the air density,  $\eta_e$  is the overall electrical efficiency. Albeit this equation simplifies some operational aspects of WT, it is deemed as acceptable for power system simulations.

The constraints for the WT follow the wind speed range in which it is able to operate. Extracting from the wind speed curve, there is the cut-in speed  $v_c$ , from which the WT operates in an approximately linear manner up to the rated speed  $v_R$ , the point from which the WT is limited to provide its rated power in order to ensure safe operation up to the point the wind speed reaches the cut-out speed  $v_f$ , at which point it needs to stop operating.

PowerFactory® allows portraying the wind speed curve relation, for which it can be stated the rate of change of power according to the wind speed, thus allowing for better degrees of approximation in the regions where the change deviates from a linear operation. Still, if deemed necessary, the wind power curve can be adjusted to follow a linear pattern as specified beforehand.

### 3.1.7 Micro-hydro

Energy Technology	Micro-hydro Generator <sup>2</sup>
Application-level with type(s)	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents a micro-hydro generator and relates the electric power produced with the water mass flow rate on an hourly basis. The energy networks involved are the electricity network and possibly the water network.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the power provided by the Micro-hydro generator is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{\mu HG,d,t}</math> is equal to 1:</p> $E_{\mu HG}^{min} \cdot x_{\mu HG,d,t} \leq E_{\mu HG,d,t} \leq E_{\mu HG}^{max} \cdot x_{\mu HG,d,t} \quad (14)$ <p>The operation constraints for the micro-hydro generator are formulated below:</p> $WMF_{\mu HG,d,t} = \frac{E_{DG,d,t}}{\eta_{e,\mu HG} \cdot H_{net} \cdot g} \forall d, t \quad (15)$ <p>that allows calculating the water mass flow rate to provide power, <math>E_{\mu HG,d,t}</math>.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{\mu HG,d,t}</math>: power provided by the micro-hydro generator [kW]</li> <li>▪ <math>WMF_{\mu HG,d,t}</math>: water mass flow rate consumed by the micro-hydro generator (dependent variable) [kg/s]</li> </ul>

<sup>2</sup> In PowerFactory®, the micro-hydro generator is represented by a synchronous machine, whose electric output power can be set as a time characteristic to supply the electricity demand, which is derived from the above equations. To do so, first, a synchronous machine type must be assigned to the "ElmSym" object. Inside this object, the local controller can be set as "Const. Q" in the "Load Flow" tab. In this tab, in section "Operational Limits", it must be defined the capability curve of the generator to set the max/min limits of P and Q.



	The binary decision variable is $x_{\mu HG,d,t}$ that indicates the on/off status of the micro-hydro generator.
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{\mu HG}^{min}</math>: minimum part load of the micro-hydro generator [kW]</li> <li>▪ <math>E_{\mu HG}^{max}</math>: maximum load of the micro-hydro generator [kW]</li> <li>▪ <math>\eta_{e,\mu HG}</math>: electrical efficiency of the micro-hydro generator [%]</li> <li>▪ <math>H_{net}</math>: the net head [m]</li> <li>▪ <math>g</math>: the gravitational constant, which is 9.81 m/s<sup>2</sup></li> </ul>

### 3.1.8 Backup Diesel Generator

Energy Technology	Backup diesel generator <sup>3</sup>
Application-level with type(s)	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents a Diesel internal combustion engine (ICE) Generator and relates the electric power produced with diesel fuel consumed on an hourly basis. The energy networks involved are fuel and electricity networks.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the power provided by the diesel generator is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{DG,d,t}</math> is equal to 1:</p> $E_{DG}^{min} \cdot x_{DG,d,t} \leq E_{DG,d,t} \leq E_{DG,d,t}^{max} \cdot x_{DG,d,t} \quad (16)$ <p>The operation constraints for the diesel generator are formulated below:</p> $E_{DG,d,t} = DF_{DG,d,t} \times (\eta_{e,DG} LHV_{df}) \cdot (\eta_{e,DG} \cdot LHV_{df}) \forall d, tt \quad (17)$ <p>that links the power provided by the diesel generator to the mass flow rate of the fuel required <math>DF_{DG,d,t}</math>, its electrical efficiency, <math>\eta_{e,DG}</math>, and the lower heat value of diesel fuel <math>LHV_{df}</math>.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{DG,d,t}</math>: power provided by the diesel generator [kW]</li> </ul>

<sup>3</sup> In PowerFactory®, the diesel generator is represented by a synchronous machine, whose electric output power can be set as a time characteristic to be used for supplying the electricity demand. First, the synchronous machine must be configured as a backup Diesel unit by enabling it as "Reference Machine" and selecting the local controller as "Const. V", along with the option "Spinning if circuit breaker is open" in the "Load Flow" tab. By means of these options, the diesel unit operates when the equivalent network is out of service. On the other hand, if the diesel unit is required to work in parallel with the network, the equivalent network must be configured as the slack node. Besides, in the "Load Flow" tab of the Diesel unit, the "Reference Machine" and "Spinning if circuit breaker is open" options must be unchecked, and the local controller must be defined as "Const. Q".



	<ul style="list-style-type: none"> <li>▪ <math>DF_{DG,d,t}</math>: diesel fuel consumed by the diesel generator [kg/s]</li> </ul> <p>The binary decision variable is <math>x_{DG,d,t}</math> that indicates the on/off status of the diesel generator.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{DG}^{min}</math>: minimum part load of the diesel generator [kW]</li> <li>▪ <math>E_{DG}^{max}</math>: maximum load of the diesel generator [kW]</li> <li>▪ <math>\eta_{e,DG}</math>: electrical efficiency of the diesel generator [%]</li> <li>▪ <math>LHV_{df}</math>: lower heat value of diesel fuel [kWh/kg]</li> </ul>

### 3.1.9 Electrolyser

Energy Technology	Electrolyser <sup>4</sup>
Application-level with type(s)	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents an Electrolyser and relates the hydrogen produced with electric power consumed on an hourly basis. The energy networks involved are hydrogen and electricity networks.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the hydrogen produced by the electrolyser is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{EL,d,t}</math> is equal to 1:</p> $E_{EL}^{min} \cdot x_{EL,d,t} \leq E_{EL,d,t} \leq E_{EL}^{max} \cdot x_{EL,d,t} \quad (18)$ <p>The operation constraints for the electrolyser are formulated below:</p> $H2_{EL,d,t} = \frac{E_{EL,d,t} \cdot \eta_{e,EL}}{HHV_{H2}} \forall d, t \quad (19)$ <p>that allows calculating the amount of electric power required by the electrolyser to provide hydrogen, <math>H2_{EL,d,t}</math></p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H2_{EL,d,t}</math>: hydrogen provided by the electrolyzers (dependent variable) [kg/s]</li> <li>▪ <math>E_{EL,d,t}</math>: electric power consumed by the electrolyser [kW]</li> </ul> <p>The binary decision variable is <math>x_{EL,d,t}</math> that indicates the on/off status of the electrolyser.</p>

<sup>4</sup>In PowerFactory®, the Electrolyser is represented by a general load with constant power. For this model, the electric power can be set as a time characteristic to demand electricity from the grid, which is derived from the above equations.



<b>Parameters</b>	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{EL}^{min}</math>: minimum part load of the electrolyser [kW]</li> <li>▪ <math>E_{EL}^{max}</math>: maximum load of the electrolyser [kW]</li> <li>▪ <math>\eta_{e,EL}</math>: efficiency of the electrolyser [%]</li> <li>▪ <math>HHV_{H2}</math>: Higher heat value of hydrogen [kWh/kg]</li> </ul>
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### 3.1.10 Electricity storage (battery), including EV

<b>Energy Technology</b>	Battery Energy Storage System or EV V2G charging/discharging <sup>5</sup>
<b>Application-level with type(s)</b>	The application is at the level of EH and $\mu$ EH.
<b>Mathematical model</b>	<p>The model represents the BESS/EV charging and discharging operation constraints.</p> <p>The capacity constraints formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the charging power, <math>E_{Bat,d,t}^{Ch}</math> and discharging power, <math>E_{Bat,d,t}^{Disch}</math>, of the BESS/EV are limited as follows:</p> $0 \leq E_{Bat,d,t}^{Ch} \leq x_{Bat,d,t}^{Ch} \cdot E_{Bat,d,t}^{Ch,max} \forall d, t \quad (20)$ $0 \leq E_{Bat,d,t}^{Disch} \leq x_{Bat,d,t}^{Disch} \cdot E_{Bat,d,t}^{Disch,max} \forall d, t \quad (21)$ $x_{Bat,d,t}^{Ch} + x_{Bat,d,t}^{Disch} \leq 1 \quad (22)$ <p>The BESS/EV state-of-charge (SOC) is defined as follows:</p> $SOC_{Bat,d,t} = SOC_{Bat,d,t-1} + E_{Bat,d,t}^{Ch} \eta_{Bat} D_t - \frac{E_{Bat,d,t}^{Disch}}{\eta_{Bat}} \cdot D_t \quad \forall d, t \quad (23)$ <p>and is limited as follows:</p> $SOC_{Bat,d,t}^{min} \leq SOC_{Bat,d,t} \leq SOC_{Bat,d,t}^{max} \forall d, t \quad (24)$ <p>The EV charging model is subject to several constraints to be met. These constraints are the following ones:</p> <ol style="list-style-type: none"> <li>1. SOC must be less than or equal to 1 (equivalent to 100% of SOC) at any time slot, as shown in equation (25).</li> </ol>

<sup>5</sup> In PowerFactory®, the EV station is represented by a general load, whereas the BESS unit is defined through a static generator. The behaviour of such devices is enabled through the use of time characteristics that allow for a representation of generation and consumption patterns, which would be derived from their corresponding mathematical models.



	$\sum_t^{dT} aT(P_n \cdot \eta_n \cdot x_{n,t}) \leq (Q_n - q_n) \cdot BC_n \quad \forall t \quad (25)$ <p>2. SOC must be equal to final SOC at final charging time <math>dT</math>, as shown in equation (26).</p> $\sum_t^{dT} aT(P_n \cdot \eta_n \cdot x_{n,t}) \leq (Q_n - q_n) \cdot BC_n \quad (26)$ <p>where,</p> <ul style="list-style-type: none"> <li>▪ <math>n</math> is the number of the EV (vehicle ID),</li> <li>▪ <math>t</math> the time slot,</li> <li>▪ <math>aT</math> and <math>dT</math> are the arrival and departure times,</li> <li>▪ <math>P_n</math> is the rated charging power of the <math>n</math>th EV,</li> <li>▪ <math>x_{n,t}</math> is the charging set-point of the <math>n</math>th EV during the time slot <math>t</math>,</li> <li>▪ <math>\eta_n</math> is the charging or the discharging efficiency of the <math>n</math>th EV,</li> <li>▪ <math>BC_n</math> is the battery capacity of the <math>n</math>th EV,</li> <li>▪ <math>Q_n</math> is the final SOC required for the <math>n</math>th EV,</li> <li>▪ and <math>q_n</math> is the initial SOC for the <math>n</math>th EV,</li> </ul> <p>that are all parameters.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{Bat,d,t}^{Ch}</math>: charging power of the BESS/EV [kW]</li> <li>▪ <math>E_{Bat,d,t}^{Disch}</math>: discharging power of the BESS/EV [kW]</li> <li>▪ <math>SOC_{Bat,d,t}</math>: the BESS/EV state-of-charge [%]</li> </ul> <p>The binary decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>x_{Bat,d,t}^{Ch}</math>: On/Off status of the BESS/EV charging [%]</li> <li>▪ <math>x_{Bat,d,t}^{Disch}</math>: On/Off status of the BESS/EV discharging [%]</li> </ul>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{Bat,d,t}^{Ch,max}</math>: maximum load of the BESS/EV charging [kW]</li> <li>▪ <math>E_{Bat,d,t}^{Disch,max}</math>: maximum load of the BESS/EV discharging [kW]</li> <li>▪ <math>\eta_{Bat}^{Ch}</math>: overall conversion efficiency of the BESS/EV charging [%]</li> <li>▪ <math>\eta_{Bat}^{Disch}</math>: overall conversion efficiency of the BESS/EV discharging [%]</li> <li>▪ <math>SOC_{Bat,d,t}^{min}</math>: minimum value of BESS/EV state-of-charge [%]</li> <li>▪ <math>SOC_{Bat,d,t}^{max}</math>: maximum value of BESS/EV state-of-charge [%]</li> </ul>



## 3.1.11 Solar Thermal Systems

Energy Technology	Solar Thermal System
Application-level with type(s)	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents a Solar Thermal System and relates the heat rate produced with solar irradiance on an hourly basis. The energy network involved is the heat network.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the heat rate provided by the Solar Thermal System is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{STS,d,t}</math> is equal to 1:</p> $H_{STS}^{min} \cdot x_{STS,d,t} \leq H_{STS,d,t} \leq H_{STS}^{max} \cdot x_{STS,d,t} \quad (27)$ <p>The operation constraints for the Solar Thermal System are formulated below:</p> $H_{STS,d,t} = SI_{STS,d,t} \cdot (\eta_{th,STS} \cdot A_{STS}) \quad \forall d, t \quad (28)$ <p>that links the heat rate, <math>H_{STS,d,t}</math> to the solar irradiance.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{STS,d,t}</math>: heat rate provided by the Solar Thermal System [kW]</li> </ul> <p>The binary decision variable is <math>x_{STS,d,t}</math> that indicates the on/off status of the Solar Thermal System.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{STS}^{min}</math>: minimum part load of the Solar Thermal System [kW]</li> <li>▪ <math>H_{STS}^{max}</math>: maximum part load of the Solar Thermal System [kW]</li> <li>▪ <math>A_{STS}</math>: total Solar Thermal System panel area [m<sup>2</sup>]</li> <li>▪ <math>\eta_{th,STS}</math>: overall thermal efficiency of the Solar Thermal System [%]</li> <li>▪ <math>SI_{STS,d,t}</math>: solar irradiance impacting the tilted surface of the Solar Thermal System [kW/m<sup>2</sup>]</li> </ul>

Energy Technology	Solar CSP – Concentrated Solar Power
Application-level with type(s)	The application is at the level of EH
Mathematical model	<p>The model represents a solar CSP system and relates the electric and thermal power produced with solar irradiance on an hourly basis. The energy networks involved are heating and electricity networks.</p> <p>The capacity constraint formulated below in eq. (29) ensures that for each time step hour <math>t</math> of day <math>d</math>, the thermal power provided by the solar CSP generator is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable</p>



	<p><math>x_{CSP,d,t}</math> is equal to 1; while eq. (30) ensures that for each hour <math>t</math> of day <math>d</math>, the electrical power provided by the turbine of the solar CSP generator is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{CSP,d,t}</math> is equal to 1:</p> $H_{CSP}^{min} \cdot x_{CSP,d,t} \leq H_{CSP,d,t} \leq H_{CSP,d,t}^{max} \cdot x_{CSP,d,t} \quad (29)$ $E_{T,CSP}^{min} \cdot x_{CSP,d,t} \leq E_{T,CSP,d,t} \leq E_{T,CSP,d,t}^{max} \cdot x_{CSP,d,t} \quad (30)$ <p>The operation constraints for the solar CSP generator are formulated below:</p> $H_{CSP,d,t} = A_{CSP} \cdot \eta_{CSP} \cdot I_{dir,d,t} \quad \forall d, t \quad (31)$ $E_{T,CSP,d,t} = H_{CSP,d,t} \cdot \eta_{e,T,CSP} \quad \forall d, t \quad (32)$ <p>Eq. (31) links the thermal power provided by the solar CSP system to the direct component of the solar irradiance level required by the solar CSP generator to provide power, <math>H_{CSP,d,t}</math>, by means of the collectors' area and thermal efficiency of the solar CSP system. Eq. (32) links the electrical power generated by the turbine of the solar CSP system to the thermal power provided by the solar CSP generator by means of the electrical efficiency of the turbine.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{CSP,d,t}</math>: thermal power provided by the Solar CSP generator [kW]</li> <li>▪ <math>E_{T,CSP,d,t}</math>: power provided by the turbine of the Solar CSP generator system [kW]</li> </ul> <p>The binary decision variable is <math>x_{CSP,d,t}</math> that indicates the on/off status of the solar CSP generator.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{CSP}^{min}</math>: minimum thermal part load of the solar CSP generator [kW]</li> <li>▪ <math>H_{CSP}^{max}</math>: maximum thermal part load of the solar CSP generator [kW]</li> <li>▪ <math>E_{T,CSP}^{min}</math>: minimum electrical part load of the turbine of the solar CSP generator [kW]</li> <li>▪ <math>E_{T,CSP}^{max}</math>: maximum electrical load of the turbine of the solar CSP generator [kW]</li> <li>▪ <math>A_{CSP}</math>: total Solar CSP panel area [m<sup>2</sup>]</li> <li>▪ <math>\eta_{CSP}</math>: thermal efficiency of the solar CSP generator [%]</li> <li>▪ <math>\mu_{e,T,CSP}</math>: overall electrical efficiency of the turbine of the solar CSP generator [%]</li> <li>▪ <math>I_{dir,d,t}</math>: direct component of the solar irradiance [kW/m<sup>2</sup>]</li> </ul>



## 3.1.12 Electric boiler

Energy Technology	Electric boiler
Application-level with type(s)	The application is at the level of $\mu$ EH
Mathematical model	<p>The model represents an Electric Boiler and relates the heat rate produced with electric power supplied on an hourly basis. The energy networks involved are the heat network and electricity network.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the power provided by the Electric Boiler is limited by its lower and upper bounds. If the technology is on, i.e., the binary decision variable <math>x_{EB,d,t}</math> is equal to 1:</p> $H_{EB}^{min} \cdot x_{EB,d,t} \leq H_{EB,d,t} \leq H_{EB}^{max} \cdot x_{EB,d,t} \quad (33)$ <p>The operation constraints for the Electric Boiler are formulated below that allows calculating the electric power required by the Electric Boiler to provide thermal power, <math>H_{EB,d,t}</math>:</p> $E_{EB,d,t} \leq \frac{H_{EB,d,t}}{\eta_{th,EB}} \quad \forall d, t \quad (34)$ <p>that allows calculating the electric power required by the Electric Boiler to provide thermal power, <math>H_{EB,d,t}</math>.</p>
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{EB,d,t}</math>: heat rate provided by the Electric Boiler [kW]</li> <li>▪ <math>E_{EB,d,t}</math>: electric power consumed by the Electric Boiler [kW]</li> </ul> <p>The binary decision variable <math>x_{EB,d,t}</math> that indicates the on/off status of the Electric Boiler.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{EB}^{min}</math>: minimum thermal part load of the Electric Boiler [kW]</li> <li>▪ <math>H_{EB}^{max}</math>: maximum thermal part load of the Electric Boiler [kW]</li> <li>▪ <math>\eta_{th,EB}</math>: overall thermal efficiency of the Electric Boiler [%]</li> </ul>

## Notes for PowerFactory®

This model is already included in the PowerFactory® library. The consumption of the electric boiler can be modelled as follows:

$$P_{boiler} = \frac{H_{boiler}}{\eta_{th}}$$



where  $P_{boiler}$  is the electric consumption,  $H_{boiler}$  is the heating provided from the boiler and  $\eta_{th}$  is the conversion efficiency.

The operation of the electric boiler depends on the heating component, specifically on the temperature of the water tank or by manual input from the user. Seen as a control system regulating the temperature of the tank, it can be stated that the control of the boiler  $x_{boiler}$  follows this:

$$x_{boiler} = \begin{cases} OFF; x_{boiler} = 0; T \geq T_{high} \\ Idle; x_{boiler} = 0; T_{low} \leq T \leq T_{high} \\ ON; x_{boiler} = 1; T \leq T_{low} \end{cases}$$

For this, the PowerFactory® model offers time characteristics in which it can be stated the time of the day in which it operates. Coupling of this with the thermal model is also needed in order to update the time characteristics according to its use and possible DR response.

### 3.1.13 Fuel cell

Energy Technology	Fuel Cell <sup>6</sup>
Application-level with type(s)	The application is at the level of $\mu$ EH
Mathematical model	<p>The model represents a Fuel Cell Generator (with heat recovery) and relates the power produced with hydrogen consumed and the heat rate recovered with the power produced on an hourly basis. The energy networks involved are hydrogen, electricity, and heat networks. The cooling network can also be included in case there is an absorption chiller.</p> <p>The capacity constraint formulated below ensures that for each time step <math>t</math> of day <math>d</math>, the power provided by the fuel cell is limited by its minimum lower and upper bound. If the technology is on, i.e., the binary decision variable <math>x_{FC,d,t}</math> is equal to 1:</p> $E_{FC}^{min} \cdot x_{FC,d,t} \leq E_{FC,d,t} \leq E_{FC}^{max} \cdot x_{FC,d,t} \quad (35)$ <p>The operation constraints for the fuel cell are formulated below that allows calculating the amount of hydrogen required by the fuel cell to provide power, <math>E_{FC,d,t}</math>:</p> $H2_{FC,d,t} = \frac{E_{FC,d,t}}{\eta_{e,FC} LHV_H} \quad \forall d, t \quad (36)$

<sup>6</sup> Regarding the PowerFactory® model, the fuel cell would be working as a static generator that would be able to supply the electrical load, obtaining from it the heating component and the hydrogen that is required. It was based on a quasi-dynamic simulation, albeit with minor modifications, it can be replicated in other simulations. Also, the thermal electrical and thermal efficiency were stated based on some CHP figures for fuel cells but depending on the technology that is going to be tested, this may be modified as well. This model was done considering electricity as the main carrier and heating as a by-product from it. If the heating demand is to be shown as an input, the fuel cell would require a time characteristic based on the electricity obtained, as well as backup generation in order to cover the full electricity consumption.



	<p>that allows calculating the amount of hydrogen required by the fuel cell to provide power, <math>E_{FC,d,t}</math>.</p> <p>The heat rate recovered by the fuel cell is formulated below:</p> $H_{FC,d,t} = \frac{E_{FC,d,t} \cdot \eta_{e,FC}}{\eta_{e,FC}} \quad \forall d, t \quad (37)$ <p>The equation below allows linking the amount of heat recovered by the fuel cell to the shares used to meet the thermal demand and to meet the cooling demand through the absorption chiller.</p> $H_{FC,d,t} = H_{FC,d,t}^{Th} + H_{FC,d,t}^{SC} \quad \forall d, t \quad (38)$
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{FC,d,t}</math>: electric power provided by the fuel cell [kW]</li> <li>▪ <math>H_{2FC,d,t}</math>: hydrogen consumed by the fuel cell [kg/s]</li> <li>▪ <math>H_{FC,d,t}</math>: heat rate recovered by the fuel cell [kW]</li> <li>▪ <math>H_{FC,d,t}^{Th}</math>: heat rate for thermal purposes [kW]</li> <li>▪ <math>H_{FC,d,t}^{SC}</math>: heat rate for cooling purposes [kW]</li> </ul> <p>The binary decision variable is <math>x_{FC,d,t}</math> that indicates the on/off status of the fuel cell.</p>
Parameters	<p>In the mathematical model, the parameters are:</p> <ul style="list-style-type: none"> <li>▪ <math>E_{FC}^{min}</math>: minimum part load of the fuel cell [kW]</li> <li>▪ <math>E_{FC}^{max}</math>: maximum load of the fuel cell [kW]</li> <li>▪ <math>\eta_{e,FC}</math>: electrical efficiency of the fuel cell [%]</li> <li>▪ <math>\eta_{th,FC}</math>: thermal efficiency of the fuel cell [%]</li> <li>▪ <math>LHV_H</math>: Lower heat value of hydrogen [kWh/kg]</li> </ul>

### 3.1.14 Thermal storage

Energy Technology	Thermal Storage for heating and cooling
Application-level	The application is at the level of EH and $\mu$ EH
Mathematical model	<p>The model represents a thermal energy storage system for heating and cooling purposes and relates the thermal energy stored at each time step, <math>H_{TES,d,t}^{sto}</math>, to the thermal energy stored and not dissipated at the previous time step, <math>H_{TES,d,t-1}^{sto}</math>, based on a loss factor, <math>\varphi_{TES}(D_t)</math>, plus the net energy flow, <math>(H_{TES,d,t}^{Ch} - H_{TES,d,t}^{Disch})D_t</math>.</p> <p>The operating constraint for thermal storage systems is formulated as follows:</p> $H_{TES,d,t}^{sto} = H_{TES,d,t-1}^{sto}(1 - \varphi_{TES}(D_t)) + (H_{TES,d,t}^{Ch} - H_{TES,d,t}^{Disch}) \cdot D_t \quad \forall d, t \quad (39)$
Decision variables	<p>In the mathematical model, the continuous decision variables are:</p> <ul style="list-style-type: none"> <li>▪ <math>H_{TES,d,t}^{sto}</math> that indicates the thermal energy stored at each time step [kWh]</li> </ul>



	<ul style="list-style-type: none"> <li>▪ <math>H_{TES,d,t}^{Ch}</math> that indicates the charging heating (cooling) rate [kW]</li> <li>▪ <math>H_{TES,d,t}^{Disch}</math> that indicates the discharging heating (cooling) rate [kW]</li> </ul>
Parameters	In the mathematical model, the parameter is $\varphi_{TES}(D_t)$ that is the loss factor, which takes into account the dissipated energy during the time interval, $D_t$ .

## 3.2 Simulation models

### 3.2.1 Network models in PowerFactory®

#### 3.2.1.1 General structure of the distribution grids

As mentioned in the methodology section, three real distribution networks from the Low Voltage Network Solutions Project [1] were modelled in PowerFactory® to provide a useful environment for testing the scenarios defined in T5.2.

These networks consist of 12 radial feeders with different cable lengths, sections, and points of power supply. They are interconnected by two MV lines of 2.8 km and 4.42 km that radially are fed from the MV node at Network 10. However, these lines can be disabled to represent a single MV point of connection from where the three networks are fed, i.e., three MV/LV transformers are derived from the same MV substation. These networks were selected to represent different types of grids with different load levels capturing different types of regions (i.e., rural, industrial, residential etc.). This selection provides the desired flexibility when building the scenarios to integrate the flexibility elements and other technologies in different parts of the grids.

A total number of 435 loads are connected in the networks, which are divided as follows: 200, 171, and 64 loads for Networks 1, 6, and 10, respectively.

Every load is linked to a specific time characteristic object that allows allocating a particular profile to be considered in the execution of the quasi-dynamic load flow. Note that every object must be configured based on the input data, i.e., if the data are time-stamped, the corresponding format must be selected accordingly. Besides, if the data are yearly defined, these can only be read by hourly resolution if these are not linked to a time stamp.

It is recommended that all profiles to be placed in the same file (e.g., csv or txt) in order to easily read each of them through the “Data Colum” parameter, which indicates its position in the file.

#### 3.2.1.2 Integration methodology

Taking advantage of the integration capability of PowerFactory® with Python, two scripts named 'main.py' and 'pfcall.py' were defined to automate the integration process of multiple technologies and different quantities into the LV networks modelled. The 'main.py' script contains the required input information to call the allocation functions defined in the 'pfcall.py' script. The allocation of the technologies is randomly performed through a uniform distribution that considers the penetration level either for the whole three networks, a particular network, or a feeder. The technologies can only be assigned to a single- or three-phase node with a load connected. Therefore, for those technologies that need to be installed at the feeder's header, their connection



must be manually made. Note that for every technology connected, a particular time series profile is assigned.

Depending on the technology type, three types of objects can be generated: i) general loads for those technologies that only consume power, ii) PV generators, and iii) static generators for the remaining technologies. The main inputs for creating whatever of the above three objects are the folder where the time series profile is stored, the grid object, and the number of elements, which derives from the penetration level.

Once the allocation of the technologies is done, it can be selected either to perform the quasi-dynamic load flow or not.

Note that both scripts must be located in the same folder to be executed, and PowerFactory® must be closed as it runs in unattended mode.

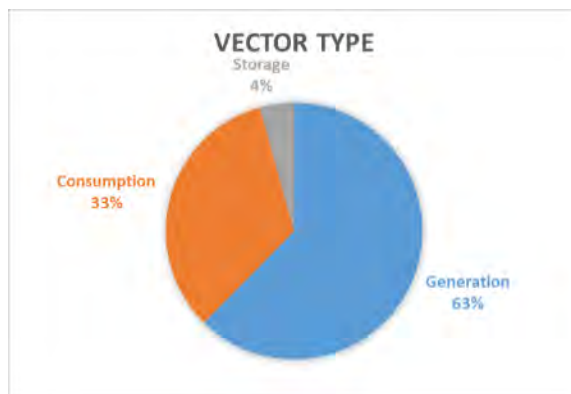


## 4 Time series and database definition

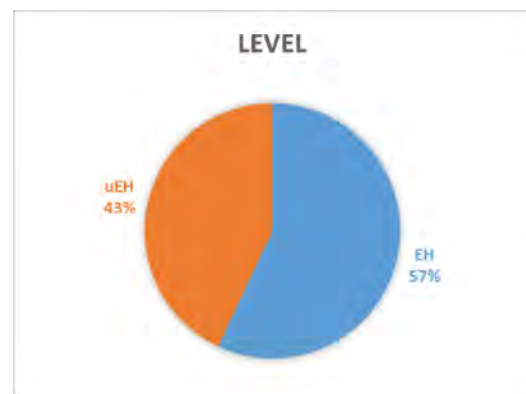
The scenarios designed in Task 5.2 make use of the distribution grid and technology models defined in Section 3 within Task 5.1. Together with these models, the scenarios must be characterized by specific time series associated with the generation, consumption, and storage technologies. Task 5.2 has started the creation of the eNeuron Database with 93 time series and a total data size of 1.5 GB. Time series are based on real and synthetic data and will support the simulation of the scenarios in future tasks. Moreover, there is an intention for the eNeuron database to continue growing it and making it open for the data that have no confidential aspects.

The 93 inputs created under T5.2 and linked to the scenarios (see Section 5), represent an important distribution of energy carriers and technologies to be used in the eNeuron scenarios simulations. Regarding the energy carrier type (see Figure 2a), 58 time series are devoted to generation, 31 to consumption and 4 to storage, divided into 18 technology types (see Figure 2c); 53 are devoted to the energy hubs level while the other 40 to the micro-energy hub (see Figure 2b). From the total of 93 inputs, 53 are based on real data, while 40 are created based on synthetic models (see Figure 2f). According to the country distribution, time series are located in 8 different countries, with 2 of them independent of the location (see Figure 2e). Time series have been obtained focusing on different sectors, with the aim of providing information to all defined scenarios. Therefore, time series are gathered from commercial, educational, health, industrial, office and residential sectors (see Figure 2d).

Most of the data have a time resolution of 1 hour (41), but some data series have a discretization period of 1 minute (see Figure 2g). Moreover, some time series provide real monitored information for more than 12 years (21), and most of them provide information for at least one year (87) (see Figure 2h).



(a)



(b)



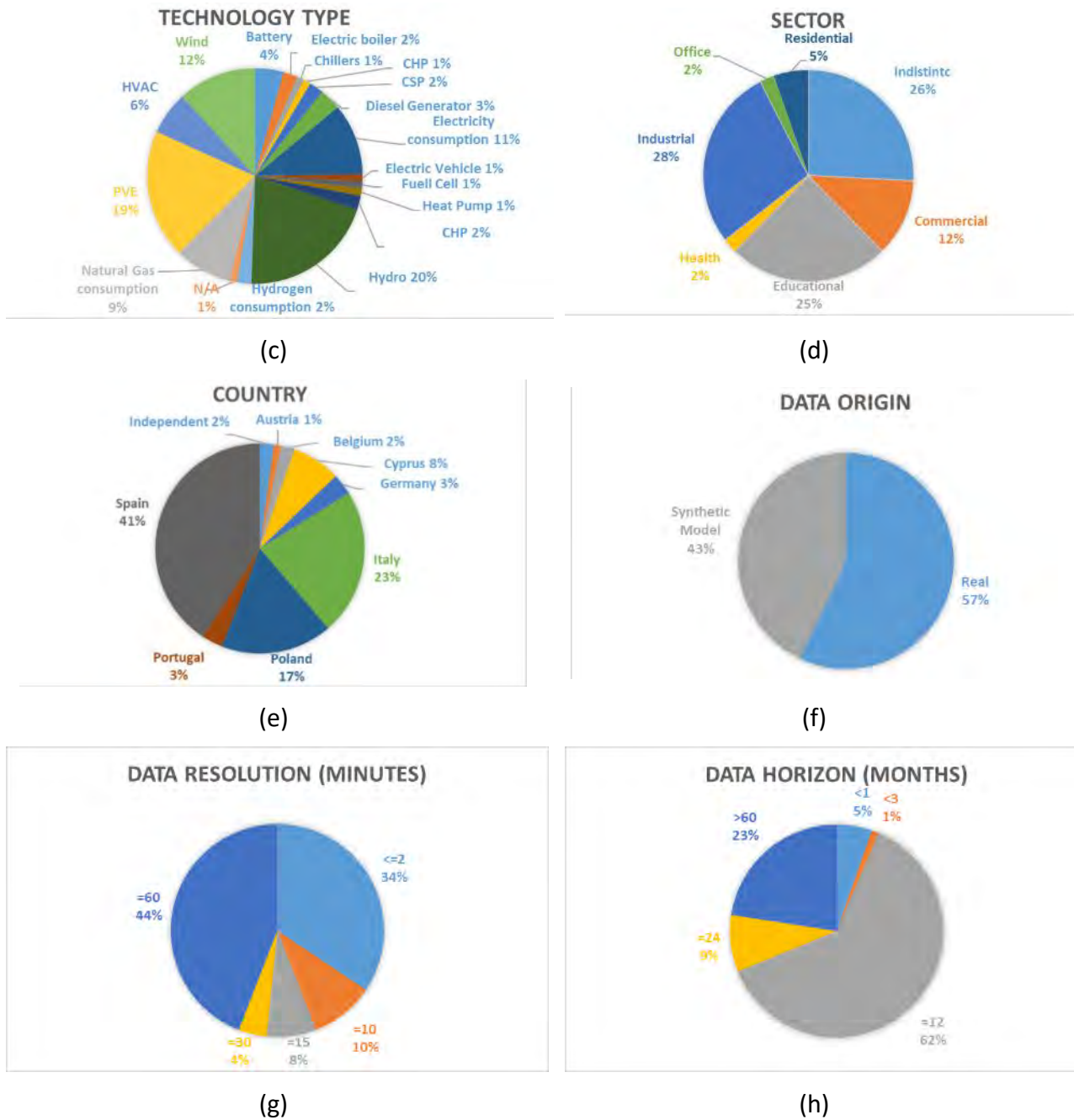


Figure 2. Time series distribution within the eNeuron time series database.

In the following subsections, the eNeuron Database is summarized and divided by generation, consumption, and storage vectors. These subsections provide a view of the vector type, energy source, technology involved and the sector from which the data have been extracted. Therefore, they provide the needed information to select the input data that could be applied to any scenario, not only the ones defined in Task 5.2 but any scenario that could be defined and created for a future simulation besides eNeuron project.



For these reasons, a public link has been created on the eNeuron website so that the general public can access non-confidential inputs. Therefore, a complete description of the time series is found on the eNeuron website<sup>7</sup>.

#### 4.1 Generation

58 time series inputs of the eNeuron Database correspond to generation (see Table 2), most of them with electricity as an energy source. Technologies are mainly divided into hydroelectric (19), photovoltaic (17), and wind (11), while the other 11 also include diesel generation, CSP, CHP or electrolyzers. 40 inputs correspond to data whose origin is real, while 18 come from mathematical models. Data resolution goes from 1 minute to 1 hour. Moreover, some time series have information for less than one month while two time series have a 30-year horizon.

*Table 2. Generation time series database summary.*

ID	Energy Carrier	Technology	Sector	Data Origin	Data resolution (min)	Time Horizon (months)
001	Electricity	Wind	Industrial	Synthetic	60	12
002	Electricity	Wind	Industrial	Real	10	12
003	Electricity	Wind	Independent	Real	10	84
004	Electricity	Photovoltaic	Independent	Synthetic	60	360
005	Electricity	CSP	Independent	Real	10	60
006	Electricity	Photovoltaic	Independent	Real	10	60
007	Electricity	Wind	Independent	Real	15	24
008	Electricity	Wind	Independent	Real	15	12
009	Electricity	Wind	Independent	Real	15	12
010	Electricity	Wind	Independent	Real	15	120
011	Electricity	Wind	Independent	Real	15	156
012	Electricity	Photovoltaic	Independent	Real	15	120
013	Electricity	Wind	Independent	Synthetic	60	360
014	Electricity	Photovoltaic	Office	Real	1	12
019	Electricity	Hydro	Industrial	Real	60	78
020	Electricity	Hydro	Industrial	Real	60	78
021	Electricity	Hydro	Industrial	Real	60	12
022	Electricity	Hydro	Industrial	Real	60	84
023	Electricity	Hydro	Industrial	Real	60	14
024	Electricity	Hydro	Industrial	Real	60	14

<sup>7</sup> <http://eneuron.eu/wp-content/uploads/2022/06/Time-series-summary.pdf>



ID	Energy Carrier	Technology	Sector	Data Origin	Data resolution (min)	Time Horizon (months)
025	Electricity	Hydro	Industrial	Real	60	78
026	Electricity	Hydro	Industrial	Real	60	78
027	Electricity	Hydro	Industrial	Real	60	12
028	Electricity	Hydro	Industrial	Real	60	12
029	Electricity	Hydro	Industrial	Real	60	24
030	Electricity	Hydro	Industrial	Real	60	78
031	Electricity	Hydro	Industrial	Real	60	65
032	Electricity	Hydro	Industrial	Real	60	78
033	Electricity	Hydro	Industrial	Real	60	78
034	Electricity	Hydro	Industrial	Real	60	58
035	Electricity	Hydro	Industrial	Real	60	78
036	Electricity	Photovoltaic	Educational	Real	1	24
037	Electricity	Photovoltaic	Educational	Real	1	60
045	Electricity	Diesel Generator	ALL	Real	10	12
046	Electricity	Hydro	ALL	Real	10	12
047	Electricity	Wind	ALL	Real	10	12
049	Electricity	Photovoltaic	Educational	Real	30	12
050	Electricity	Photovoltaic	Educational	Real	30	12
051	Irradiance	Photovoltaic	ALL	Synthetic	60	144
056	Electricity	Hydro	Industrial	Real	60	12
057	Irradiance	Photovoltaic	Industrial	Real	60	12
063	Electricity	Electrolyser	Industrial	Synthetic	60	12
065	Irradiance	Photovoltaic	ALL	Synthetic	60	12
066	Natural Gas	CHP	Industrial	Real	1	0
070	Electricity	Heat Pump	Educational	Synthetic	1	12
071	Electricity	CHP	Commercial	Synthetic	1	12
072	Electricity	CHP	Commercial	Synthetic	1	12
073	Electricity	Photovoltaic	Commercial	Synthetic	1	12
074	Electricity	Photovoltaic	Commercial	Synthetic	1	12
075	Electricity	Photovoltaic	Commercial	Synthetic	1	12
076	Electricity	Photovoltaic	Educational	Synthetic	1	12
078	Electricity	Photovoltaic	ALL	Synthetic	1	12
080	Electricity	Diesel Generat.	Educational	Synthetic	1	12
081	Electricity	Diesel Generat.	Office	Synthetic	1	12
082	Electricity	Photovoltaic	Commercial	Synthetic	1	12



ID	Energy Carrier	Technology	Sector	Data Origin	Data resolution (min)	Time Horizon (months)
083	Electricity	Photovoltaic	Commercial	Synthetic	1	12
084	Heat/Cooling	CSP	Commercial	Synthetic	1	12
090	Electricity	Wind	Other	Real	2	12

## 4.2 Consumption

31 time series inputs of the eNeuron Database correspond to consumption (see Table 3), nearly half of them (14) has electricity as an energy source, 8 for heat and cooling, 7 of natural gas and 2 for hydrogen. 12 inputs correspond to real data, while 19 come from math models or distributions. Data resolution goes from less than 1 minute (in the case of the electric vehicle) to 1 hour. Moreover, only one time series has information for less than one month, while the majority (17) has a one-year time horizon.

Table 3. Consumption time series database summary.

ID	Energy Carrier	Technology	Sector	Data Origin	Data resolution (min)	Time Horizon (months)
015	Electricity	Electric consumption	Educational	Real	1	24
016	Electricity	Electric consumption	Educational	Real	1	24
017	Electricity	Electric consumption	Educational	Real	1	24
018	Electricity	Electric consumption	Educational	Real	1	24
038	Electricity	Electric consumption	Residential	Synthetic	60	12
039	Heat/Cooling	HVAC	Residential	Synthetic	60	12
040	Electricity	Electric consumption	ALL	Synthetic	60	12
041	Heat	HVAC	ALL	Synthetic	60	12
042	Cooling	HVAC	ALL	Synthetic	60	3
044	Electricity	Electric consumption	ALL	Real	10	12
048	Electricity	Electric consumption	Educational	Real	10	24
052	Electricity	Electric consumption	Educational	Real	60	12
053	Natural Gas	Natural Gas consumption	Educational	Real	60	12
054	Cooling	HVAC	Educational	Synthetic	60	12
055	Heat	HVAC	Educational	Synthetic	60	12
058	Natural Gas	Natural Gas consumption	Educational	Synthetic	60	12
059	Natural Gas	Natural Gas consumption	Educational	Synthetic	60	12
060	Natural Gas	Natural Gas consumption	Residential	Synthetic	60	12
061	Natural Gas	Natural Gas consumption	Residential	Synthetic	60	12
062	Hydrogen	Hydrogen consumption	Industrial	Synthetic	60	12
067	Heat/Cooling	Electric boiler	Educational	Synthetic	1	12



ID	Energy Carrier	Technology	Sector	Data Origin	Data resolution (min)	Time Horizon (months)
068	Heat/Cooling	Electric boiler	Educational	Synthetic	1	12
069	Electricity	CHP	Educational	Synthetic	1	12
077	Hydrogen	Fuel Cell	Industrial	Synthetic	1	12
079	Electricity	Electric consumption	Educational	Real	1	12
085	Natural Gas	Natural Gas consumption	Health	Synthetic	1	12
086	Natural Gas	Natural Gas consumption	Health	Synthetic	1	12
089	Electricity	Electric Vehicle	Commercial	Synthetic	<1	<1
091	Electricity	PVE	Residential	Real	30	12
092	Electricity	Chillers	ALL	Real	30	12
093	Heat	HVAC	ALL	Real	60	12

### 4.3 Storage

4 time-series inputs of the eNeuron Database, correspond to storage (see Table 4), and all of them focus on battery storage. Three are based on synthetic data, while one is extracted from real data.

*Table 4. Storage time series database summary*

ID	Energy Carrier	Technology	Sector	Data Origin	Data resolution (min)	Time Horizon (months)
043	Electricity	Battery	Educational	Synthetic	60	12
064	Electricity	Battery	Industrial	Real	15	<1
087	Electricity	Battery	Commercial	Synthetic	1	<1
088	Electricity	Battery	Commercial	Synthetic	1	<1



## 5 Scenario's definition

This section provides the definition of 16 scenarios at different European locations (see Figure 3) for future simulation with the eNeuron toolbox.

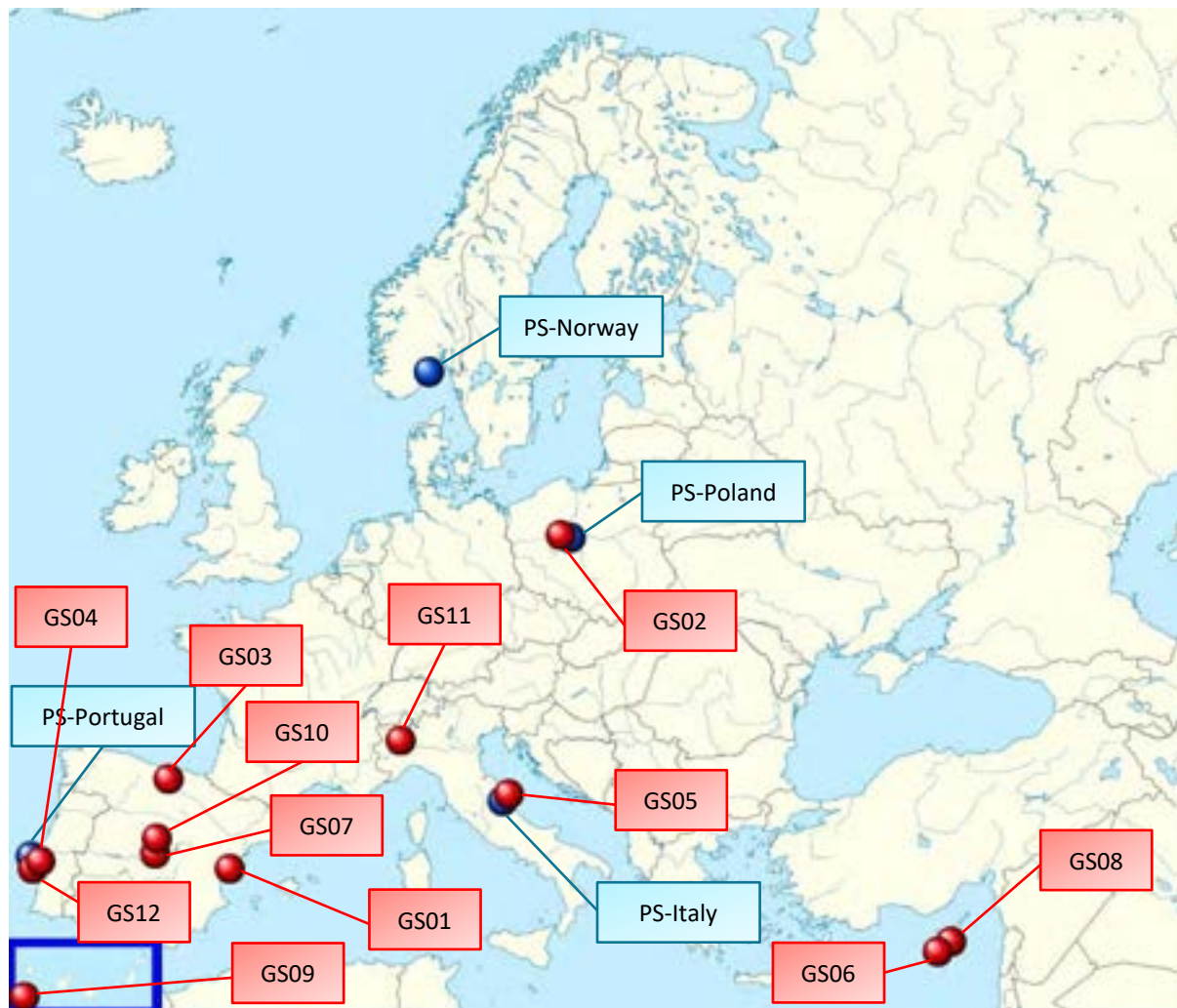


Figure 3. All scenarios location.

Twelve scenarios, named General Scenarios (GS, see Section 5.1), have been designed with the aim of covering a wide spectrum of energy carriers (i.e., gas, hydrogen, water, electricity, heating, and cooling) and locations. Moreover, to envision a future multi-energy carrier usage, all scenarios include at least two different energy carriers.

The other four scenarios, named Pilot Scenarios (PS, see Section 5.2), specifically focus on the pilots available at eNeuron consortium. These scenarios envision their implementation in the medium term, and their definition will allow a precise simulation prior to its real implementation within the project. Moreover, pilot scenarios plan different use cases to be simulated with the eNeuron toolbox.

A summary of the 16 defined scenarios is provided in Table 5.



Table 5. Description of the eNeuron's scenarios.

Scenario	Name	Gas	Hydrogen	Water	Electricity	Heat	Cooling	Sector
GENERAL	Scenario 01	X	X		X			Industrial
	Scenario 02	X		X	X			Commercial / Educational
	Scenario 03	X			X	X	X	Commercial / Educational/Industrial
	Scenario 04	X	X	X	X	X	X	Residential
	Scenario 05	X			X	X	X	Health
	Scenario 06		X	X	X			Industrial
	Scenario 07		X		X			Educational
	Scenario 08		X	X	X	X	X	Commercial / Educational / Residential
	Scenario 09			X	X			Commercial / Educational/Industrial / Residential
	Scenario 10			X	X	X		Commercial / Residential
	Scenario 11	X			X	X	X	Commercial / Industrial / Residential
	Scenario 12				X	X		Commercial / Industrial / Residential
PILOTS	Portuguese	X		X	X	X	X	Commercial / Industrial / Residential
	Norwegian				X			Commercial / Residential
	Polish	X			X	X		Commercial / Educational
	Italian	X			X	X	X	Educational

Every scenario, independently of being general or based on a pilot, must cover the following requisites: to include a description (including location) and a general diagram of the scenario for the scenario understanding and comprehension. Afterwards, technical characteristics, either available or planned to be included during the project duration, are described. Once the technical aspects are defined, energy management strategies and regulatory aspects to be considered in the scenario are included. Moreover, an analysis of economic costs, benefits and impacts is also included in every scenario definition.

Finally, every scenario is linked with the eNeuron Database. For every technology included in the scenario, real or synthetic time series are identified on the eNeuron Database.



## 5.1 General Scenarios

### 5.1.1 Scenario 01

CARRIERS					
				X	Gas
				X	Hydrogen
					Water
				X	Electricity
				X	Heat
					Cooling
				X	Industrial
					Commercial
					Residential
					Academic/Educational
					Health
					Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind	X	Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
	CHP		Cool		Water
	Diesel		Pumped Hydro	X	Hydrogen
X	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
X	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
Country	Spain		City	Vila-real	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



### 5.1.1.1 Scenario description

This scenario is based on the operation of a ceramics' plant production placed in Vila-real, Spain. This plant is composed of two principal lines, one of the high-temperature ovens and the other of medium-temperature electric boilers. The ovens are supplied by natural gas and the electric boilers by electricity, as shown in Figure 4.

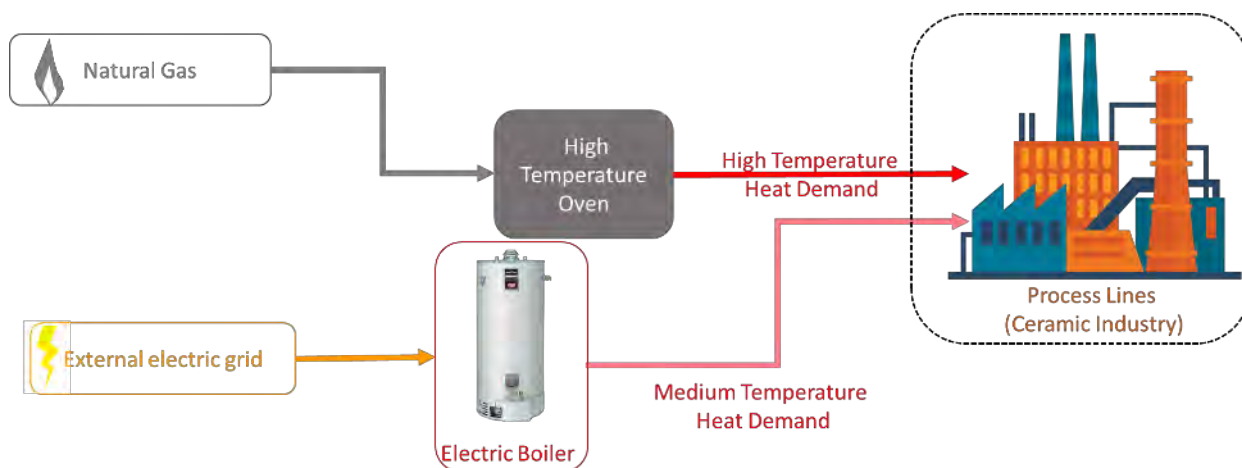


Figure 4. Scenario 01 - Initial scenario diagram.

The scenario is modified in order to consider producing green hydrogen by means of an electrolyser supplied by a PV system. Ovens used currently in ceramic processes use only natural gas [2]. For this reason, the oven's combustion system will be changed to admit both natural gas and hydrogen ( $H_2$ ). Moreover, the electric boiler will be changed for a high-efficient heat pump which can utilize excess waste heat from the processes lines by means of a new heat-conduction system. Performing these improvements will allow to reduce the use of fossil fuels, energy consumption and  $CO_2$  emissions and produce electrical energy from 100% renewable sources.

### 5.1.1.2 Scenario location

The ceramic industry consumes a great amount of energy due mainly to thermal energy-intensive processes. For this reason, the production plants of ceramic products are supplied by dedicated power centres. Also, to carry out the thermal processes, high temperature ovens and boilers are used in different production lines. To accomplish the technical and logistics requirements, these plants are located in industrial areas. For this scenario, the ceramic plant of 10,000  $m^2$  selected is placed in an industrial area near Vila-real, Spain (see Figure 5).

The climate conditions of this area are conducive to photovoltaic generation; minimum temperatures stay above  $0^\circ C$  even in winter, and the average hours of sunshine reach almost 200 h per month, as shown in Figure 6 and Figure 7.





Figure 5. Scenario 01 – Scenario Location.

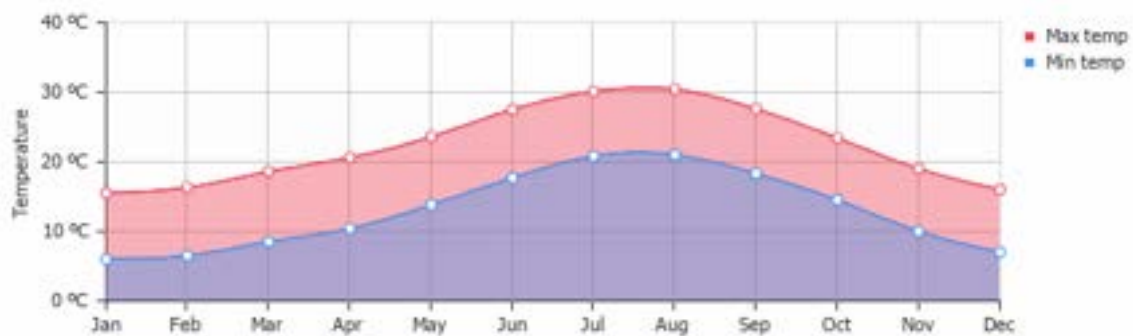


Figure 6. Scenario 01 - Temperature historic data [3].



Figure 7. Scenario 01 – Sun hours historic data [3].

### 5.1.1.3 Scenario diagram

In this scenario, the combustion system of the high temperature oven will be modified to use H<sub>2</sub> (from electrolyser) and natural gas (until 50% H<sub>2</sub> - 50% NG). In this way, this scenario introduces H<sub>2</sub> as a new carrier. Moreover, the boiler will be replaced by a high-efficiency heat pump, and a heat-



conduction structure will be included to utilize the waste heat excess from the production lines. These changes are shown in Figure 8.

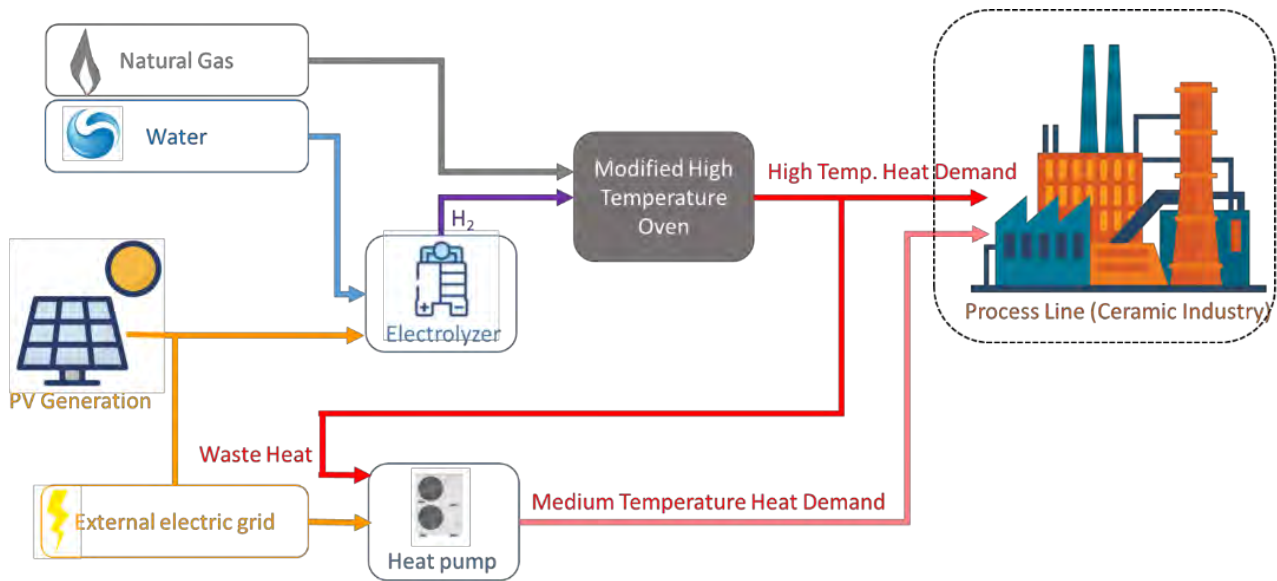


Figure 8. Scenario 01 – Scenario diagram.

Technological innovations included in this scenario have been proposed in the GREENH2KER project [4]. According to the analysis done in the project to produce renewable energy, a PV system of 6,000 m<sup>2</sup> can be installed in parking canopies around the plant. This energy will be used to supply an electrolyser producing green H<sub>2</sub> to feed high-temperature ovens. The surplus energy (not used for H<sub>2</sub> production) will be used to supply electricity to the new heat pump replacing the electric boiler. As a result, it is not expected to release electrical energy into the electric grid. The existing electrical installation will continue to supply the electricity necessary for medium temperature processes and other usages of the production plant. Also, water from the supply network is needed to feed the electrolyser. Hydrogen is produced and stored in the plant to be used as a fuel for the high-temperature oven combined with natural gas.

The scenario includes H<sub>2</sub> as a new carrier produced by the electrolyser. The addition of this new carrier is expected to reduce the amount of natural gas used and the CO<sub>2</sub> emissions of the high-temperature process. The change of the electric boiler for a heat pump and the use of the waste heat of the processes by means of the heat-conduction system will allow reducing the energy consumption and CO<sub>2</sub> emissions in the medium temperature process line.

#### 5.1.1.4 Technical characteristics

The PV power plant will have a new electrical installation formed by two electric transformers (650 kVA each), two groups of on-grid inverters (700 kW each), electrical protections and a smart meter. This plant has a photovoltaic system of 1.4 MWp with an estimated yearly production of 1.9 GWh. For this plant, an Energy Efficiency Ratio (EER) of 90% is assumed [5].

The rated power of the electrolyser is 900 kW. The production of green H<sub>2</sub> can be estimated as 3 tons/h [6]. Considering 2,000 h/year of electrolyser's operation, the production of H<sub>2</sub> can reach



6,000 tons/year. The average natural gas consumption of the high-temperature oven is 1,500 kWh/ton (considering only natural gas supply). The rated power of the new heat pump is 500 kW. Therefore, an average electricity consumption of this heat pump of 75 kWh/ton is expected. An EER of 60% is assumed for the electrolyser, and an EER of 85% is assumed for the new heat pump [5].

#### 5.1.1.5 Energy management strategies

This scenario focuses on three main objectives:

- a) Maximizing the electricity consumption from the PV power plant.
- b) Maximizing the energetic efficiency of the oven fed by H<sub>2</sub> and natural gas.
- c) Minimizing the CO<sub>2</sub> emissions of the new plant.

The scenario does not consider sharing energy with other users or releasing energy into the electric grid.

#### 5.1.1.6 Regulatory aspects

This scenario does not envision any regulatory limitation related to the local PV generation. The Spanish Royal Decree 244/2019 [7] regulates the administrative, technical and economic conditions of the self-consumption of electric energy.

On the other side, the ability of the Spanish government to commit large hydrogen infrastructure investments is limited due to economic costs, and no specific regulatory aspects have yet been developed. Therefore, this scenario relies on a feasible technical approach with the perspective that in 2050 the regulation of hydrogen will be a reality.

#### 5.1.1.7 Economic costs and benefits

As with the regulatory aspects, local PV generation is mature and ready to be installed in the industrial plant proposed in the present scenario. However, the analysis presented in [2] highlights the lack of industrial-scale demonstration projects of hydrogen and proposes public investment to develop innovative technologies. In addition to public investment, the costs associated with setting up the green H<sub>2</sub> production can be compensated with the reduction of the payment of CO<sub>2</sub> allowances.

From the analysis presented in [5] and [8], the following set-up costs per technology are estimated:

- Photovoltaic plant: 1,300 €/kWp.
- Electrolyser and H<sub>2</sub> storage: 700 €/kW.
- Heat pump: 600 €/kW.
- Heat recovery system: 20 €/kW.
- Water storage and supply system: approx. 180 €/m<sup>3</sup>.



#### 5.1.1.8 Impacts

The main environmental impact of the proposed scenario lies in reducing the CO<sub>2</sub> emissions by introducing H<sub>2</sub> as a green fuel and reducing 60% of electricity in a medium-temperature process by means of the heat pump performance. As a result, a saving of 2,350 tCO<sub>2</sub> eq/year is estimated, as is highlighted in [4].

#### 5.1.1.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

##### PV generation

- 006\_GEN-ELEC-PVE\_NONE-ELEC\_ES-NONE\_02062015-31122020

##### H<sub>2</sub> generation and storage

- 058\_CON-NGC-NGC-NGC-NGC-IT-SAVONA-01012019-31122019
- 059\_CON-NGC-NGC-NGC-NGC-IT-SAVONA-01012019-31122019
- 060\_CON-NGC-NGC-NGC-NGC-IT-TURIN-01012019-31122019
- 061\_CON-NGC-NGC-NGC-NGC-IT-ANCONA-01012019-31122019



## 5.1.2 Scenario 02

<b>CARRIERS</b>				X	Gas
					Hydrogen
				X	Water
				X	Electricity
					Heat
					Cooling
<b>SECTOR</b>					Industrial
				X	Commercial
					Residential
				X	Academic/Educational
<b>LOCATION</b>					Health
					Inland
					Island
					North Europe
				X	Centre Europe
					South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
	PV		Batteries	X	Electric
	Wind	X	Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
X	CHP		Cool	X	Water
	Diesel		Pumped Hydro		Hydrogen
	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Poland		<b>City</b>	Bydgoszcz	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>					Csa
				X	Cfb
					Dfb
					Dfc
					Cfa



### 5.1.2.1 Scenario description

In Poland, most public facilities are supplied with heat from the municipal heating network. Electricity supply is provided by the local electricity distributor, including all public buildings. Most heat and power plants in Poland produce heat from hard coal. On the other hand, commercial power plants generate electricity from lignite. Therefore, Polish cities have very poor air quality, which means they are heavily polluted with CO<sub>2</sub>, CO and NO<sub>x</sub> and particulate matter.

In recent years, there have been many programs supported by the Polish government aimed at reducing the emission of greenhouse gases. One of them, the installation of co-generation sources, relieves the local electricity grid.

This scenario focuses on the buildings of a school. The complex of buildings (school, swimming pool, sports hall...) is a public utility facility intended to the provision of sports services and an educational program of common swimming lessons. The facility relates to the existing school via a connector (through the sports and entertainment hall).

The designed multi-functional swimming pool with fitness rooms and a gym as well as a large meeting area are at the heart of the school. It connects the existing sports and entertainment hall and the School Complex in terms of its program and spatial design.

According to the function of the complex, the basic group of rooms in the facility is the swimming pool complex (including changing room). In addition, in the indoor swimming pool building, there is a spacious lobby with a waiting room for children, a large meeting area, an administrative block and cloakrooms.

During the school's operating hours, swimming lessons for students of the School Complex are offered. In the afternoons and evenings, the swimming pool is open to the general public. Occasionally, swimming competitions take place in the pool.

The functional layout and attractions allow the indoor swimming pool to be used independently from the school activities. For this purpose, there are independent entrances, changing rooms, toilets, as well as heating, lighting and ventilation.

The complex has a total of three basins (25 m swimming pool, 12.5 m swimming learning pool connected with a recreational pool) and a paddling pool for babies, two whirlpools and a tubular slide of 50 m. Also, its composition includes facilities for rescuers and a changing room. This combination of functions creates many possibilities for fun and learning for children of different ages.

The scenario considers the production of heat and electricity using a co-generation unit and thermal storage for the needs of buildings. The main source of heat is the municipal heating network and the source of electricity is the distributor of electricity. The heat supply of the facility system has been changed to allow both heat sources: natural gas and municipal heat. The co-generation system will provide electricity for the needs of buildings. Implementation of these improvements will reduce fossil fuel consumption, energy consumption and CO<sub>2</sub> emissions and produce electricity from 100% clean sources.



### 5.1.2.2 Scenario location

The Polish pilot covers the area of the city of Bydgoszcz (see Figure 9) and its major energy nodes, connected to both the LV and MV grid. Most of them are newly constructed buildings with some degree of energy self-sufficiency; they are also equipped with smart meters registering 15-minute energy consumption profiles and 10-minute phase voltage profiles.



Figure 9. Scenario 02 – Scenario location.

In this area, minimum temperatures stay above  $-3^{\circ}\text{C}$  even in winter (see Figure 10), with a maximum solar irradiance of  $160 \text{ kWh/m}^2$  (see Figure 11).

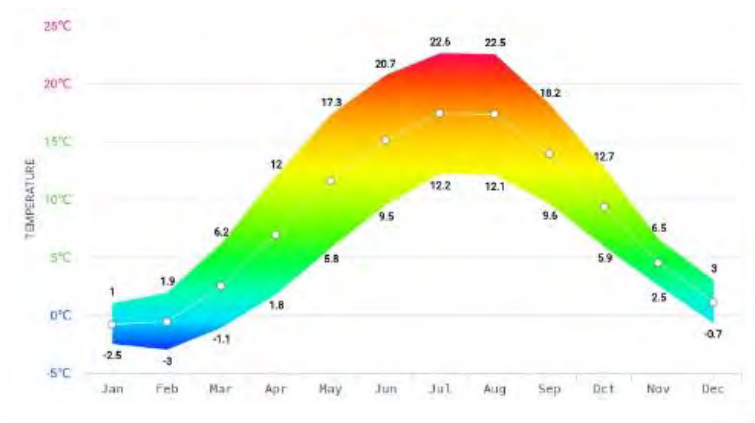


Figure 10. Scenario 02 – Temperature historic data.



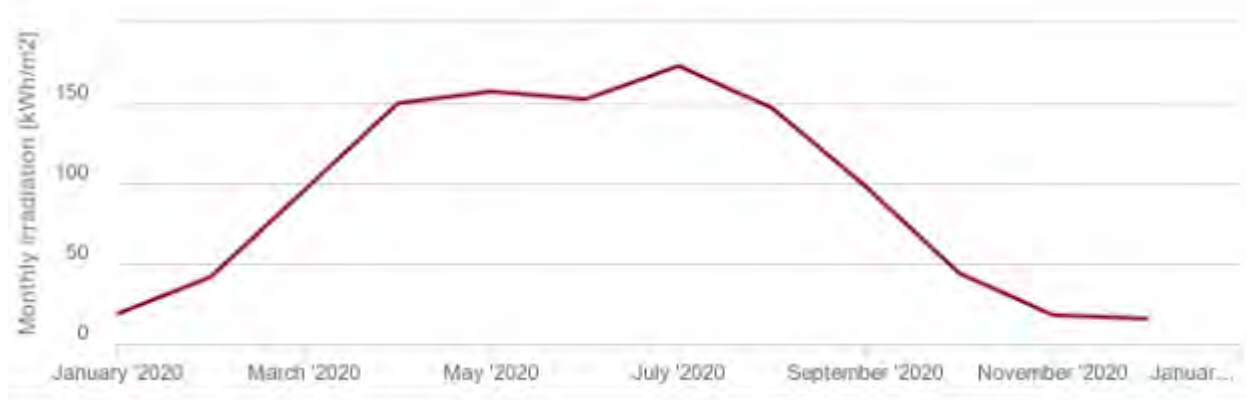


Figure 11. Scenario 02 – Irradiance historic data.

The site of the scenario is an indoor swimming pool with technical infrastructure and land development located in the school complex No. 28 at 11 Kromera Street in the northeast area of Bydgoszcz (see Figure 12).



Figure 12. Scenario 02 - Indoor swimming pool with technical infrastructure and land development.

### 5.1.2.3 Scenario diagram

The scenario considers three different carriers: high-methane natural gas, electricity, and municipal heating (see Figure 13). Building Management System (BMS) controls CHP units and storage boilers (two independent pairs of devices). In this scenario, the high-methane natural gas carrier is used to produce heat and electricity. Electricity is consumed locally by building needs or can be used for heating boilers. Electricity excess is transferred to the LV grid. The production of thermal energy is consumed locally, and the excess is stored in boiler plants.



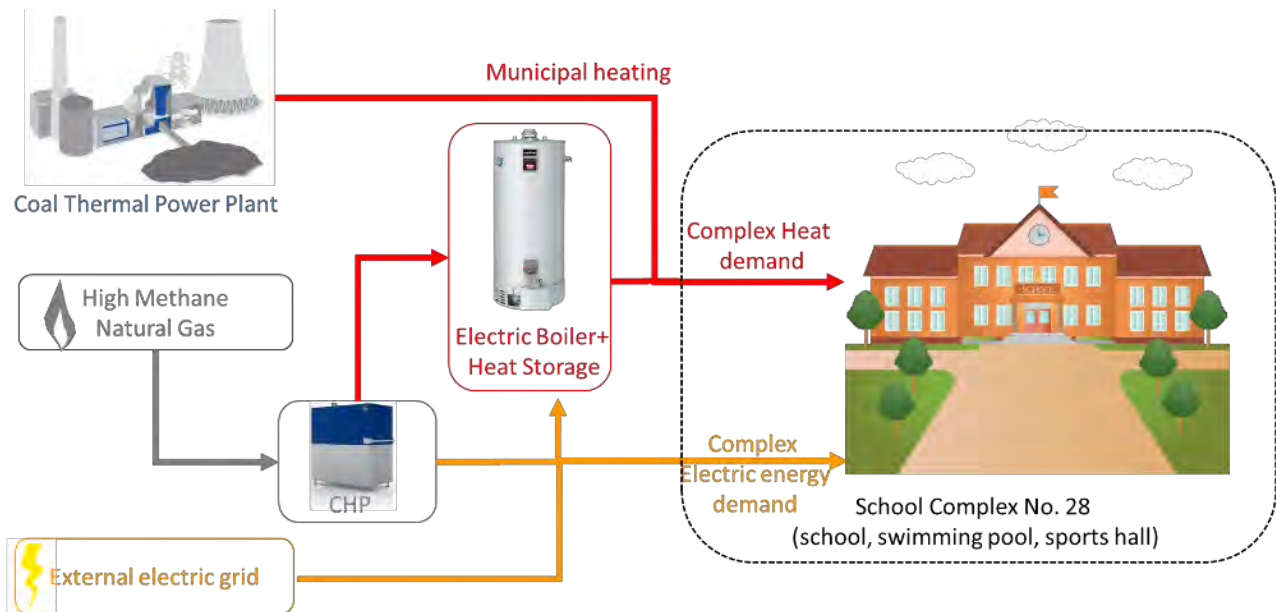


Figure 13. Scenario 02 – Scenario Diagram.

#### 5.1.2.4 Technical characteristics

The cogeneration system (gas engine) includes two separate units XRGI-20 (named XRG 1 and XRG 2), with the following technical parameters (each).

- Electric power 10÷20 kWe.
- Thermal power 26.1÷38.7 kWth.
- Boiler. Bufor tank 800 L with electric heater 2x9 kW.
- Total efficiency of XRGI-20 is 86.5%.

Two separate XRGI-20 cogeneration units are intended for installation in small rooms. The aggregate provides electricity and heat for supplying domestic hot water inside the building or for the heating system. XRGI devices with a power of 20 kWe are among the most compact CHP systems. The aggregate consists of 3 components: an engine unit, a heat distributor and an electronic system controlling the whole.

The CHP system consists of a cogeneration unit (see Figure 14a), a heat storage tank (see Figure 14b), and a control panel (see Figure 14c) connected to BMS.

The cogeneration unit is powered by a combustion engine powered by high-methane natural gas. The system can smoothly regulate the operation in the ranges presented above.



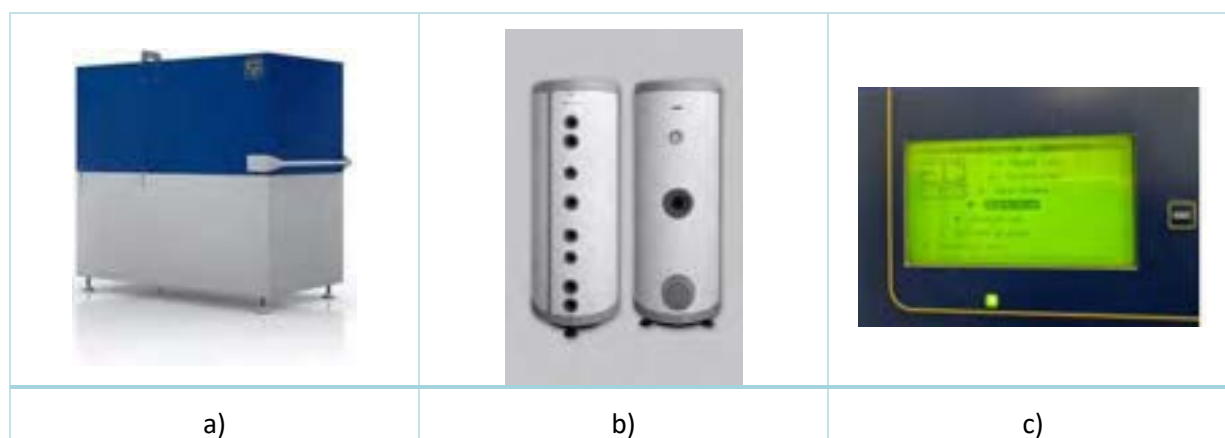


Figure 14. Scenario 02 - Elements of the cogeneration unit.

The balance of energy production and demand is presented in Table 6. The data are collected through a BMS. The BMS records the values of voltage, current, active power, frequency, and thermal power. The entire regulating process can be performed using the control in the BMS.

Table 6. Scenario 02 - Balance of energy production and demand on the facility.

		XRGI 1	XRGI 2	Total
1	Number of connections to the service base	717	190	<b>907</b>
2	Total operating time [h/y]	2,940	3,405	<b>6,345</b>
3	Fuel consumption of the CHP units [MWh/y]	242.0	232.7	<b>475</b>
4	Heat production by the CHP units [MWh/y]	139.2	133.8	<b>273</b>
5	Electric energy production [MWh/y]	70.3	67.6	<b>138</b>
6	Total number of generator starts [1/y]	1,469	1,458	<b>2,927</b>
7	The facility total electric power consumption [MWh/y]	735.4		<b>735..4</b>
8	The facility's electric power consumption covered by the XRGI® system [MWh/y]	70.3	67.6	<b>138</b>
9	The facility electric power consumption covered by power purchase from grid [MWh/y]	306.8	310.9	<b>596</b>
10	Sold electricity [kWh/y]	1.0	0.0	<b>1</b>

#### 5.1.2.5 Energy management strategies

This scenario focuses on four main objectives:

- Maximization of electricity and heat production for building's needs. In this way, minimization of energy consumption from the municipal network and electricity will be achieved.
- Maximizing the electrical and thermal energy production of the CHP generators.
- Maximizing the energetic efficiency of the boilers.
- Minimizing the CO<sub>2</sub> emissions of the facility.

#### 5.1.2.6 Regulatory aspects



In Poland, there is no need to obtain a license for an installation of a cogeneration plant with a total installed electrical capacity less than 50 kW, connected to a power grid with a rated voltage of less than 110 kV or with a combined heat output of not more than 150 kW when the total installed electric power is not more than 50 kW.

The Polish government encourages it through a system of subsidies for the replacement of old, dirty heat and energy sources.

#### 5.1.2.7 *Economic costs and benefits*

All systems are already installed and operational on this Scenario. They are designed to reduce the local energy consumption of installed facilities. An additional cost that must be borne by the user is the adaptation of devices for remote reading of measurement data and control of operating settings. This work will be carried out as part of the eNeuron project.

From the analysis presented in [4] and [8], the following set-up costs per technology are estimated:

- CHP unit: 6,000 €/kWp.
- Photovoltaic plant: 1,300 €/kWp.
- Heat pump: 600 €/kW.
- Heat recovery system: 20 €/kW.
- Water storage and supply system: approx. 180 €/m<sup>3</sup>.

#### 5.1.2.8 *Impacts*

The main environmental impact of the proposed scenario lies in adding new cogeneration gas heat sources and natural gas boilers devices. Instead of exclusively working with electricity and network heat (imported), the scenario includes heat and electricity generation. As a result, a saving of 5,800tCO<sub>2</sub> eq/year is estimated.

#### 5.1.2.9 *Database linkage*

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

Natural gas generation:

- 072\_GEN-ELEC-CHP\_ELEC-NONE\_PL-BYDGOSZCZ2\_01012021-31122021

Heat storage:

- 067\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ31\_01



## 5.1.3 Scenario 03

<b>CARRIERS</b>				X	Gas
					Hydrogen
					Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>					Industrial
				X	Commercial
				X	Residential
				X	Academic/Educational
<b>LOCATION</b>					Health
					Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
<b>TECHNOLOGIES</b>					
<b>Generation</b>		<b>Storage</b>		<b>Consumption</b>	
X	PV	X	Batteries	X	Electric
	Wind	X	Heat	X	HVAC
	Hydro		Electric Vehicle	X	Electric Vehicle
	CHP		Cool		Water
	Diesel		Pumped Hydro		Hydrogen
X	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
	Electric				
X	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
X	Absorption Chiller				
<b>LOCATION</b>					
<b>Country</b>	Spain		<b>City</b>	Bilbao	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>					Csa
				X	Cfb
					Dfb
					Dfc
					Cfa



### 5.1.3.1 Scenario Description

The presented scenario gathers four energy carriers: electricity, gas, heating, and cooling. The scenario is located in Bilbao (Spain, South Europe) and focuses on the Zorrotzaurre district in combination with municipal buildings located in the centre of Bilbao. Zorrotzaurre is an urban geographic island but electrically connected to the main electricity grid with the same facilities as the urban surroundings.

According to the local strategy for sustainable and integrated urban development, Zorrotzaurre island will become a residential and business district that will be an area for the deployment of new sustainable solutions. A district-scale vision for 2050 has been planned in the pathway of full decarbonization, in which Zorrotzaurre island is intended to be a Positive Energy District [9] with only thermal and electricity-based energy generation but without any gas infrastructure.

To complete the scenario with the presence of the gas carrier, it includes some additional buildings beside the island, in particular three municipal structures in the centre of Bilbao. The set of municipal buildings (Town Hall, San Agustín building and Annex building), with natural gas consumption, are very close between them with the possibility of setting up a shared electricity self-consumption community according to the Spanish regulation.

As the two locations for the scenario are around three kilometres apart, two EHs have been considered in the scenario, and several micro-energy hubs ( $\mu$ EHs) are included in each EH.

Therefore, the proposed scenario will be inspired by Zorrotzaurre island, including some future planned actions and the mentioned municipal buildings. The set of both districts is aligned with the energy carriers and technologies of the eNeuron project:

- The **Zorrotzaurre island** includes thermal facilities for heating, electricity generation based on PV, storage units based on Li-ion batteries and EVs infrastructure.
  - External electricity network is considered to interact with the EH.
  - Buildings will be equipped with smart meters in connection to the Smart Energy Management System, which controls the electric and thermal demand, storage, and local renewable generation.
  - PV installation on rooftops for generating renewable electricity, which feeds residential electricity demand, EVs and heat pumps. Electric storage (batteries) is considered for residential purposes.
  - Some buildings will be connected to a low-temperature heating network, fed by solar thermal and heat pumps as a support system. The thermal network is equipped with thermal storage.
  - Smart mobility services are considered from Smart Public Charging Hub for cars and bikes.
- The set of **municipal buildings**, gathered in the second EH, contains natural gas infrastructure, PV-based generation, lead acid-based UPS storage, and EVs infrastructure.
  - External electricity and natural gas networks are considered to interact with the EH.
  - PV installation on rooftops for generating renewable electricity, which feeds the office demand.
  - Heat pumps and natural gas boilers are used to feed heating demand.



- Heat pumps and chillers are used to feed the cooling demand in one of the buildings.
- One EV charger is included in one of the buildings to charge the public float.
- Lead-acid batteries are installed as an uninterruptible power supply.

### 5.1.3.2 Scenario location

The scenario is located in Bilbao (Spain, South Europe) with a Mediterranean climate (see Figure 15). Based on the European Köppen-Geiger classification, Bilbao has the Cfb climate zone without a dry season and warm summer [10]. Bilbao has a humid oceanic climate with an average temperature of about 8°C in winter and 20°C in summer. Therefore, only heating demand for winter is considered to model this scenario. Figure 16 provides a geographic map to show where the scenario should be planned.



Figure 15. Scenario 03 – Scenario Location.



Figure 16. Scenario 03 - Geographic map of Zorrotzaurre EH (left) and City Hall EH (right) for scenario 3.

### 5.1.3.3 Scenario Diagram

Figure 17 depicts the complete scenario and connection between all carriers and the involved technologies and infrastructures in each EH: electricity carrier (external electricity network, solar



PV, batteries and EV), thermal generation (solar thermal, heat pumps, heat storage, and electric chiller), gas network (external gas network, and natural gas boiler).

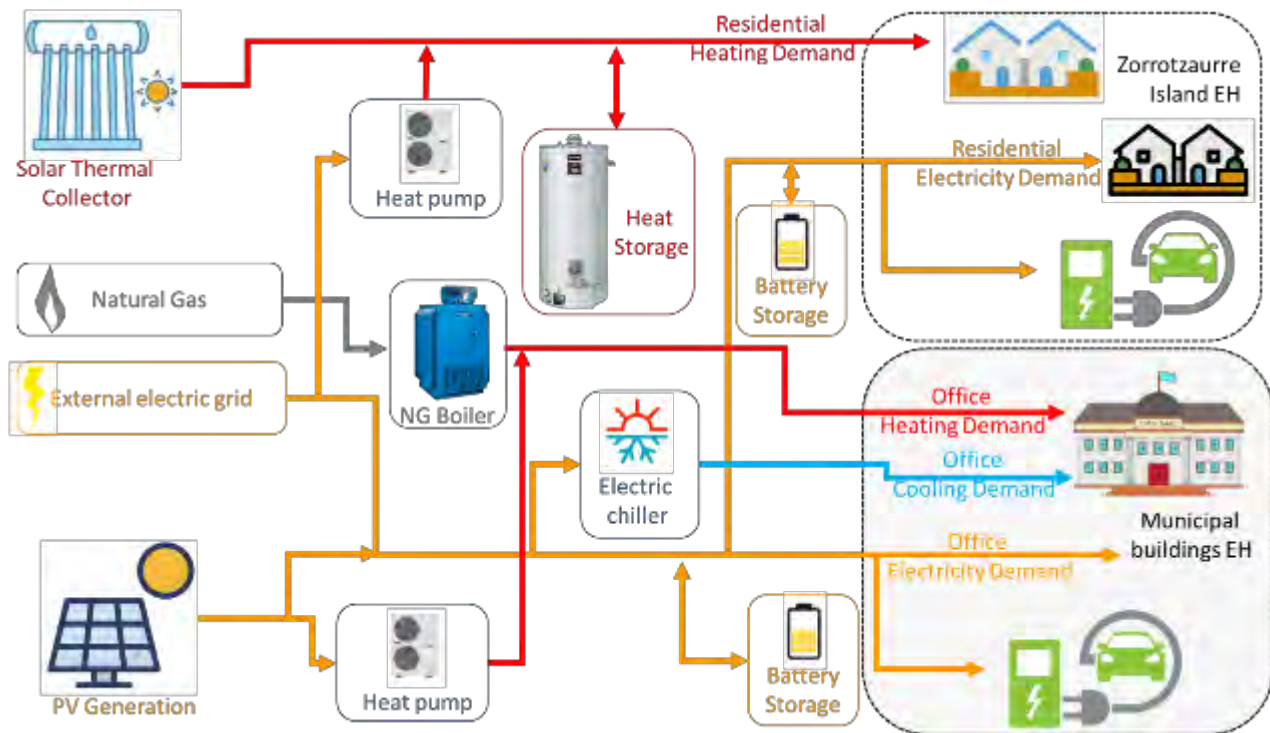


Figure 17. Scenario 03 – Scenario diagram.

The Zorrotzaurre EH is composed of two  $\mu$ EHs, located in the northwest and southeast area of the island. The north  $\mu$ EH oversees the control of thermal production, management and exchange with the southeast  $\mu$ EH (including a heat pump, solar thermal and heat storage). The southeast  $\mu$ EH contains the EV infrastructure (including EV chargers and battery storage in the main electric station). Both  $\mu$ EHs are composed of several buildings with local PV generation, electricity and heating needs (see Figure 18).

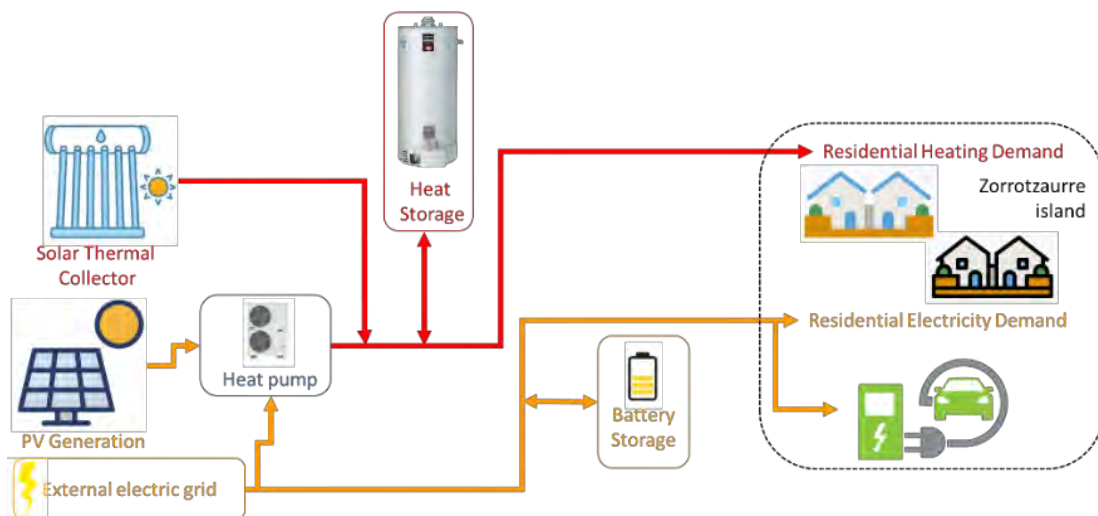


Figure 18. Scenario 03 - Zorrotzaurre EH diagram disclosed by  $\mu$ EHs.

The City Hall EH is composed of three buildings ( $\mu$ EHs) with their own electricity and thermal demands (see Figure 19) and their own equipment and generation assets, allowing them to share electricity via the external electricity grid. The electricity demand is fed by the external electricity grid, rooftop PV system (in annexe buildings and San Agustín) and UPS batteries to support blackouts in all  $\mu$ EHs. The heating demand is supplied via one heat pump per building and additionally with natural gas boilers (in the City Hall and San Agustín). As for the cooling demand, an electric chiller and a heat pump are installed in the San Agustín building. Additionally, a small EV charging station is considered in San Agustín  $\mu$ EH.

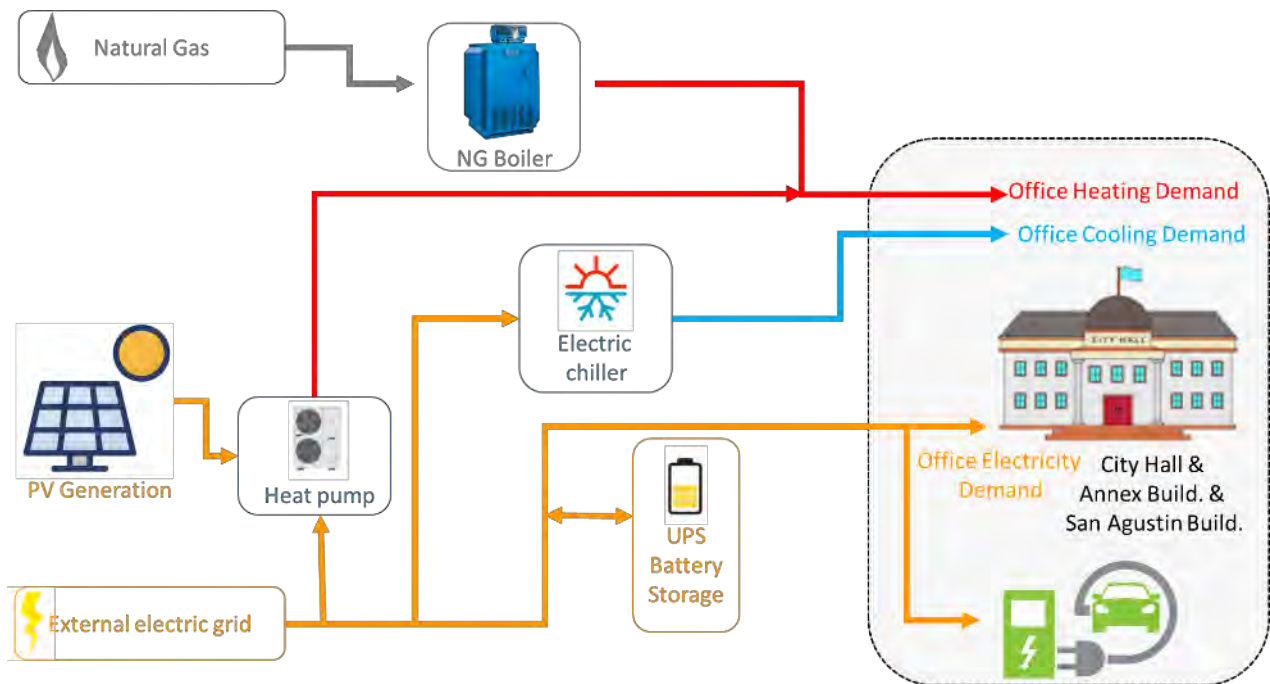


Figure 19. Scenario 03 - City Hall EH diagram disclosed by  $\mu$ EHs.

#### 5.1.3.4 Technical characteristics

The upstream electrical network of the city of Bilbao is composed of 6 MV substations [11], with HV/MV and MV/MV transformers (32 in total) at different voltage levels, from 13.2 kV up to 32 kV and 132 kV. The *Zorrotzaurre* substation comprises a 13 MW - 30 kV transformer, while the *Mazarredo* substation feeds the city centre, including the City Hall, through one transformer of 16 MW - 30 kV and four transformers of 21 MW – 13.2 kV each of one. Both MV substations are connected to the HV mesh network (132 kV) but at two different points of connection [12]. The LV network in both EHs is supposed to be 13.2 kV. The topology and other information about the LV network and the connection between MV substations are unknown (confidential). It is supposed 10% of electrical losses for MV and LV lines.

All known technical characteristics related to the elements included in the scenario are detailed below.

The north  $\mu$ EH is characterized as follows:



- Electricity demand of 800 MWh/year for residential, academic, and commercial buildings.
- Heating demand of 3,400 MWh/year for residential, academic, and commercial buildings.
- Installed rooftop photovoltaic system of 225 kWp with a production of 270 MWh/year.
- A central Li-Ion battery system (37.5 kW/70 kWh) will be considered for residential purposes.
- The heat pump should be optimally sized to support peak heating demand.
- Solar thermal installation with 3,500 OKP-10 (3500 m<sup>2</sup>) and an average efficiency of 70%, resulting in around a yearly heat production of 4,000 MWh. Seasonal heat storage should be optimally sized according to the storage needs or pre-defined around 1,000 m<sup>3</sup>, in addition to heat pumps that will support the thermal network.

The south  $\mu$ EH is characterized as follows:

- Residential and commercial electricity demand of 200 MWh/year.
- Residential and commercial heating demand of 900 MWh/year, supplied by north  $\mu$ EH.
- Smart Public Recharge Hub is supported by a PV system of 6 kWp (6.6 MWh/year).
- 70 kW/100 kWh Li-Ion battery system will be considered to foster cheaper EV charging.
- 2 double fast EV chargers of 50 kW and 2 double medium power EV chargers of 22 kW.

The electricity and heating demand profiles are unknown as most of the area is under construction. Therefore, the eNeuron toolbox is needed for design and sizing purposes. Previous simulations must be required to select optimally the installed power of heat pumps and seasonal heat storage size to meet the thermal demand.

In the case of City Hall EH, these buildings are used for the public and citizen services offices.

- Installed rooftop photovoltaic system of 30 kWp (36 MWh/year) in Annex building.
- Installed rooftop photovoltaic system of 64 kWp (77 MWh/year) in San Agustín building.
- The office demand per year: 300 MWh electricity, 100 MWh heating and 50 MWh cooling.

#### 5.1.3.5 *Energy management strategies*

This section includes all energy management strategies and modules foreseen.

- Renewable forecasting (photovoltaic and solar thermal).
- Electric and thermal load forecasting module (electricity demand for residential, commercial, and academic buildings in Zorrotzaurre EH, while office demand in City Hall EH).
- Energy market (day-ahead price) forecasting module.
- Energy trading module for day-ahead optimal dispatch (no ancillary services for distribution system operator (DSO)).
- Energy sharing (collective self-consumption) between  $\mu$ EHs along a perimeter of 500 meters is considered, while no energy sharing between EH is permitted.
- Peer-to-peer (P2P) markets downstream the  $\mu$ EHs (between consumers/prosumers) can be addressed.
- Boilers in City Hall EH should be used efficiently based on electricity and natural gas price.
- The eNeuron toolbox is needed for heat pump and heat storage optimally sizing.



### 5.1.3.6 Regulatory aspects

All regulatory aspects related to the considered scenario are included. Renewable energy communities and independent aggregators have been presented in the recent national regulation, but their technical and economic aspects, as well as practical implementation, are being under development. Directive 2019/943 on common rules for the internal electricity market allows consumers to benefit from the implementation of smart metering systems, as well as contracts with dynamic electricity prices.

The RED II Directive [13] introduces the "Renewable Energy Community (REC)". These communities must have the right to produce, consume, store, and sell renewable energy [18]. They will also be able to exchange, within the same community, the renewable energy produced by them and access all the appropriate electricity markets, directly or through aggregation, in a non-discriminatory way.

The Integrated Energy and Climate National Plan in Spain [14] states the right of the final customers to choose price-based tariffs to effectively participate in demand management and foreseen bilateral contracts and energy exchanges toward a P2P system. However, as of now, the Royal Decree 244/2019 [15] regulates the administrative, technical and economic conditions of the collective self-consumption of electric energy, not only for the residential sector but also for the industry sector. In collective self-consumption, the distance between the generation and loads must be less than 500 m.

Finally, the Royal Decree 23/2020 [16] incorporates urgent energy-related measures and new concepts. The independent aggregator is an agent which provides aggregation services and is not related to the customer's energy supplier, understanding aggregation as combining the demand of several electricity consumers and/or of several generators for sale, purchase, or auction in any market of electricity, which will drive the dynamic demand response. The renewable energy communities, which are legal entities based on open and voluntary participation, controlled autonomy and effectively by partners or members who are located close to the renewable energy projects, could be composed of consumers, SMEs or local authorities, whose primary purpose is to provide environmental, economic, or social benefits to their members, or to the local areas where they operate, instead of financial gains.

### 5.1.3.7 Economic costs and benefits

The future benefits and energy costs of the scenario should be provided through the eNeuron toolbox application.

- Installed rooftop photovoltaic system: 1,225 €/kWp.
- Residential Li-Ion battery system: 500 €/kWh.
- Solar thermal for district heating: 350 €/kWth, whose LCOHEAT is around 5 c€/kWh.
- Heat pump: CAPEX between 500 – 800 €/kW and OPEX between 5 – 10 c€/kWh.
- Heat water storage tank: around 200 €/m<sup>3</sup>.
- Natural gas boiler: 250 – 350 € / horsepower.
- Electric chiller: 450 – 650 € / ton.



- Lead-acid UPS battery: 100 €/kWh.
- Smart Public Recharge Hub Charging infrastructure in Zorrotzaurre EH: 300,000 €
- Electricity network IT infrastructure and smart meters in Zorrotzaurre EH: 60,000 €

#### 5.1.3.8 Impacts

A positive environmental impact, mainly related to the reduction of CO<sub>2</sub> emissions, is obtained through the adoption of low-carbon energy solutions for electricity, heating, and transport.

The expected impacts will be linked to the avoidance of CO<sub>2</sub> emissions in the transport and residential/commercial sectors. Electric means of transport reduce the CO<sub>2</sub> emissions hugely compared to fossil fuel-based vehicles [17], as shown in Table 7. In fact, a reduction of 64% of CO<sub>2</sub> emissions is reached with an electric car compared to a combustion-based car.

Table 7. Scenario 03 - CO<sub>2</sub> emission per transport.

Transport	gCO <sub>2</sub> per kilometre and passenger
Combustion car	121
Hybrid car	103
Motorcycle	53
Urban bus	49
GNG – CNG bus	42 - 37
Electric car	43
Electric motorcycle	17
Electric bicycle	3

Moreover, the self-consumption of local renewable generation will reduce the carbon footprint of the EH compared to the CO<sub>2</sub> emissions associated with the external grid dependence (0.19 tCO<sub>2</sub>/MWh, 2019) [18]. Finally, a gas-fired boiler for thermal demand (mainstream technology) is combined with solar thermal energy in Zorrotzaurre. CO<sub>2</sub> emissions related to heating demand could be partially associated with the boiler (gas emissions) and heat pumps/chiller (electricity emissions) in their share of heat demand.

Electric surpluses can be sold to the surrounding area through the wholesale day-ahead market, reducing the need for other polluting sources of energy. Due to local energy production (electric and thermal), the external energy dependency is also reduced, and it is expected to have a lower cost of energy.

#### 5.1.3.9 Database linkage

Time series for consumption and generation, as well as the technology models, are extracted from the eNeuron Database on an hourly basis. PV and solar thermal generation can be considered in warm climates and with a good level of irradiance (around 1,200 kWh/kWp, based on the historical monthly data from PVGIS tool [19]). Default values for technical parameters of the involved technologies will be considered according to eNeuron technology models.



For the simulation north  $\mu$ EH of this scenario, the following time series of the eNeuron Database can be used:

- PV generation
  - 004\_GEN-ELEC-PVE\_NONE-ELEC\_EU-NUTS2\_01011986-31122015
- Electric demand
  - 040\_CON-ELEC-ELC\_ELEC-ELEC\_IT-Turin\_01012019-31122019
- Heating demand
  - 041\_CON-THER-HVA\_HEAT-HEAT\_IT-TURIN\_01012019-31122019
- Solar thermal
  - 065\_GEN-THER-CSP\_IRRA-IRRA\_ES-BILBAO\_01012015-31122015

For the simulation south  $\mu$ EH of this scenario, the following time series of the eNeuron Database can be used:

- Electric demand
  - 040\_CON-ELEC-ELC\_ELEC-ELEC\_IT-Turin\_01012019-31122019
- Heating demand
  - 041\_CON-THER-HVA\_HEAT-HEAT\_IT-TURIN\_01012019-31122019
- PV generation
  - 036\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-MADRID\_15102015-04082017
- Electric vehicle demand:
  - 089\_CON-ELEC-ELM\_ELEC-NONE\_ES-MADRID\_11032017\_11032017

The electricity and heating demand profiles are unknown as most of the area is under construction.

In case of City Hall EH, both buildings are used as public and citizen services offices.

- PV generation
  - 004\_GEN-ELEC-PVE\_NONE-ELEC\_EU-NUTS2\_01011986-31122015
  - 004\_GEN-ELEC-PVE\_NONE-ELEC\_EU-NUTS2\_01011986-31122015
- Office/commercial electric demand:
  - 052\_CON-ELEC-ELEC-ELEC-ELEC-IT-ANCONA-01012019-31122019
- Office/commercial heating demand:
  - 055\_CON-THER-HVA-HEAT-HEAT-IT-ANCONA-01012019-31122019
- Office/commercial cooling demand:
  - 054\_CON-THER-HVA-COLD-COLD-IT-ANCONA-01012019-31122019
- Electric vehicle demand:
  - 089\_CON-ELEC-ELM\_ELEC-NONE\_ES-MADRID\_11032017\_11032017

As a first approach, synthetic demand and production profiles will be used from the eNeuron Database as exposed above. In the case of available measured data related to the scenario, the synthetic profiles will be substituted by real generation/consumption profiles and linked to the associated database file. Consequently, the magnitudes of the electricity and heating demands, as well as the size of some equipment, might be adapted to the final scope, interest, or data availability of the scenario.



## 5.1.4 Scenario 04

<b>CARRIERS</b>				X	Gas
				X	Hydrogen
				X	Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>				X	Industrial
					Commercial
				X	Residential
					Academic/Educational
<b>LOCATION</b>					Health
				X	Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV	X	Batteries	X	Electric
	Wind	X	Heat	X	HVAC
	Hydro	X	Electric Vehicle	X	Electric Vehicle
	CHP		Cool	X	Water
	Diesel		Pumped Hydro	X	Hydrogen
X	Heat pump	X	Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
X	Solar thermal				
X	Electrolyser				
	NG Reforming				
	Fuel Cell				
X	Absorption Chiller				
LOCATION					
<b>Country</b>	Portugal		<b>City</b>	Almada	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



#### 5.1.4.1 Scenario description

This scenario focuses on a Naval Base campus (see Figure 20) envisioning an ambitious multi-carrier scenario for 2050.



*Figure 20. Scenario 04 - Lisbon Naval Base overview.*

Most of the Portuguese Naval fleet ships are based there, as well as many of its administrative, training and support services. Within its perimeter are also located the Naval School, the Naval Technologies School, the Alfeite Arsenal, the Marine Corps Base, and other Portuguese Navy units.

Accordingly, the Base can be considered divided into “units” with very different profiles: residential (messes/canteens, living quarters), tertiary (offices, sports centre) and industrial (wharves, workshops, etc.). These “units” are relatively independent and are considered in this scenario as  $\mu$ EHs.

In 2050, it is expected that the Lisbon Naval Base will have the following grids/carriers at the EH level: electricity, water, natural gas, and hydrogen. At the  $\mu$ EH level, additionally, the heat and cooling carriers are expected.

At the EH level, large-scale PV systems and grid-forming Battery Energy Storage Systems (BESS), water storage tanks and pumps, natural gas compressors and storage tanks, and hydrogen electrolyser and storage tanks will be centralized. This will partly have the objective of making the Base energetically independent during short to medium time duration periods.

At the  $\mu$ EH level, the different units/compartments can be slightly different in terms of resources participating, but most of them will have PV and/or solar thermal generation, heat pumps, heat and cooling storage, and Vehicle-to-Grid (V2G) EV chargers. Building/Home Energy Management Systems (H/BEMS) will also be installed. In 2050, it is expected that at least five different  $\mu$ EHs will be present within the Lisbon Naval Base EH: the Sports Centre, the Canteen, the Residential Mess, the Workshops, and an Administrative Building to be defined.

This setup, in addition of contributing to strategic goals, will provide huge flexibility opportunities, and use cases, and ultimately will lead to significant environmental and economic benefits.



#### 5.1.4.2 Scenario location

This scenario is located in the Lisbon Naval Base practically at sea level (see Figure 21). Established in a very large area, despite the name, Lisbon Naval Base is located in the city of Almada, on the southern bank of the Tagus River estuary.



Figure 21. Scenario 04 – Scenario Location.

Almada has a similar climate to Lisbon (see Figure 22), namely mild to warm, moderated temperatures, winters are very mild for its latitude, the influence of the Portugal Current, a weak current by-product of the Gulf Stream, average highs during this season vary between 15°C and 16°C. Lisbon has the mildest winter nights out of any major European city, ranging between 8°C and 10°C. Summers are warm to hot; regions east of the Tagus Estuary usually average around 30°C maxima in July and August. Summer nights are often independent of the location, averaging a comfortable 16–19°C. For this reason, cooling needs usually surpass heating needs.

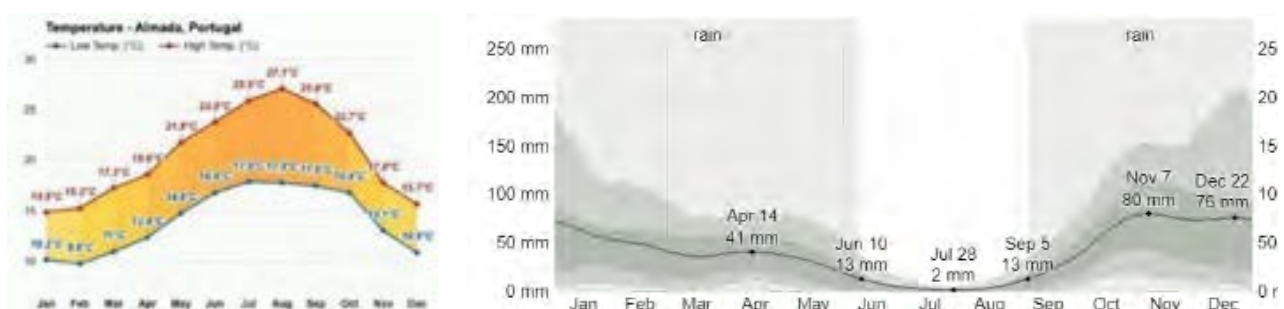


Figure 22. Scenario 04 – Climate historic data.



### 5.1.4.3 Scenario diagram

Figure 23 depicts the complete scenario and connection between all carriers and technologies involved in the Lisbon Naval Base Energy Hub scenario for 2050. The main differences between the 2050 scenario and the present-day scenario are:

- Usage of only Heat Pumps and Solar Thermal for supplying Heating and Cooling needs.
- Large-scale installation of V2G EV chargers.
- Installation of a grid-forming BESS system.
- Large-scale expansion of PV generation.
- Local H<sub>2</sub> production by electrolyser, to be used in the ships.

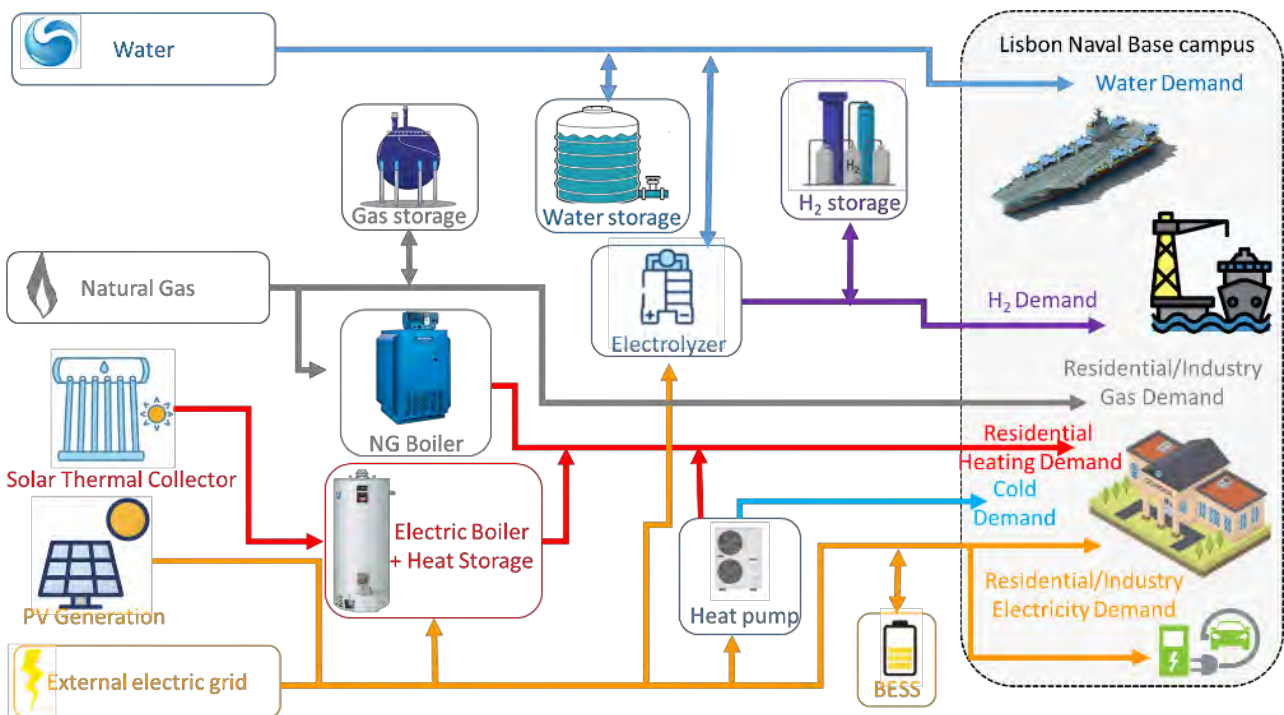


Figure 23. Scenario 04 – Scenario diagram.

As aforementioned, each “unit” in the base can be considered as a  $\mu$ EH. Despite each one having its own characteristics, every  $\mu$ EH can be generally characterized by the same schematic with electricity, heating, and cooling, with the variation between different  $\mu$ EHs being basically the consumption profiles and volumes.

### 5.1.4.4 Technical characteristics

The most important grid to be considered in this scenario is the electrical grid because it interfaces with all the other carriers, and it is where the largest power flows occur.

The coupling point to the electrical grid is a 30 kV/6 kV main substation with an apparent power of 5 MVA. Despite this, there is a secondary substation fed at 30 kV, with 2 x 1.2 MVA installed power. All the MV and LV connections are made with buried insulated cables. The cables are all of the type monopolar, XPLE insulation, and aluminium core with varying core cross-sections. The transformers



in the Secondary Substations (SS) fed at 6 kV have nominal powers between 400 kVA and 1,600 kVA, and each SS serves one or two units, as shown in Figure 24. The five  $\mu$ EHs are indicated in the figure as the 5 units that have decentralized PV.

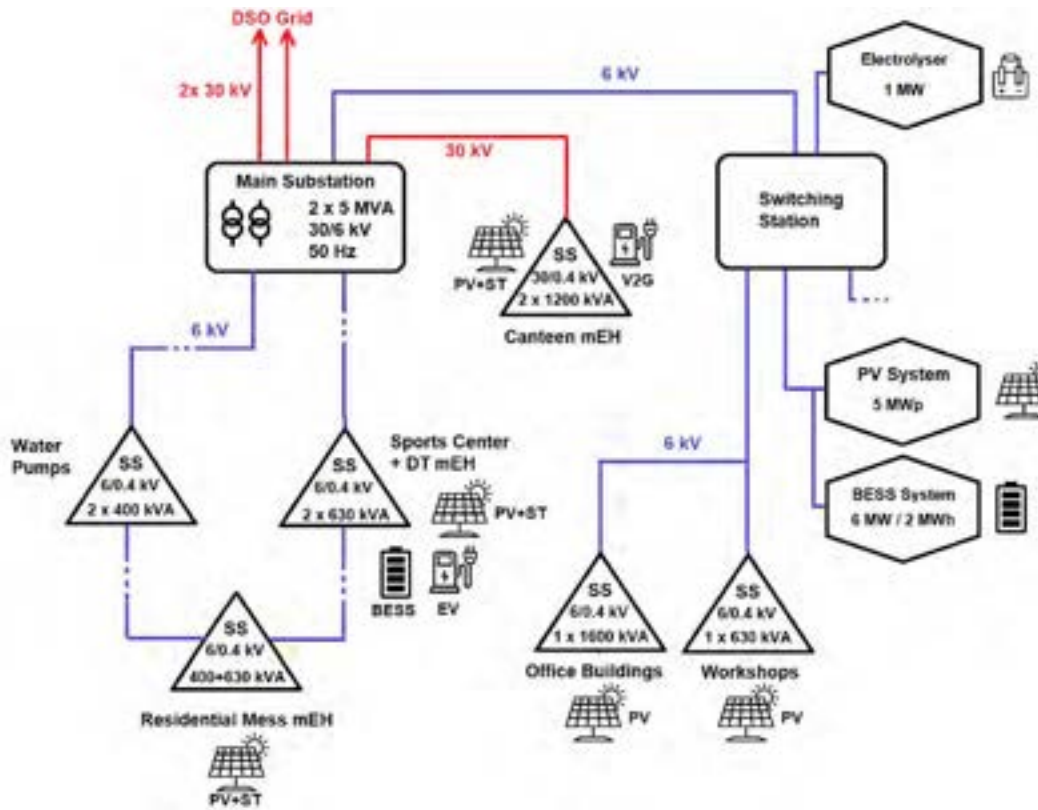


Figure 24. Scenario 04 - Lisbon Naval Base electrical grid diagram.

There is a 60 Hz sub-grid which is fed by a 3.5 MVA dynamic converter, which is used to feed the warships. This grid (as of 2021) has a total consumption of 25 GWh/year and a peak annual load of 6 MW. Apart from EV penetration and H<sub>2</sub> production, consumption is not expected to increase significantly in the next years. It may even decrease due to efficiency gains and conversion from electric heating and cooling to heat pumps and solar thermal.

The main grid-forming BESS system will be a containerized solution which will have 6 MW/2 MWh. This will enable max load pickup for a short time and critical load for a significant period. It will be installed in the main PV system in order to easily absorb excess generated power.

The maximum installed PV power is estimated to be 5 MWp centralized + 1 MW decentralized ( $\mu$ EH level), which at this location can generate up to 9 GWh/year.

The electrolyser will have a 1 MW capacity and 40% minimum part load.

Regarding the water carrier, there are 3 water tanks with a capacity of 50 m<sup>3</sup> each. Each one has 2 x 1 kW pumps for water pumping from the well to the storage tank.



Regarding natural gas, for the 2050 scenario, only industrial usage will be considered. There will also be 2 storage tanks (70 m<sup>3</sup> total capacity can be considered) and 2 compressors to store a reserve of natural gas.

Moving on to the «units», or  $\mu$ EH level, most of the units in the Lisbon Naval Base have good conditions to install PV generation. An average of 200 kWp can be installed on each unit. Some units will have only PV generation and heat pumps for HVAC; others will have only solar thermal or a mix of thermal and PV. These units will have H/BEMS systems that can cooperate with the eNeuron toolbox. Initially, there will not be any small-scale battery storage. It is expected that they will be installed over time, using second-life batteries from the Navy EV or warship fleet.

Nowadays, there is only one EV charging station at the Lisbon Naval Base. This is expected to change soon, ramping up to at least 20 EV chargers per  $\mu$ EH by 2050. Some of these chargers will be V2G-type for increased flexibility opportunities.

#### 5.1.4.5 Energy management strategies

The Lisbon Naval Base EH operation will focus on the following main objectives:

- Minimizing the importation of electricity from the upstream external network.
- Short to medium duration islanding operation possibility, in order to guarantee strategic continuity of supply.
- Analyse the possibility of exporting electricity and providing ancillary services to the external network.
- Maximizing the usage of RES resources and thus, minimizing overall CO<sub>2</sub> emissions.
- Maximize flexibility in order to minimize costs for the different  $\mu$ EHs and for the whole LEC/EH.

To accomplish these objectives, there are a number of strategies/functionalities that should be in place and will be offered by the eNeuron toolbox. The ones that are crucial for this scenario development are the following:

- Renewable forecasting (PV generation).
- Electric and thermal load forecasting.
- Demand-side management.
- Energy market forecasting.

#### 5.1.4.6 Regulatory aspects

Practically all the technology implementation presented in Figure 23 is already in place as of today, except for the electrolyser, the BESS and the V2G chargers. PV, BESS systems and V2G can be used easily at present on a self-consumption basis, according to the Portuguese Law Decree no. 162/2019. But, in order to export electricity to the public grid, at present, the Base has to be registered as a producer and make a contract.

The Lisbon Naval Base LEC has the advantage of having its own private grids, with single-point interfaces with the public grids. Accordingly, the EH and  $\mu$ EH can be much more flexibly managed



as long as the requirements at the interface points are met. In this case, there is no need to wait for the LEC legal framework that is still pending to be published.

#### 5.1.4.7 *Economic costs and benefits*

Overall technology costs can be extracted from eNeuron public deliverable D2.2: «Technical solutions for multi-carrier integrated systems under the LEC concept: A review» and «Renewable power generation costs in 2020» [20]. In detail:

At EH level:

- Medium Voltage PV: ~1,000 €/kWp.
- Medium Voltage Grid-forming BESS: 100-200 €/kWh.
- Electrolyser:
  - ALK: 500-1,000 €/kWe.
  - PEM: 700-1,200 €/kWe.
  - SOEC: 2,000-3,000 €/kWe.

At  $\mu$ EH level:

- Solar Thermal: ~1,000 €/kW.
- Low Voltage PV: ~1,000 €/kWp.
- Low Voltage BESS: 100-200 €/kWh.
- EV chargers:
  - 3 – 7 kW (public): 3,400 €.
  - 11 – 22 kW (public): 4,500 €.
  - 50 kW: 31,000 €.
  - 150 kW: 75,000 €.
  - 250 – 350 kW: 150,000 – 200,000 €.
- HVAC heat pumps: CAPEX between 450 €/kW to 850 €/kW for systems with a capacity of 7-20 kW. Installation costs begin from 300 €/kW. OPEX is 3 c€/kWh.

Therefore, the benefits for the LEC are expected to be very significant and threefold: economical, environmental, and strategical (to reduce dependence from external sources). With an optimized operation of the Lisbon Naval Base LEC enabled by the eNeuron toolbox, return of investment (ROI) should occur fast and the energy costs for end-users are expected to reduce by a minimum of 40%, whereas CO<sub>2</sub> emissions are expected to decrease by 80% (40% directly plus 40% indirectly). The benefits should be felt outside the LEC also, due to decreased consumption and investment in assets by the DSO, and by the possibility of exporting energy and providing ancillary services.

#### 5.1.4.8 *Impacts*

The city of Almada is a signatory of the Covenant of Mayors and has developed a SECAP which has been in force since 2018, committing to a goal of a 60% reduction in CO<sub>2</sub> emissions by 2030 and 80% by 2050.



It is expected that this LEC will contribute to numbers in line with the Almada SECAP objective. This can happen especially if the Lisbon Naval Base LEC can prove to be energy net-zero or even export renewable electricity to the upstream network.

#### 5.1.4.9 Database linkage

Unfortunately, there are still no specific time series obtained from real data of the scenario. This is because smart meters and the required data infrastructure are non-existing as of the time of the writing of this deliverable and are currently in the process of being acquired and installed in the next few months at the Lisbon Naval Base. Nonetheless, usual profiles for the different generation technologies and for the different demand patterns can be considered, with the respective scaling to meet the main numbers. Therefore, some possible eNeuron Database time series that can be used for the scenario generation are:

At  $\mu$ EH level:

- Solar PV:
  - 078\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-ELHIERRO\_01012005-31122016
  - 057\_GEN-ELEC-PVE-IRRA-ELEC-IT-ANCONA-01012018-31122018
- Battery Storage:
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
- V2G:
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
  - 088\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017
- Heat Pump:
  - 070\_CON-HVAC-HEP\_ELEC-NONE\_PL-BYDGOSZCZ3\_01012021-31112021
- Electricity consumption
  - Residential:
    - 038\_CON-ELEC-ELC\_ELEC-ELEC\_IT-TURIN\_01012019-31122019
  - Residential, office, commercial aggregated:
    - 040\_CON-ELEC-ELC\_ELEC-ELEC\_IT-Turin\_01012019-31122019
  - Residential, Industrial and Commercial aggregated:
    - 044\_CON-ELEC-ELC\_ELEC-ELEC\_ES-ELHIERRO\_01012018-3112201
- Heat consumption:
  - 070\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ31\_01012021-31122021
  - 039\_CON-THER-HVA\_HEAT+COLD-HEAT+COLD\_IT-TURIN\_01012019-31122019
- Cold consumption:
  - 054\_CON-THER-HVA-COLD-COLD-IT-ANCONA-01012019-31122019
- EV mobility consumption (kW) – real data, 15 min resolution.
  - 087\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017
  - 088\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017

At EH level:

- Solar PV:



- 078\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-ELHIERRO\_01012005-31122016
- Grid-forming BESS:
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021 (scaled)
- Electrolyser:
  - 063\_GEN-HYDR-H2E-WIND-HYDR-PT-PORTO-01012023-31122023 (scaled)
- H<sub>2</sub> consumption:
  - 062\_CON-HYDR-H2C-HYDR-NONE-PT-PORTO-01012023-31122023 (scaled)



## 5.1.5 Scenario 05

<b>CARRIERS</b>				X	Gas
					Hydrogen
					Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>					Industrial
					Commercial
					Residential
					Academic/Educational
				X	Health
<b>LOCATION</b>					Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind		Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
X	CHP		Cool		Water
	Diesel		Pumped Hydro		Hydrogen
	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Italy		<b>City</b>	Ancona	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



#### 5.1.5.1 Scenario description

This scenario focuses on a real hospital building with a high number of places to host important and several medical interventions. A thermal power plant is located at the site of the hospital and is composed of natural gas boilers and a Combined Cooling, Heat and Power (CCHP) unit that supplies both the heating and cooling energy demands of the hospital. PV panels are also installed on the roof of the hospital to supply part of the required electrical energy demand together with the CCHP unit, while the remaining one is withdrawn from the national electric grid.

The present scenario considers data on the energy demands (heating and cooling) as well as the energy production from i) natural gas boilers, ii) a Combined Cooling, Heat and Power (CHP) unit, and iii) PV panels.

#### 5.1.5.2 Scenario location

This scenario focuses on the “Torrette” hospital located in Ancona, namely in the Marche Region (centre of Italy, see Figure 25).



Figure 25. Scenario 04 – Scenario Location.

The “Torrette” hospital has been chosen for the current scenario, and Figure 26 shows a top view of the site under investigation.





Figure 26. Scenario 05 - Map of the “Torrette” hospital in Ancona (Italy). The thermal power plant is highlighted in red.

Since the site of “Torrette” hospital is located at the geographical coordinates  $43^{\circ} 34' 53''$  N  $13^{\circ} 30' 10''$  E, the lowest and the highest values of direct solar radiation are equal to  $0.7517 \text{ kW/m}^2$  (21<sup>st</sup> of December) and  $1.025 \text{ kW/m}^2$  (21<sup>st</sup> of June), respectively. Figure 27 shows the number of hours when the sun is shining each day, which is the number of hours between sunrise and sunset each day.

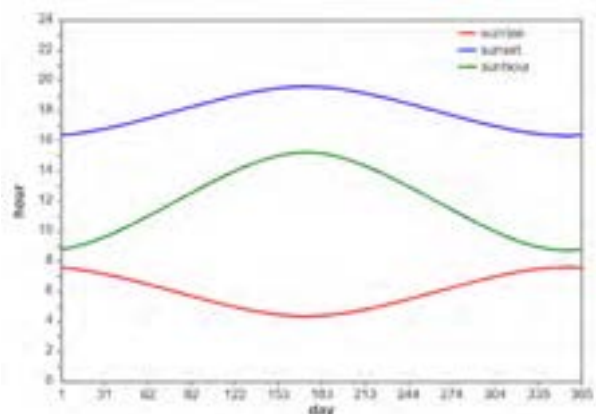


Figure 27. Scenario 05 – Sun hours' historic data.

The climate of Ancona is Mediterranean, with quite cold, relatively rainy/snowy winters and hot, sunny summers. The city is the chief town of the Marche Region, and it is in the centre of Italy, close to the Adriatic Sea (East coast). Winter, from December to February, is relatively cold. The rains are



quite frequent (few snowfalls) but generally not abundant. Summer, from June to August, is hot and sunny. Spring and autumn are mild and variable, with sunny periods.

#### 5.1.5.3 Scenario diagram

The present scenario considers four energy carriers: electricity, natural gas, heating, and cooling. Figure 28 shows the energy carriers and the technologies involved in the site under investigation.

The electricity is partially produced by PV panels installed on the roof of the hospital and the CCHP unit, while the remaining one is withdrawn from the national grid.

The heating demand of the hospital is supplied by i) natural gas boilers and ii) a CCHP unit, while the adsorption chillers use the heat from the exhausts to provide cooling energy when needed. All the thermal technologies previously mentioned are located in the thermal power plant at the site of the “Torrette” hospital.

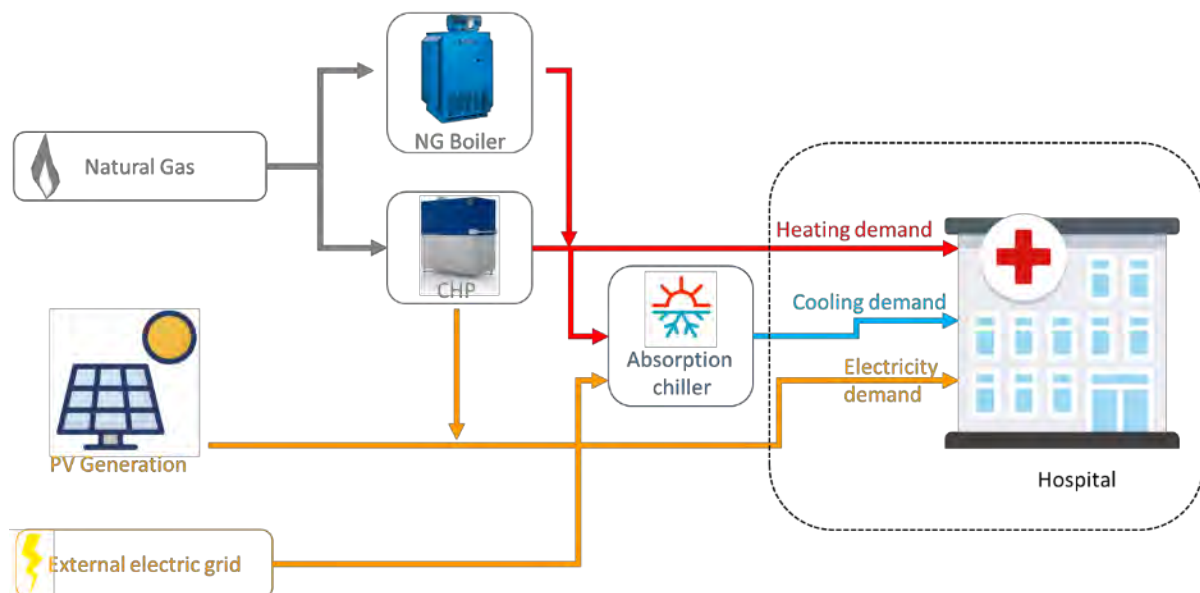


Figure 28. Scenario 05 – Scenario diagram.

#### 5.1.5.4 Technical characteristics

##### Electric network

The electric network provides part of the electricity to each building of the “Torrette” hospital site. The yearly electricity demand of the hospital is about 16 GWhe/year.

##### Heating and cooling network

Heating and cooling energy is provided to each building of the “Torrette” hospital. The yearly thermal energy demand of the hospital is about 30 GWhth/year for heating and about 6 GWhth/year for cooling.



**Gas network**

The gas network refers to the national pipelines since the natural gas is withdrawn from them. The natural gas is used to feed both natural gas boilers and the CCHP unit: their fuel consumption is about 8.000.000 m<sup>3</sup>/year.

**PV panels - 500 kWe capacity**

PV panels, together with the CCHP unit, cover the most electrical energy demand of the “Torrette” hospital. The solar PV production is about 520 MWhe/year.

**CCHP unit - 2 MWe, 2.3 MWth capacity**

The CCHP unit is installed in the thermal power plant located in the site investigated in this scenario (see the highlighted building in red in Figure 26), and provides electrical and thermal energy of 7 GWhe/year and 20 Gwhth/year, respectively, to the “Torrette” hospital. It is worth noting that the cooling demand is completely supplied by the CCHP unit.

**Natural gas boilers - 1.2 MWth capacity**

Natural gas boilers are installed in the thermal power plant located in the site investigated in this scenario (see the highlighted building in red in Figure 26) and provide 10 GWh/year of thermal energy to the “Torrette” hospital.

*5.1.5.5 Energy management strategies*

This scenario focuses on the optimisation of the energy consumption within the “Torrette” hospital site. In particular, the optimisation is aimed at minimizing the withdrawal of electricity from the national electric grid.

*5.1.5.6 Regulatory aspects*

EU incentives provided by the Italian Energy Service Management under Italian Government policy were initially proportional only to the energy produced by the PV systems. It is worth noting that the adopted feed-in-tariff scheme was not at all based on self-consumption of the PV energy production [21], [22]. Consequently, the adopted incentive scheme strongly increased the PV market, boosting the demand for new PV systems. Many new large-size PV systems appeared in Italy during the period 2008–2010 [23] because of a reduced capital cost of medium/large PV size with respect to small ones under economies of scale. A subsequent considerable decrease in the PV module price in the period 2010–2012 [24] induced the Italian Government to reduce year-by-year the feed-in-tariff contribution for PV energy production. Moreover, the incentive pricing was differentiated by PV size, encouraging the installation of smaller systems for residential and tertiary applications. In this context, the energy self-consumption aspect was finally introduced in the feed-in-tariff scheme by making the local consumption of PV energy production more profitable rather than selling it into the grid. However, the regulatory framework introduced by the Italian Government in July 2013 [25] definitively closed the feed-in-tariff scheme in Italy, and no further incentives can be obtained for PV energy production. This situation potentially reduces the



prospects for an increasing PV market since the feed-in-tariff scheme represented a relevant income for the investors in RESs. Indeed, the lack of supporting actions harms the PV market, which is no longer perceived as lucrative by investors in PV. This trend is confirmed by [26], which highlights a reduced growth of the installed PV capacity in Italy in 2012 and 2013.

Regarding the promotion of RESs, several legislative initiatives have been taken over the years. Among them, the establishment of an Emission Trading Scheme (ETS), the adoption of targets to limit the Greenhouse Gas (GHG) emissions from the sectors not covered by the ETS, the introduction of an electricity market design that better reflects the specificities of RES-based generation, the deployment of measures supporting energy efficiency, and the definition of long-term Energy and Climate Plans at the national level have been proposed and actuated [27].

#### 5.1.5.7 *Economic costs and benefits*

The “Torrette” hospital site currently consists of natural gas boilers, a CCHP unit with adsorption chillers, and PV panels.

Since the technologies previously mentioned have been already installed, benefits due to i) CO<sub>2</sub> emissions reduction, ii) the gaining of Energy Efficiency Certificates (ECCs) that lead to economic revenues by the deployment of the use of RESs, and ii) the reduction of monthly electricity bills will be evaluated by comparing the results obtained from the current energy asset with the previous one where only natural gas boilers were installed.

To have a better insight of the economy of scale of the technologies previously mentioned, their costs are listed and reported hereinafter:

- Natural gas boilers [28]
  - Total installed cost: 3,000€/kWth
  - Levelized cost of natural gas: 0.05 €/kWh
- CCHP [28]
  - Total installed cost: 3,500 €/kWe
  - Levelized cost of electricity: 0.01 €/kWh
- PV panels [20]
  - Total installed cost: 778.01 €/kWe
  - Levelized cost of electricity: 0.05 €/kWh

However, since the previously mentioned technologies are installed in the Hospital, the information related to both total installed cost and levelized cost of electricity are here reported for informational purposes only.

#### 5.1.5.8 *Impacts*

The final aim of this scenario is to achieve a considerable reduction of CO<sub>2</sub> emissions, namely 30%, by 2030. Further CO<sub>2</sub> emissions reduction by 2050 will be achieved through electricity produced by renewables and fed into the national grid, as well as using cleaner fuels (e.g., the use of green



hydrogen and natural gas blend fed by the national natural gas network). This last approach is one of the main targets since the Italian natural gas transmission system operator has already proved the effectiveness of 10% hydrogen blending used in modified gas turbines, in terms of CO<sub>2</sub> emissions reductions, by 2030 [29].

#### 5.1.5.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

Electricity consumption:

- 068\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ32\_01012021-31122
- 070\_CON-HVAC-HEP\_ELEC-NONE\_PL-BYDGOSZCZ3\_01012021-311220

Thermal and cooling energy consumption (from natural gas boilers and CHP):

- 055\_CON-THER-HVA-HEAT-HEAT-IT-ANCONA-01012019-31122019
- 054\_CON-THER-HVA-COLD-COLD-IT-ANCONA-01012019-31122019

Natural gas consumption:

- 053\_CON-NGC-NGC-NGC-NGC-IT-ANCONA-01012019-31122019

Natural gas boilers:

- 085\_CON-NGC-NGC-NGC-NGC-IT-TURIN-01012019-31122019
- 086\_CON-NGC-NGC-NGC-NGC-IT-TURIN-01012019-31122019

CCHP unit:

- 066\_GEN-ELECTHERM-CHP-NG-ELECTHERM-IT-ANCONA-27022006-27022006
- 071\_GEN-ELEC-CHP\_BIO-ELEC\_PL-BYDGOSZCZ\_01012021-31122021
- 072\_GEN-HVAC-CHP\_ELEC-NONE\_PL-BYDGOSZCZ2\_01012021-31122021

PV generation:

- 006\_GEN-ELEC-PVE\_NONE-ELEC\_ES-NONE\_02062015-31122020



## 5.1.6 Scenario 06

<b>CARRIERS</b>					Gas
				X	Hydrogen
				X	Water
				X	Electricity
					Heat
					Cooling
<b>SECTOR</b>				X	Industrial
					Commercial
					Residential
					Academic/Educational
					Health
<b>LOCATION</b>					Inland
				X	Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind		Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
	CHP		Cool	X	Water
	Diesel		Pumped Hydro	X	Hydrogen
	Heat pump	X	Hydrogen		Gas
	Natural Gas		Electric boiler		
	Electric				
	Solar thermal				
X	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Cyprus		<b>City</b>	Nicosia	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



### 5.1.6.1 Scenario description

This scenario focuses on an industrial factory for concrete production in Cyprus. This factory occupies an area of approximately 33,500 m<sup>2</sup> (with an external perimeter of 750 m). This factory supplies the raw material, such as sand and gravel, from the quarries of the area and produces concrete, supplying a large part of the construction industry of Cyprus. For this reason, this plant has high demands for electricity and water, which are necessary components to produce concrete. Figure 29 shows the industrial area of Nicosia, where the perimeter of the area of the factory for this scenario has been marked in green.



Figure 29. Scenario 06 - Map of the industrial area of Nicosia with the area of the factory of this scenario marked in green and the buildings for the installation of PV systems in yellow.

The scenario pretends to move from diesel generators to hydrogen by removing most of the diesel generators and using fuel cells. At the same time, a photovoltaic system will be installed, depending on the needs of the factory, and additionally, an electrolyser will be installed as well to produce hydrogen to supply the fuel cells.

In the context of this scenario, the installation of photovoltaic systems is required, mainly for the supply of the electrolyser, but also for the direct supply of the factory buildings with electricity in some cases. Thus, for space-saving purposes, and because the free space within the factory area is limited, it was decided that the photovoltaic panels would be installed on the roofs of the buildings. Most of the factory buildings have inclined roofs with mainly south and southeast orientations.



Therefore, these buildings, which are shown in yellow in Figure 29, are the ideal installation location for photovoltaic panels.

#### 5.1.6.2 Scenario location

This industry is located in the industrial area of Nicosia, just outside the city Nicosia, Cyprus. Cyprus is located at the north-eastern edge of the Mediterranean between the 33rd and 35th parallels. It is the third largest island in the Mediterranean, with a total area of 9251 km<sup>2</sup> (see Figure 30), of which 47% is arable land, 19% is covered by forests, and the remaining 34% is uncultivated land. Cyprus is characterized by a temperate Mediterranean climate with mild winter, long hot summer and very limited autumn and spring.



Figure 30. Scenario 06 – Scenario Location.

The use of solar energy in Cyprus is very promising because all regions of Cyprus have a long duration of sunshine compared to many other countries. In the lowlands, the average number of hours of sunshine for the whole year is 75% of the hours the sun is above the horizon. Throughout summer, sunshine averages 11.5 hours a day, while in December and January, which have the most clouds, the duration of the sunshine decreases only to 5.5 hours a day. Even in the highest areas of Troodos in the winter months with much mist, the average sunshine is about 4 hours a day, and in June and July, this value reaches 11 hours. The highest possible sunshine duration in Cyprus (from sunrise to sunset), according to the Cyprus Meteorology Department, ranges from 9.8 hours a day in December to 14.5 hours a day in June [30].

Average daily solar radiation in a horizontal plane in Cyprus is estimated at 5.4 kWh/m<sup>2</sup>, and the average annual sum of Direct Normal Irradiation in Cyprus is 2000 kWh/m<sup>2</sup> [31]. Figure 31 shows the yearly sum of global irradiation received by optimally – inclined PV modules in Cyprus.



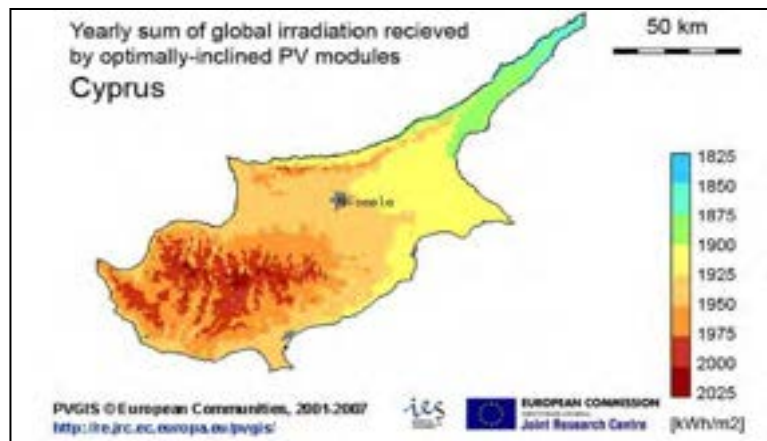


Figure 31. Scenario 06 - Yearly sum of global irradiation received by optimally – inclined PV modules in Cyprus [30].

### 5.1.6.3 Scenario diagram

The scenario considers three carriers: hydrogen, water, and electricity, as it is presented in Figure 32. Water in this scenario is needed for the production of hydrogen, while the water produced from the fuel cells is used for the production of concrete. The required amount of water for the electrolysis process is provided by the district water distribution system.

In this scenario, hydrogen is produced and stored locally and then used by fuel cells to generate electricity and water as a by-product which, of course, is then used to produce concrete.

Finally, the internal electricity network connects all buildings and all the electric machines (for the concrete production) in the area of the factory and provides electricity to the loads. The electricity production excess can be exported to the electrical distribution network of the Electricity Authority of Cyprus.

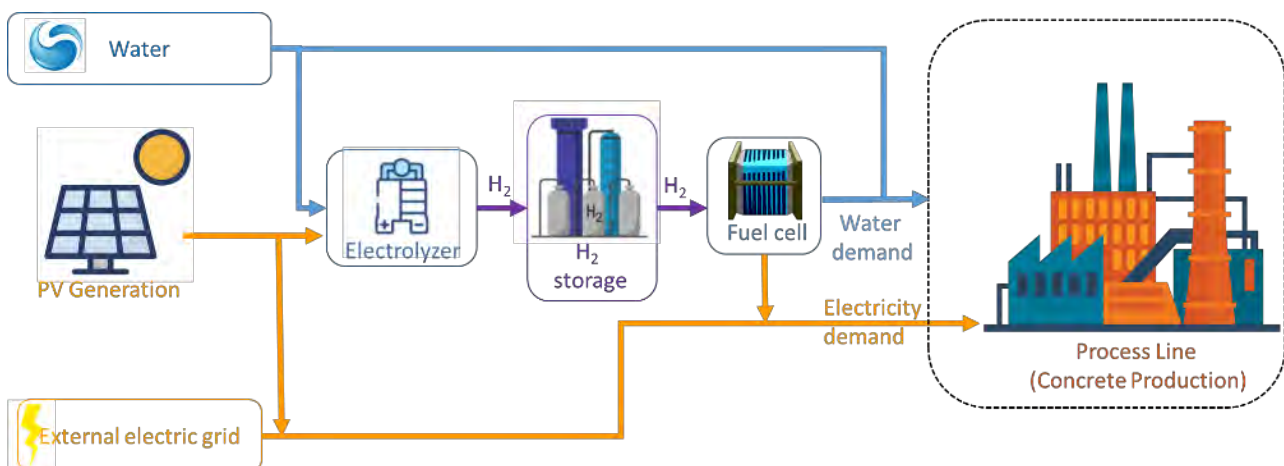


Figure 32. Scenario 06 – Scenario diagram.

#### 5.1.6.4 Technical characteristics

##### Power grid

The power grid provides electricity to every building in this scenario. There is a central substation which is connected to the medium-voltage (MV) network of the electricity distribution system. The substation has a transformer that supplies all the loads of the plant facilities in this scenario. The installed transformer has a capacity of 500 kVA. The voltage of the high voltage side is 11 kV, and the voltage of the low voltage side is 400 V.

For the implementation of this scenario, it is necessary to install a photovoltaic system on the roofs of the factory buildings. The sizing of the photovoltaic system should be done considering the system requirements as well as the limitations that exist regarding the area and the durability of the roofs of the buildings of the specific scenario.

According to the appropriate calculations, about 70 m<sup>3</sup> H<sub>2</sub>/day is required to meet the energy needs of the plant (200 kWh / day). For the production of this amount of hydrogen, according to the typical production of a photovoltaic system in Cyprus (≈1600 kWh/kWp/year), a photovoltaic system with an installed capacity of about 70 kWp is required. The photovoltaic system will be installed on the roofs of the factory buildings and will be connected to the external electricity distribution network within the framework of the net billing scheme. The priority of the photovoltaic system is to supply the electrolyser, while in the case for some reason the production of hydrogen is not required, or the factory does not have energy consumption (periods of non-operation of the factory), the energy produced by the photovoltaic will be channelled directly to the grid. Conversely, in the absence of production from the photovoltaic system, the plant's electricity requirements will be met directly by the external electricity grid.

##### Hydrogen network

For the implementation of this scenario, the electrolysis systems as well as the fuel cells must be installed. In addition, the installation of a hydrogen storage unit in accordance with the specifications required by international law is required, as well as the hydrogen network pipelines. The piping should be dimensioned considering the requirements of the factory and the size of the system to be installed. The capacity of the hydrogen storage should be at least 70 m<sup>3</sup>, as are the system requirements for hydrogen for each day.

##### Energy and water need

This factory assumes that it produces about 100 m<sup>3</sup> of concrete per day. So, about 15,000 litres of water are needed per day for the production of concrete. According to studies, the production of 1 m<sup>3</sup> of concrete requires approximately 0.77 kWh of electrical energy.

Taking into consideration the above, as well as the electrical consumption of the various buildings of the factory, the total electricity consumption of the factory is about 200 kWh/day. Based on [32], a hydrogen fuel cell supplying this electricity demand would produce approximately 100 L/day of water. Therefore, the amount of water produced by the fuel cell system is quite small compared to



the water needed to produce concrete. Nevertheless, it can be used to meet part of the needs of the factory buildings.

#### 5.1.6.5 *Energy management strategies*

The main objective of the current scenario is the maximization of the energy self-consumption of the factory with the local production of energy.

Therefore, energy management strategies will take into account these possibilities with the aim of reducing losses in energy conversion or transport. Therefore, the energy management strategy will be multi-objective, with two main optimisation objectives. The maximization of self-consumption and the minimization of energy losses.

#### 5.1.6.6 *Regulatory aspects*

The Government of Cyprus has implemented relevant plans to provide financial incentives in the form of Government subsidies with the main goal of promoting the integration of RES technologies in the electricity generation system of Cyprus. Currently, in Cyprus, local PV generation is highly promoted by the government, especially in the residential sector and industry as well. In the industrial sector, the net billing scheme is applied with the time of use tariffs.

Concerning hydrogen storage and hydrogen generation, no regulatory framework has been provided so far in Cyprus.

#### 5.1.6.7 *Economic costs and benefits*

Regarding the implementation of this scenario and the installation of the required equipment, the following costs and benefits are being considered:

##### **Costs:**

- Capital cost for the purchase of the mentioned equipment.
- Capital cost for the installation of the equipment.
- Operation and maintenance costs.
- Capital cost for the communication devices and data acquisition system.

Indicative costs of the required components of the current scenario are presented below [20], [33]:

- Capital cost of electrolyser: 750 €/kW.
- Operation and maintenance costs of electrolyser: 25 €/kW/yr.
- Capital cost of PV system: 900 – 950 €/kW.
- Operation and maintenance costs of PV system: 20 €/kW/yr.
- Capital cost for the communication devices and data acquisition system: 1,000 €.

##### **Benefits:**

- Savings related to the increase in self-consumption.



- Increased energy security within the “microgrid”.
- Active role of the users within the residential premises.
- Reduction in GHG emissions.

#### 5.1.6.8 Impacts

The main impact of this scenario is the reduction of greenhouse gas emissions, which is due to local production by the photovoltaic system and the storage of “green” hydrogen to produce electricity through fuel cells. This, of course, requires increased protection measures for the proper storage and management of hydrogen in accordance with international law and regulations. In addition, by implementing this scenario brings financial benefits to the system owner in the long run. In fact, the proposed system of this scenario has been dimensioned to meet all the energy needs of the factory. Thus, the greenhouse gas emissions are expected to be reduced to around 100%. The external network will be used as a backup plan in cases there is not enough energy production from the photovoltaic system, and the hydrogen storage cannot meet the needs of the factory.

#### 5.1.6.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

Electrical consumption of buildings:

- 044\_CON-ELEC-ELC\_ELEC-ELEC\_ES-ELHIERRO\_01012018-31122018
- 048\_CON-ELEC\_ELC\_ELEC\_ELEC-HEAT-COLD\_CY\_AGLANTZIA\_011219\_31112021

PV generation

- 049\_GEN-ELEC-PVE\_IRRA-ELEC\_CY-NICOSIA\_01062019-31052020
- 050\_GEN-ELEC-PVE\_IRRA-ELEC\_CY-NICOSIA\_01122020-30112021

H<sub>2</sub> generation and storage

- 063\_GEN-HYDR-H2E-WIND-HYDR-PT-PORTO-01012023-31122023

Electricity production from Fuel Cell

- 077\_CON-HYDR-FUC-HYDR-ELEC-PT-LISBON-01012023-31122023



## 5.1.7 Scenario 07

<b>CARRIERS</b>					Gas
				X	Hydrogen
					Water
				X	Electricity
					Heat
					Cooling
<b>SECTOR</b>					Industrial
					Commercial
					Residential
				X	Academic/Educational
					Health
<b>LOCATION</b>					Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind		Heat		HVAC
	Hydro	X	Electric Vehicle	X	Electric Vehicle
	CHP		Cool		Water
	Diesel		Pumped Hydro	X	Hydrogen
	Heat pump		Hydrogen		Gas
	Natural Gas		Electric boiler		
	Electric				
	Solar thermal				
X	Electrolyser				
	NG Reforming				
X	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Spain		<b>City</b>	Madrid	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



#### 5.1.7.1 Scenario description

This scenario focuses on the Universidad Politécnica de Madrid (UPM) buildings of the Ciudad Universitaria Campus, Madrid, Spain. Ciudad Universitaria Campus is home to several universities, specifically: Universidad Politécnica de Madrid, Universidad Complutense de Madrid and Universidad Nacional de Educación a Distancia. Figure 33 shows the Ciudad Universitaria Campus, where the UPM buildings have been marked in blue. Although this scenario could be extended to all buildings in the campus, it is restricted to some UPM buildings.



Figure 33. Scenario 07 - Map of the Ciudad Universitaria Campus with UPM buildings highlighted in blue.

The scenario is intended to move from natural gas heating to hydrogen by removing boilers and installing fuel cells and aerothermal system. The high initial capital costs of new pipeline construction constitute a major barrier to expanding hydrogen pipeline delivery infrastructure; therefore, the current natural gas pipeline will be used for hydrogen transport. In the first stage, hydrogen will share transport with the natural gas, requiring only some modifications to the pipeline [34] and once completely deployed, pipes will transport hydrogen solely.

Moreover, the scenario considers PV generation for all the buildings in the hub. At present, the energy demand in this scenario is electric-based (i.e. cooling, heating, electric vehicles and standard electric consumption).

Nonetheless, Ciudad Universitaria is a convergence point of public buses that transport students from many different areas of Madrid, and some of them from outside the city too. Moreover, it is also connected to other four university campuses in Madrid by means of specific inter-campus buses. Therefore, the scenario plans to consider a station to supply hydrogen to the buses.



### 5.1.7.2 Scenario location

The scenario is located the northwest of Madrid, in the centre of the Iberian Peninsula (see Figure 34), in an area of 2 km<sup>2</sup> (with an external perimeter of 7 km).



Figure 34. Scenario 07 – Scenario Location.

In order to choose the buildings to be included in the scenario, architectural characteristics, as well as activities carried out in them, have been considered. In particular, most of the buildings hosting similar activities (teaching, research, administration and catering services) and having flat roofs have been considered in the selection, with the aim of including PV systems on them [35].



Figure 35. Scenario 07 - Flat roofs from several UPM buildings are comprised in this scenario.

The flat-roof typology is very common in Spanish high-educational buildings, as shown in Figure 35. Construction with non-flat roofs has been excluded because all the buildings on the campus are



protected by architectural heritage issues, and because of this, the installation of PV systems is permitted only if they are not visible from the public area. Consequently, eight different buildings, including the government building of the UPM (Rectorate), have been selected (see Figure 36).



Figure 36. Scenario 07 - UPM selected buildings for the scenario [35].

Special interest in energy generation and consumption are related to Madrid's climate. The climate of Madrid is moderately continental, with quite cold, relatively rainy winters and hot, sunny summers. The city is the capital of Spain and is in the centre of the Meseta (see Figure 34), the plateau that occupies the interior of the country, at an altitude ranging between 570 and 740 meters. The city centre is at 655 meters. Winter, from December to February, is relatively cold. The rains are quite frequent but generally not abundant. Days can be mild with highs around 13/15°C, but nights remain typically cold, with minimum temperatures near freezing (0°C). Summer, from June to August, is hot and sunny. There is often scorching heat during the day, and in fact, the temperature easily reaches 35/36°C. In addition, at night, the temperature becomes fairly cool, hovering typically from 15°C to 20°C. Spring and autumn are mild and variable, with sunny periods, but also the passage of Atlantic disturbances, which bring clouds and rain. Spring, being the most contrasted season of the year, is also the windiest.

#### 5.1.7.3 Scenario diagram

The scenario accounts for two carriers, hydrogen and electricity, plus a water input for hydrogen generation (see Figure 37). In this scenario, water is only used for electrolysis. Hydrogen is transported by the natural gas pipes at first, and it creates a connection ring between all buildings in Ciudad Universitaria. In this sense, hydrogen is produced and stored locally, and it can also be shared between the different buildings in the scenario. Electricity can also be shared among the buildings by using the already existing electric network. This sharing can be physically implemented, by means of energy sharing or virtual, compensating generation and consumption between the buildings. In any case, if the buildings share hydrogen or electricity, it is something that should be



analysed according to the building needs and transport costs. Finally, the electric network connects all buildings on the campus, and the buildings are able to import and export energy from and to it.

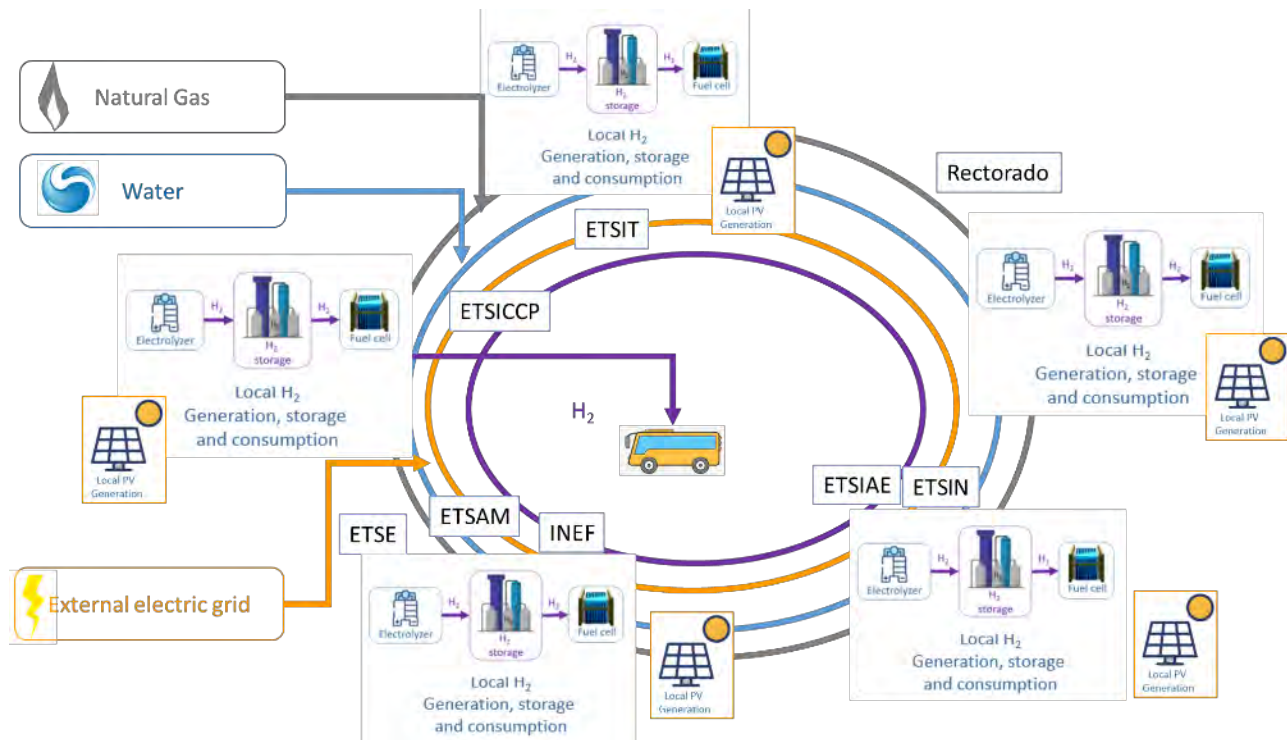


Figure 37. Scenario 07 – Scenario diagram.

It is assumed that all buildings have common characteristics (see Figure 38). From the electric side, all of them include PV generation and fuel cells which can produce local electricity for self-consumption. Both electric generation systems are connected to a distribution panel through a three-phase inverter. This distribution panel is also connected to the secondary circuits of the distribution transformers, allowing a bidirectional connection to the external grid. All the electric demands, including electric HVAC and charging points for electric vehicles, are fed directly from this common point, maximizing the building's self-consumption.

PV generation is directly linked with the weather conditions, the day/night cycle and the casuistry of each building (i.e., shadow-free roof area, roof dimensions). In order to integrate this intermittent generation, local energy storage using a hydrogen tank is proposed for every building in this scenario.

For the aforementioned reasons, a hydrogen tank is planned to be considered next to each building. This tank will allow input from “externally” and locally generated hydrogen. Externally generated hydrogen can be provided by the other buildings, generating the hydrogen and sending it through the hydrogen network. However, if more demand is needed on the campus, it will also allow input from the general hydrogen network. The locally generated hydrogen is obtained at each building from water by electrolysis once the water has been purified.

As aforementioned, all building consumptions planned in this scenario are electric-based, including electric vehicle charge, heating and cooling. However, it is assumed that the campus will include a



station to supply hydrogen to the buses. This station will be connected to the hydrogen supply network (at the first stage, the natural gas network) and could obtain hydrogen generated by electrolysis in the energy hub or elsewhere.

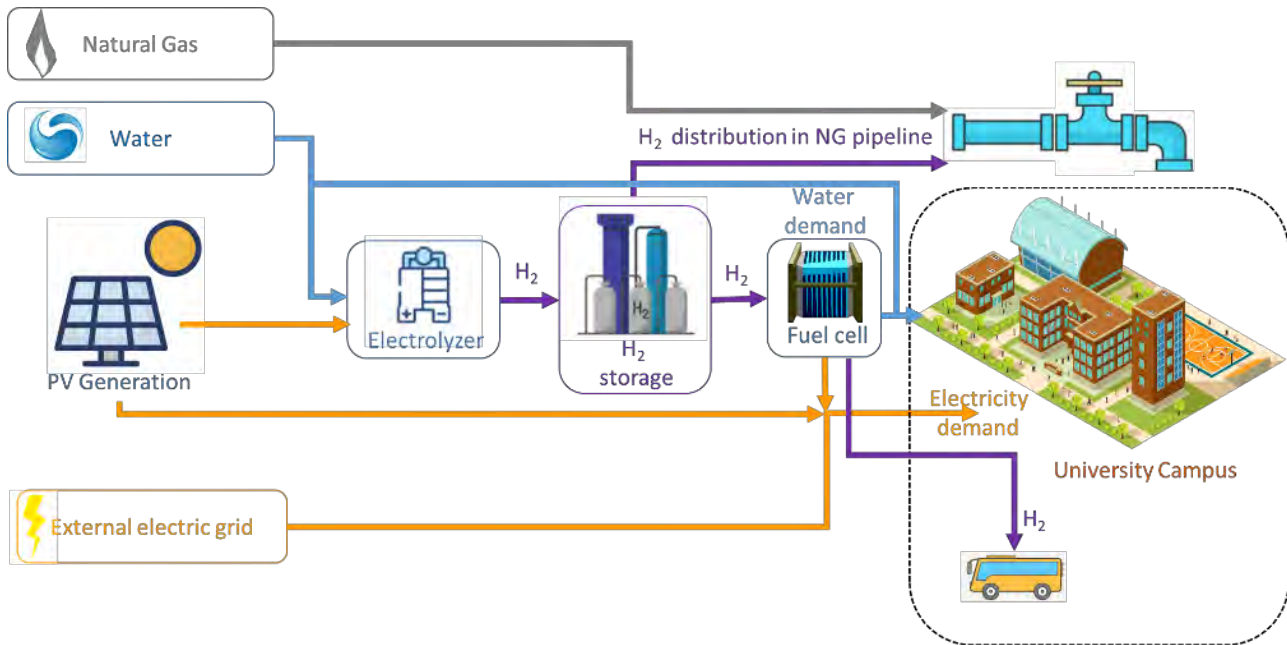


Figure 38. Scenario 07 - Micro-Energy Hub diagram. It represents every building within the scenario.

#### 5.1.7.4 Technical characteristics

##### Electric network

The electric network provides electricity to every building in this scenario. However, each building has its own transformer (see Table 8). Table 8 shows the electric demand for HVAC ( $D_g$ ) and the electricity demand for the rest of the consumptions ( $D_e$ ).  $Tr$  is the power rating of the transformation centre. Moreover,  $PV_p$  represents the PV power installed,  $PV_G^y$  the estimated annual generation and  $PV_G^d$  the estimate daily generation based on [25]. Finally,  $N_{fc}$  represents the number of fuel cells and hydrogen storage tanks.

Moreover, annual electricity consumption for the 2020 year has been measured for all the buildings as well as an estimation of the annual potential electricity which could be generated by the PV systems proposed to be installed in these buildings. In the current configuration, heating is based on natural gas boilers. However, for this scenario, natural gas boilers have been replaced with aerothermal heating with electric technology. We have used 2.6 as coefficient improvement, according to the literature, given the location of the University Campus in Madrid [36].

##### Hydrogen network

Every building is assumed to host an electrolyser and a specific number of hydrogen elements ( $N_{fc}$ ) of 5 kW Fuel Cells each and hydrogen storage vessels with a storage capacity of 40 kWh each, to provide one day of autonomy ( $PV_G^d$ ). Every hydrogen element comprises a vessel with a maximum



of 20,000 cycles of storage and charge. For the sake of simplicity, the complete set of elements is represented as one single box (Fuel Cell or H<sub>2</sub> tank) in Figure 38.

Table 8. Scenario 07 - Electric technical information.

Centres	Dg[MWh/year]	De[MWh/year]	Tr[kVA]	PVp [kW]	PV <sub>G<sup>y</sup></sub> [MWh/year]	PV <sub>G<sup>d</sup></sub> [kWh/day]	Nfc
ETSAM	228	351	660	389	549	1,504.1	38
ETSE	58	291	630	264	391	1,071.2	27
ETSIAE	131	1,509	2,000	251	341	934.2	23
ETSICCP	640	661	1,050	1,071	1392	3,813.7	95
ETSIT	166	1,215	2,260	710	1091	2,989	75
ETSIN	55	375	630	288	379	1,038.4	26
INEF	302	446	1,000	102	140	383.6	10
RECTORATE	83	856	1,600	255	364	997.3	25

#### 5.1.7.5 Energy management strategies

This scenario focuses on two objectives: a) maximizing the energy self-consumption in every building, and b) maximizing the energy self-consumption within the campus, as a local energy community of the buildings involved.

The buildings' energy sharing can be done by sharing either the hydrogen or electricity locally generated (using fuel cells, electrolyser, and PV panels). Therefore, energy management strategies will consider these possibilities with the aim of reducing losses in energy conversion or transport and costs.

#### 5.1.7.6 Regulatory aspects

Local PV generation is highly dependent on each country. However, because of the new EU regulations to promote local and collective self-consumption, included in Spain, this scenario does not envision any regulatory limitation related to the local PV generation.

At this specific time, the ability of the Spanish government to commit to large infrastructure investments is limited due to economic costs, and no specific regulatory aspects have yet been developed. Therefore, this scenario relies on a feasible technical approach with the aim that in 2050 regulation of hydrogen will be a reality.

#### 5.1.7.7 Economic costs and benefits

As with the regulatory aspects, local PV generation is mature and ready to be installed in all the buildings that are planned in the present scenario. Costs of installation and materials are planned to be amortized over seven years.



On the other hand, hydrogen amortization cannot be estimated at this time because of the lack of government policies and regulations. The main problem arises with hydrogen storage. Hydrogen may be stored at higher density through different technologies, but few of these have reached commercial maturity for large-scale applications. The current technologies for using hydrogen storage differ in approach, and there are still several technical limitations. At this time, most applications for low-carbon hydrogen are not cost-competitive without direct government support. In any case, the hydrogen storage is estimated that would have a capital cost of 350 €/kg, information that is required when proposing its optimal capacity once it is analysed with the eNeuron toolbox.

#### 5.1.7.8 Impacts

The main environmental impact of the proposed scenario comes from removing the natural gas boilers and replacing the current heating devices with aerothermal devices. Instead of exclusively working with electricity (locally generated and/or imported), the scenario includes hydrogen generation and storage.

Total *Dg* calculated based on aerothermal heating amounts to 1,581MWh/year. This consumption is calculated from the 4,126.41 MWh/year that was consumed in gas in 2020 assuming a 2.6 coefficient improvement. These consumptions correspond to 352,684 m<sup>3</sup> of gas (where 1 m<sup>3</sup> relates to 11.70 kWh). Finally, a ratio of 2.15 kg of CO<sub>2</sub> per m<sup>3</sup> is applied. This means that actual gas boilers are providing 758 tons of CO<sub>2</sub> emissions.

When moving to aerothermal heating, the scenario estimates a consumption of 1,581 MWh /year of electricity, providing a total of 553 tons of CO<sub>2</sub> emissions, based on a ratio of 0.35 kg of CO<sub>2</sub> per kWh. Therefore, without considering PV local generation, a reduction of around 200 tons of CO<sub>2</sub> emissions is estimated. On top of it, a total PV generation of 4,647 MWh/year is estimated. Therefore, it will provide a reduction of 1,626.45 tons of CO<sub>2</sub> emissions, based on the same ratio of 0.35 kg of CO<sub>2</sub> per kWh

#### 5.1.7.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

Electrical consumption of buildings:

- 015\_CON-ELEC-ELC\_ELEC-ELEC\_ES-MADRID\_03022017-17052019\_1
- 016\_CON-ELEC-ELC\_ELEC-ELEC\_ES-MADRID\_03022017-17052019\_2
- 017\_CON-ELEC-ELC\_ELEC-ELEC\_ES-MADRID\_03022017-17052019\_3
- 018\_CON-ELEC-ELC\_ELEC-ELEC\_ES-MADRID\_03022017-17052019\_4

PV generation

- 037\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-MADRID\_15072015-10072021



## H<sub>2</sub> generation and consumption

- 062\_CON-HYDR-H2C-HYDR-NONE-PT-PORTO-01012023-31122023
- 063\_GEN-HYDR-H2E-WIND-HYDR-PT-PORTO-01012023-31122023
- 077\_CON-HYDR-FUC-HYDR-ELEC-PT-LISBON-01012023-31122023



## 5.1.8 Scenario 08

<b>CARRIERS</b>					Gas
				X	Hydrogen
				X	Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>					Industrial
				X	Commercial
				X	Residential
				X	Academic/Educational
<b>LOCATION</b>					Health
					Inland
				X	Island
					North Europe
					Centre Europe
					South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV	X	Batteries	X	Electric
	Wind		Heat	X	HVAC
	Hydro	X	Electric Vehicle	X	Electric Vehicle
X	CHP		Cool	X	Water
X	Diesel		Pumped Hydro	X	Hydrogen
X	Heat pump		Hydrogen		Gas
	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
X	Absorption Chiller				
LOCATION					
<b>Country</b>	Cyprus	<b>City</b>	Nicosia		
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



### 5.1.8.1 Scenario description

The current scenario is based on the microgrid that encompasses the campus premises of the University of Cyprus (UCY), including its proposed expansion. When its construction will be finalized, it will comprise 17 academic and commercial buildings plus 20 buildings where some university students would be residing, totalling around 1,500 users within the campus premises.

Currently, some rooftop PV panels have already been installed within the campus premises, specifically 70kWp for the administration building, 148kWp for the social facilities building and a 176kWp solar park that supplies the residential buildings. In the future, it is expected that a 1.175MW/2.3MWh BESS will be installed within the campus premises, as well as a 5MWp solar park.

Within this microgrid, the PV laboratory nano grid is included, which will possess a generation and storage capacity of its own, having already an installed capacity of 37.9kW of photovoltaic panels and expecting in the future for the installation of a BESS with 2.5kW/9.8kWh storage capacity. This also includes an electric vehicle charging station within its premises, with capacity of supplying 2 EV at the same time at a charging speed of 3/7/21 kW.

The UCY campus consumes annually around 7,800MWh in electricity and 15,700MWh in heating/cooling. The heating demand is covered by a district heating network around the campus, in which the cooling section is covered by electrical chillers of close to 8.7MWth in capacity for covering its cooling demand, whereas the heating is supplied by petrol-based boilers with aggregated capacity of 7,400kWth and with four 250kWp planned heat pumps that would complement this structure. Regarding the electricity demand, this is partly covered by the already mentioned rooftop PV panels with the expectation of achieving self-sufficiency with the installation of the 5MWp PV system.

The current scenario will consider the feasibility of introducing hydrogen as a way of improving the environmental footprint of the whole network. For this, two nonexclusive options have been considered based on the devices that are currently installed or being procured from the campus: the first one would be to install a fuel cell for CHP production, whereas the other one would be to replace the petrol-based boilers with ones supplied by hydrogen in order to reduce the use of fossil fuels.

### 5.1.8.2 Scenario location

This scenario locates in Cyprus (see Figure 39). The area of study would be the campus installations of the University of Cyprus located at 1 Panepistimiou Avenue, in the municipality of Aglantzia (Nicosia, see Figure 40). The campus covers 80,000 m<sup>2</sup> of land.

As previously mentioned in Scenario 06, but repeated in this Section for readability issues, Cyprus is located at the north-eastern edge of the Mediterranean between the 33rd and 35th parallels. It is the third largest island in the Mediterranean, with a total area of 9,251 km<sup>2</sup>, of which 47% is arable land, 19% is covered by forests, and the remaining 34% is uncultivated land. Cyprus is characterized by a temperate Mediterranean climate with mild winter, long hot summer and very limited autumn and spring.





Figure 39. Scenario 08 – Scenario Location.



Figure 40. Scenario 08 - UCY new campus (Google Earth).

The average number of hours of sunshine for the whole year is 75% of the hours the sun is above the horizon. Throughout summer, sunshine averages 11.5 hours a day, while in December and January, which have the most clouds, the duration of the sunshine decreases only to 5.5 hours a day. Even in the highest areas of Troodos in the winter months with much mist, the average sunshine is about 4 hours a day, and in June and July, this value reaches 11 hours. The highest possible sunshine duration in Cyprus (from sunrise to sunset), according to the Cyprus Meteorology Department, ranges from 9.8 hours a day in December to 14.5 hours a day in June [30]. Average daily solar radiation in a horizontal plane in Cyprus is estimated at 5.4 kWh/m<sup>2</sup>, and the average annual sum of Direct Normal Irradiation in Cyprus is 2,000 kWh/m<sup>2</sup> [31].



### 5.1.8.3 Scenario diagram

The map of the district cooling network of the UCY can be found in Figure 41.



Figure 41. Scenario 08 - District cooling network of the UCY.

As for the electrical representation of the UCY microgrid, the single-line diagram is shown in Figure 42.

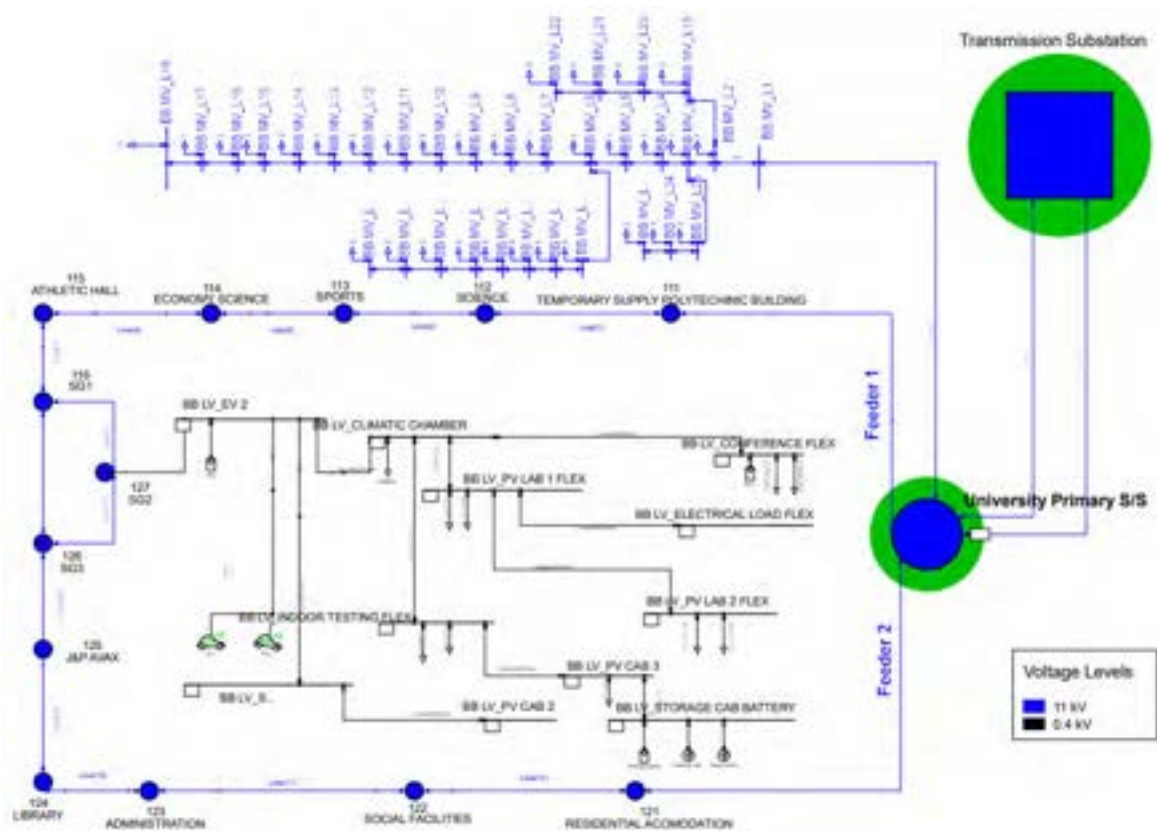


Figure 42. Scenario 08 - Current UCY microgrid one-line diagram.



The schematics for cooling pipes, BEMS and EMS connections can be seen in Figure 43, allowing for a proper understanding of the interaction between the electrical and cooling systems.

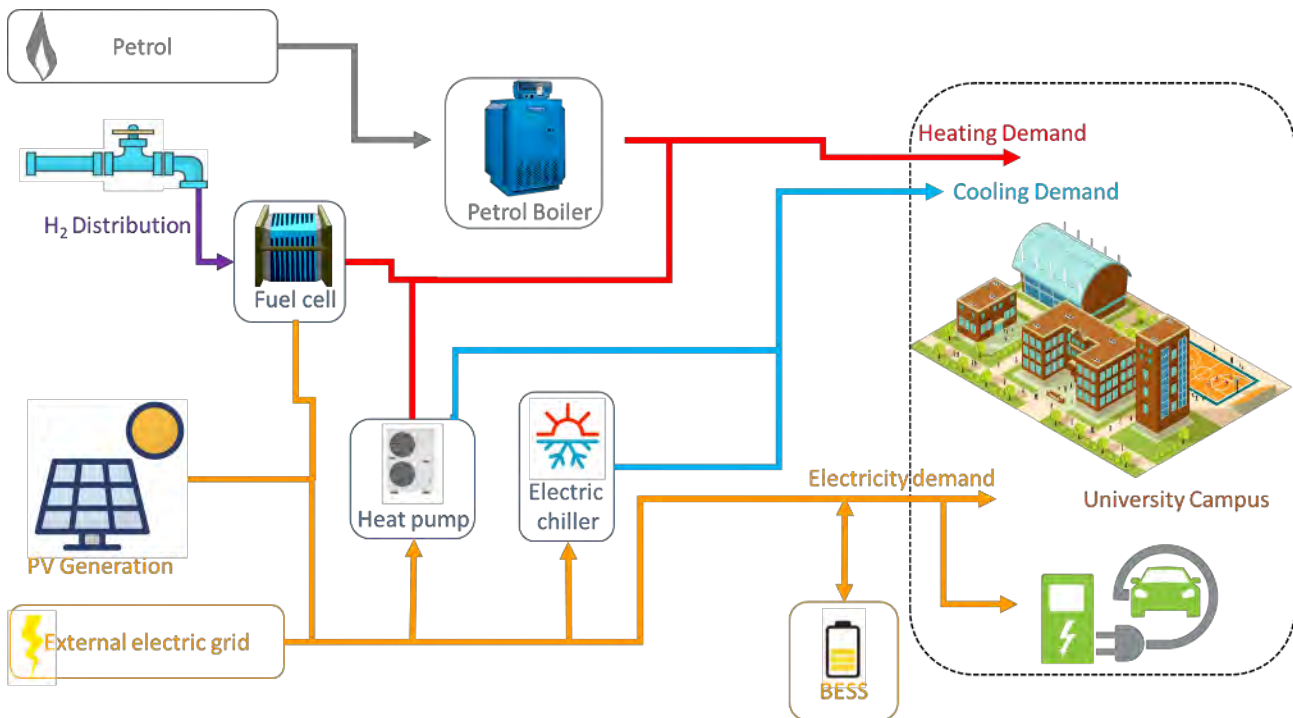


Figure 43. Scenario 08 – Scenario Diagram.

From the schematics shown, albeit the emphasis lies on the cooling system due to its relevance with Cypriot weather in which the highest consumption lies in summer, the heating section is also complemented by the four petrol-based boilers, for which its interaction in winter with the BEMS would follow the same structure

#### 5.1.8.4 Technical characteristics

Regarding the devices considered, the UCY new campus would be including the following:

##### UCY microgrid:

- The primary substation feeds the UCY microgrid via two feeders.
- Rooftop PV of 70 and 148kWp And 148 kWp.
- 176.40 kWp solar park.
- 5 MWp planned PV solar park.
- Proposed 500 kW fuel cell CHP.
- 1.175 MW / 2.3 MWh planned BESS.
- Underground cables.
- Converters associated to the photovoltaic panels and BESS.
- Transformers of 1 MVA for each building.
- Controllable loads of the buildings within the campus by exploiting the flexibility of the HVAC and lighting within them while ensuring user comfort.



**PV lab nanogrid:**

- 34.9 and 3 kWp PV panels.
- Electronic load of 4,500 W.
- BESS of 2.5kW/9.8 kWh storage capacity.
- Two charging stations with three charging speeds of 3, 7, and 21 kW each.
- Flexible loads with remote control of temperature and lighting.
- Underground cables.
- Converters associated to the photovoltaic panels and BESS.

**Heating and cooling network:**

- 2 chillers of 1,103 kW with 395 kW of nominal power input.
- 6 chillers of 1,084.3kW with 306.2 kW of nominal power input.
- 2 petrol-based boilers of 1,500kW.
- 2 petrol-based boilers of 1,750kW.
- Four heat pumps with capacity of 250 kWc for a consumption of 48.8 kW<sub>e</sub> and 345.6 kW<sub>t</sub> for 68.3kW<sub>e</sub>.
- Heat derived from the proposed fuel cell.
- BEMS installed in each building allows for controlling the HVAC system.

The buildings are connected on a radial scheme along with the two feeders, with the projected solar park connected to two separate feeders from the primary substation.

*5.1.8.5 Energy management strategies*

Currently, one of the main energy management strategies is focused on maximizing self-consumption and savings from electricity costs by obtaining electricity from the PV panels. Recently, demand-side management with its own load forecasting has been considered as well. Of these, the student residences had a successful case scenario for implicit demand response.

As for the introduction of fuel cells and hydrogen-based boilers, the main objective would be to reduce the GHG that otherwise would have been emitted by the petrol-based boilers and the planned CHP plant.

*5.1.8.6 Regulatory aspects*

Currently, in Cyprus, only a flat-tariff net-metering scheme is offered to residential consumers, whereas in other sectors, a net-billing scheme is also proposed with a time of use tariffs as one of the options to choose.

On the capacity for PV panels for self-consumption, it is structured in a way that the PV generation shall not surpass the total yearly consumption of the users unless the consumer is capable of curtailing the excess production.



There are no mentions of electricity storage or load flexibility on current Cypriot regulations, although it has been considered in different pilots within the country, such as in the DELTA project [37], in which the Electricity Authority of Cyprus made an exemption and allowed for the application of different time of use tariffs that would allow for implicit demand response within the UCY campus.

The introduction and proper use of boilers using hydrogen as a fuel can be considered technically feasible. Although this would need to be validated by local authorities, it is assumed for the time being that it will not pose any challenge in this regard, as long as the distribution and handling of hydrogen are done in a safe manner. Currently, there are no regulations in place for renewable gas such as hydrogen, but it is expected that the national regulation will be aligned with the EU Directive 2014/94/EE before the year 2025.

#### *5.1.8.7 Economic costs and benefits*

The costs and benefits of the current and planned devices that are to be installed within the campus premises will not be considered, as they are the base scenario and either the investment is already made or it is assumed to be already commissioned.

For the fuel cell, for 2030 in the European market, for large commercial applications, the estimated CAPEX is 1,500 €/kW for a total of 750,000 €, a lifetime of 20 years, and O&M costs of 0.012 €/kWh [33]. For the hydrogen storage, it is estimated that it would have a capital cost of 350 €/kg, information that is required when proposing its optimal capacity.

As for the boilers, it is expected that these would have the same price as other gas boilers when hydrogen is commercially available, as it is expected that most of the new gas boilers will be hydrogen ready. Some companies are expecting to introduce hydrogen-ready boilers in the next few years to the market [38]. The investment costs for condensing gas boilers in Cyprus are estimated at 45 €/kWth [39], which is the price for boilers with 350 kWth of installed capacity. As the boilers that are already installed are 4 to 5 times larger, it is expected that the investment costs should be lower than this, but this would still suffice as an upper threshold of the expected costs, totalling 67,500 € for 1,500kWth and 78,750 € for 1,750 kWth.

The benefits for the CHP of the fuel cell lie in the possibility of better exploiting the expected excess production of the 5MWp solar park for future uses within the campus, as well as reducing the carbon footprint in both the electrical and heating system of the studied area. As for the boilers, it would be of interest to compare the current scenario with both a 20% hydrogen blend and with 100% hydrogen. This is due to the possibility that the 20% blend will appear in the market before completely replacing gas with hydrogen.

#### *5.1.8.8 Impacts*

Introducing hydrogen into the current network would allow an overall reduction of the carbon footprint of the UCY in which the current petrol boilers would be replaced for hydrogen ready gas boilers. This also means that necessary adjustments would need to be done in order to the safe handling and distribution of hydrogen, but in the end, it would allow a more environmentally



friendly network. Added to this, the use of a fuel cell would allow for a reduction on GHG derived from the electricity consumption of the Cypriot network, which stood at 651gCO<sub>2</sub>e/kWh in 2019.

#### 5.1.8.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

PV\_Lab production\_[kW]:

- 049\_GEN-ELEC-PVE\_IRRA-ELEC\_CY-NICOSIA\_01062019-31052020

Total electrical load from the UCY campus [kW]:

- 048\_CON-ELEC\_ELC\_ELEC\_ELEC-HEAT-COLD\_CY\_AGLANTZIA\_011219\_31112021

Total PV production at the UCY campus [kW]:

- 050\_GEN-ELEC-PVE\_IRRA-ELEC\_CY-NICOSIA\_1.12.2020-30.11.2021

Chiller's consumption [kW]:

- 092\_CON-ELEC-CHI\_ELEC-COLD\_CY-NICOSIA\_01012021-31122021

Total heating demand of the UCY campus:

- 093\_CON-THER-HVA\_HEAT-HEAT\_CY-NICOSIA\_01012019-01012020



## 5.1.9 Scenario 09

<b>CARRIERS</b>					Gas
					Hydrogen
				X	Water
				X	Electricity
					Heat
					Cooling
<b>SECTOR</b>				X	Industrial
				X	Commercial
				X	Residential
				X	Academic/Educational
					Health
<b>LOCATION</b>					Inland
				X	Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV	X	Batteries	X	Electric
X	Wind		Heat		HVAC
X	Hydro		Electric Vehicle		Electric Vehicle
	CHP		Cool		Water
X	Diesel	X	Pumped Hydro	X	Hydrogen
	Heat pump	X	Hydrogen		Gas
	Natural Gas		Electric boiler		
	Electric				
	Solar thermal				
X	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Spain		<b>City</b>	El Hierro	
Type of geographic area (city, rural, ...)				Rural	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



### 5.1.9.1 Scenario description

This scenario is based on the electric power system of El Hierro island in the Canary Archipelago in Spain. El Hierro power system is not interconnected with any other power system, and in July 2014, began the operation of the Gorona del Viento wind-hydro power plant that has converted a thermal-based power system to a hybrid diesel/wind/hydropower one [40] (see Figure 44). The objective of the commissioning of the Gorona del Viento power plant was to provide 100% of the El Hierro island generation by means of renewable energy sources and retain the existing thermal power station just for backup purposes [41]. Recently, in 2019, a battery energy storage system was commissioned in the thermal power plant to help the provision of primary frequency by the diesel generators [42].



Figure 44. Scenario 09 - Different technologies in El Hierro power system: a) pump station, b) turbine station, c) thermal power station, d) wind turbines, e) battery energy storage system).

This scenario also considers other technologies that are not currently present in the electrical power system but are expected in the coming years, which are listed below:

- A solar photovoltaic generation, with a total capacity installed of 80 kWp is expected to be commissioned by 2025 according to the current expansion plans of El Hierro island [43].



- A set of electrolyzers to produce hydrogen with the generation excess of the wind and solar photovoltaic power plants, hydrogen storage tanks and a hydrogen supply system for a fleet of hydrogen-fuelled buses, similarly as analysed in the Hydrobus Project [44].

The scenario proposed is located on an island. Islands frequently have a high potential for renewable energy resources, and usually, they are isolated power systems, i.e., they are not interconnected to the mainland or other islands. In addition, the operation of these power systems often faces different operational problems due to their special characteristics, such as a high seasonality of the load and renewable generation profiles, difficulties in balancing power supply and load and limitations on the use of variable renewable generation due to dynamic security concerns of the power system [45].

The scenario proposed is interesting for the case of an islanded power system that intends to move from a thermal-based generation to a 100% renewable energy generation.

#### 5.1.9.2 Scenario location

El Hierro Island is the smallest and south-westernmost island of the Canary Archipelago (see Figure 45). The capital of this volcanic island is the municipality of Valverde, which belongs to the province of Santa Cruz de Tenerife. El Hierro has an area of 268.71 km<sup>2</sup> and a population of 11,147 inhabitants as of 2020 [46]. El Hierro was declared a Biosphere Reserve by UNESCO in 2000, and in 2014 the island was declared a UNESCO Geopark [47].



Figure 45. Scenario 09 – Scenario location

The climate of the island is very mild and sunny most of the year, with rainfall concentrated from October to March. The temperatures in the capital, located about 600 meters above sea level, are spring-like most of the year, being a little cold in winter and pleasantly warm in summer. As regards the wind, the only variable renewable source of its power system, it usually blows with greater intensity in the afternoon, often moderate or even quite strong. Figure 46 shows some statistics on the wind on the island.



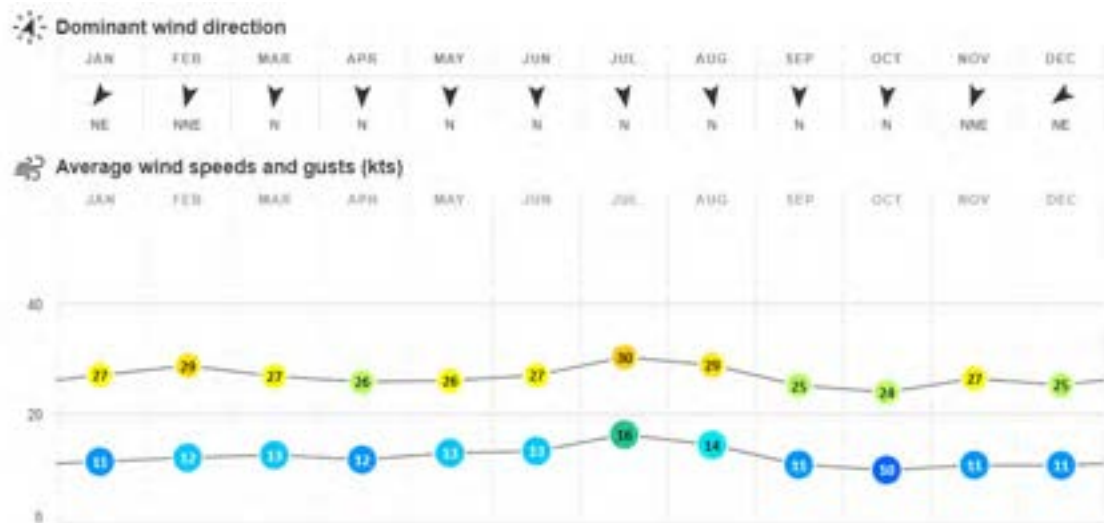


Figure 46. Scenario 09 - Wind historic data [9].

### 5.1.9.3 Scenario diagram

The scenario considers two carriers, water and electricity. The former is only considered to be used in the pumped-storage power plant.

El Hierro power system is currently composed of a thermal power station (Llanos Blancos) with 9 diesel units totalling 11.3 MW (the originally thermal-based power system) and the Gorona del Viento power plant that comprises 5 wind turbines with a capacity of 2.30 MW each and a closed-loop<sup>8</sup> pumped-storage plant with a pump station composed by 6 fixed-speed pumps each with a rated power of 500 kW and 2 variable-speed pumps each with a rated power of 1.50 MW, a turbine station composed by 4 Pelton turbines with a capacity of 2.83 MW each and finally, a lower and upper reservoir with a storage capacity of 150,000 m<sup>3</sup> and 500,000 m<sup>3</sup>, respectively. A simplified diagram of the current and expected state of El Hierro power system is depicted in Figure 47.

<sup>8</sup> There is no natural inflow in the upper reservoir.



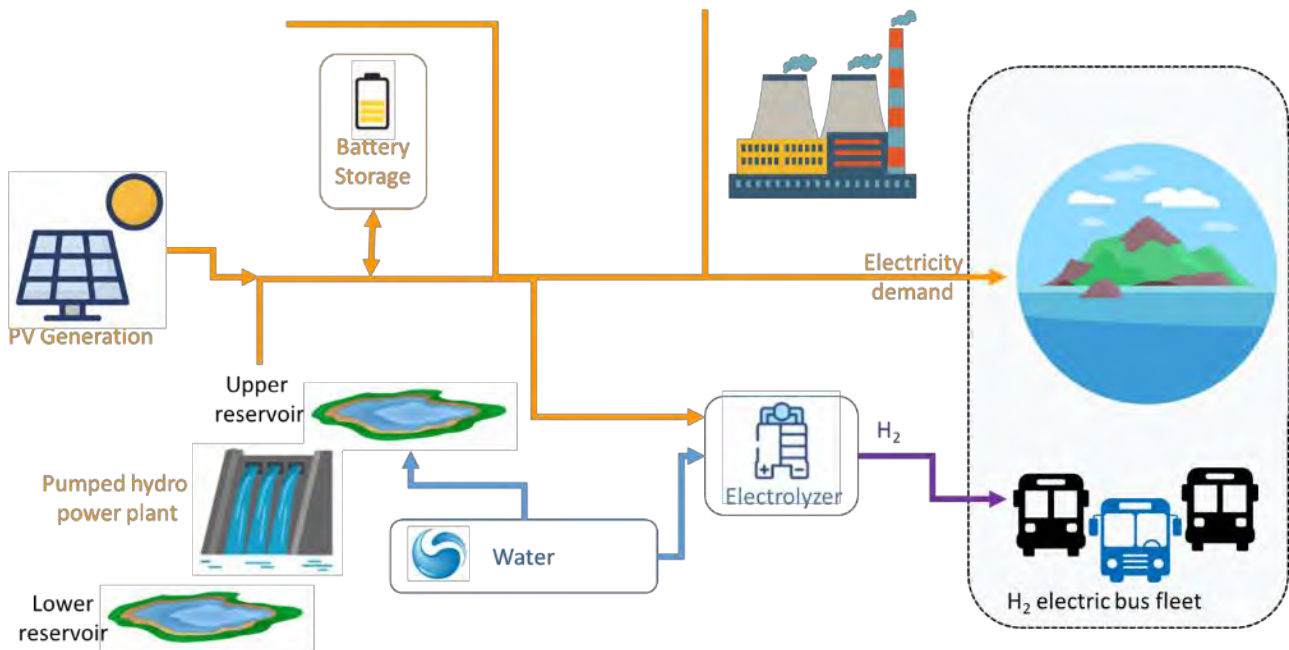


Figure 47. Scenario 09 – Scenario diagram.

Since the commissioning of the Gorona del Viento wind-hydro power plant, the transmission system operator of the El Hierro power system has been progressively increasing the instantaneous penetration limit of wind energy into the grid, reaching the maximum value of wind energy instantaneous penetration in September 2017 [48]. Despite this, as shown in Figure 48, where the number of hours per year in which the El Hierro power system achieved a 100% share of renewable electricity is depicted, the results are far from the initial objective.

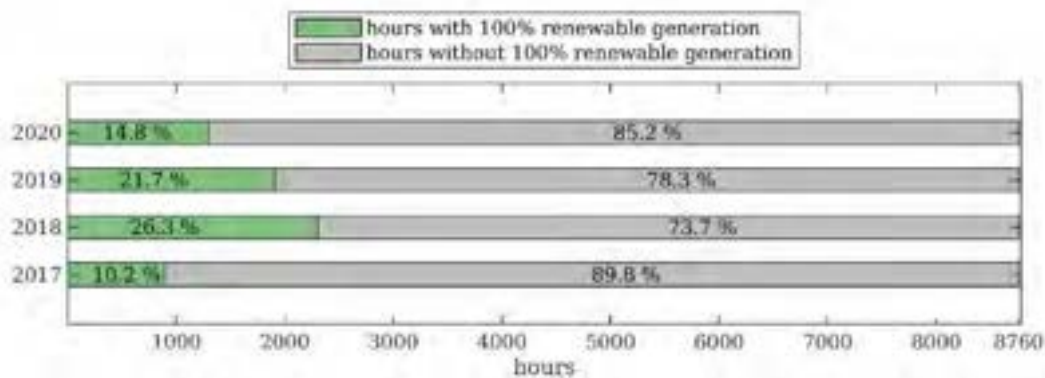


Figure 48. Scenario 09 - Percentage of hours per year with or without 100% of renewable generation. Data from [45].

Because of the difficulties in achieving a 100% renewable electricity supply, a Lithium-ion battery was installed in 2019 [42] in the thermal power plant in the framework of a research project. In the initial phase of the research project, the battery (with an installed capacity of 650 kW) is intended to cover the auxiliary systems of the thermal power plant [49] and also to help with the provision of the primary reserve of the thermal power plant [42]. In this scenario, the battery will be considered



as a generation/consumption resource of the power system, as in the simplified diagram of the scenario depicted in Figure 47, also considering the solid red line.

As regards the electric network of the power system, a single-bus approach will be considered in this scenario, similar to the approach used by the authors of [40].

#### 5.1.9.4 Technical characteristics

##### Wind farm

The wind farm of the Gorona del Viento wind-hydro power plant is composed of 5 wind turbines Enercon E70/2300, totalling an installed capacity of 11.5 MW. The characteristics of the Enercon E70/2300 turbine are exposed in Table 9.

Table 9. Scenario 09: characteristics of the Enercon E70/2300. Data from [50].

General data	Rotor
Manufacturer: Enercon	Maximum rotor speed: 21.5 rounds/minute
Model: E70/2300	Cut-in wind speed: 2 m/s
Rated power: 2,300 kW	Rated wind speed: 15.5 m/s
Rotor diameter: 71 m	Cut-off wind speed: 25 m/s
Swept area: 3,960 m <sup>2</sup>	Manufacturer: Enercon
Specific area: 1.73 m <sup>2</sup> /kW	
Number of blades: 3	
Power control: Pitch	
Tower	Generator
Minimum hub height: 57 m	Type: SYNC Wounded
Maximum hub height: 113 m	Number: 1
	Maximum speed: 21.5 rounds/minute
	Voltage: 400-2,000 V

##### Thermal power plant

The Llanos Blancos thermal power plant is in the municipality of Valverde, the capital of El Hierro Island. The thermal power plant is composed of 9 diesel power units that use diesel oil as fuel. Some of the main characteristics of the thermal generators are exposed in Table 10.



Table 10. Scenario 09 - Gross rated power of diesel generators of Llanos Blancos thermal power plant.

Units	Rated power [kW]	Manufacturer
Motor Diesel LD 7	780	CARTERPILLAR
Motor Diesel LD 9	1,100	CARTERPILLAR
Motor Diesel LD 10	1,460	CARTERPILLAR
Motor Diesel LD 11	1,460	CARTERPILLAR
Motor Diesel LD 12	1,460	CARTERPILLAR
Motor Diesel LD 13	1,460	CARTERPILLAR
Motor Diesel LD 14	2,000	MAN
Motor Diesel LD 15	2,000	MAN
Motor Diesel Mobile 1	1,280	CARTERPILLAR

### Pumped-storage power plant

The Gorona del Viento wind-hydro power plant has a closed-loop pumped-storage plant that comprises a pump station composed of 6 fixed-speed pumps, each with a rated power of 500 kW and 2 variable-speed pumps, each with a rated power of 1.50 MW, and a turbine station composed by 4 Pelton turbines with a capacity of 2.83 MW each and finally, a lower and upper reservoir with a storage capacity of 150,000 m<sup>3</sup> and 500,000 m<sup>3</sup>, respectively. Some of the technical characteristics of the hydro units are depicted in Table 11.

Table 11. Scenario 09 - Hydro unit characteristics. Data from [40].

Type	Number of units	Minimum active power [MW]	Maximum active power [MW]	rated flow [l/s]
Pelton turbine	4	0.52	2.83	500
Variable-speed pump	2	1.02	1.5	177
Fixed-speed pump	6	0.5	0.5	56

### Battery energy storage system

A Lithium-ion battery of 650 kW power output/input capacity and a storage capacity of 3 MWh is considered in the scenario to help the power system to reach higher shares of variable renewable generation.

### Solar photovoltaic system

Due to the expected capacity of the solar photovoltaic system, 80 kWp, it is considered that this installation will be directly connected to the grid at a low voltage level and mainly in rooftop



installations. This solar photovoltaic capacity will be considered as another generation asset of El Hierro island aimed to reduce the total power system's cost.

### Hydrogenerator plant

A hydrogenator plant is composed of a set of electrolyzers, hydrogen storage tanks and a hydrogen supply system for a fleet of hydrogen-fuelled buses. The hydrogenator plant will use the generation excess of the wind and solar photovoltaic power plants.

### Electrical demand

Figure 49 shows the average total electrical demand in El Hierro island for the period 2014-2021. The mean value of the period is 5.01 MWh, with a maximum value of 7.61 MWh and a minimum value of 2.69 MWh (not considering the outliers of the series). It is worth mentioning that the electricity demand provided does not consider solar photovoltaic generation and hydrogen generation.

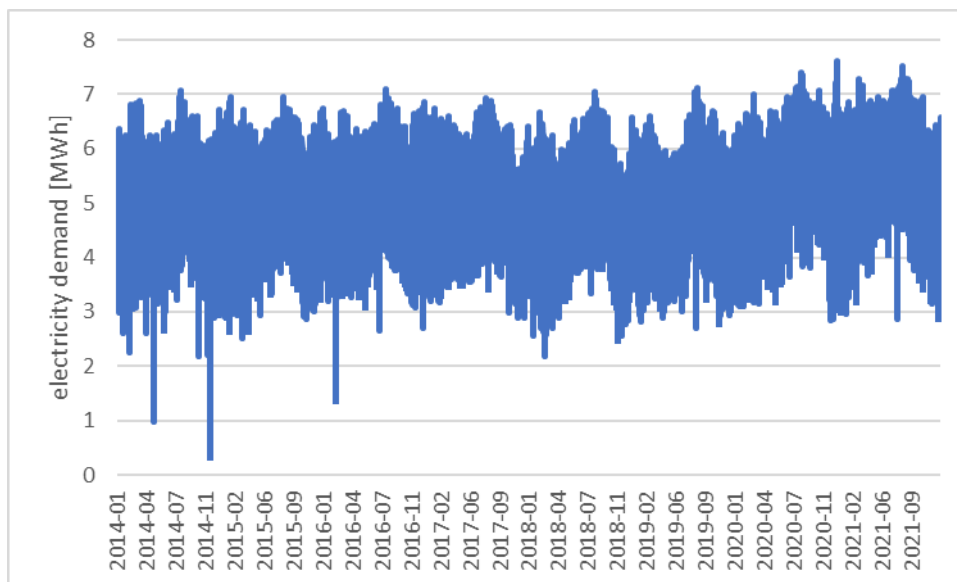


Figure 49. Scenario 09 - Electricity demand in El Hierro for the period 2014-2021. Data from [51].

#### 5.1.9.5 Energy management strategies

The objective of this scenario is to cover 100% of the El Hierro island electricity demand by using solely renewable energy sources and, exceptionally, the thermal power station just for backup purposes. To achieve this main objective, some other objectives are listed below:

- a) Minimise the thermal power plant generation and thus lower the CO<sub>2</sub> emissions.
- b) Maximise the wind energy generation due to the inclusion of the battery.



#### 5.1.9.6 Regulatory aspects

In the case of Spain, these isolated power systems are operated in a centralised way, and by doing so, there is no liberalized electricity market. However, because of the new EU regulations to promote local and collective self-consumption, included in Spain, this scenario does not envision any regulatory limitation related to the inclusion of energy storage. In any case, all installations should be regulated by the Industry Ministry.

#### 5.1.9.7 Economic costs and benefits

The operational and maintenance costs of the thermal power plant are regulated in the Spanish Royal Decree 738/2015 [52]. In the case of the Gorona del Viento wind-hydro power plant, the methodology for the calculation of fixed and variable costs for electricity production is presented in [53].

The investment and operating costs of the technologies that are not currently in the power system of El Hierro have been mainly extracted from the eNeuron «D2.2: Technical solutions for multi-carrier integrated systems under the LEC concept: A review» and «Renewable power generation costs in 2020» [20].

- Electrolysers: different technologies ranging from 500-3,000 €/kWe.
- Installed rooftop photovoltaic system: 1225 €/kWp.

The capital costs of the batteries have been reducing in the last years and are expected to continue decreasing in the next years. E.g. some works forecast that the Lithium-ion batteries will decrease the total project cost in a range of 20-25% for the period 2018-2025 [54]. The reference value for the Li-ion battery system provided by [55] is 500 €/kWh.

It is expected that the batteries will help the power system to achieve a higher share of variable renewable energy generation leading to a lower production cost. The future benefits and energy costs of the scenario should be provided through the eNeuron toolbox usage.

#### 5.1.9.8 Impacts

The main environmental impact of the proposed scenario lies in the reduction of CO<sub>2</sub> emissions due to the expected lower amount of energy generated by thermal-based generators. In 2019, the generation injected into the grid by the diesel generators represented 33.2% of the total, equivalent to 4521 tons of diesel-oil consumption [56]. In addition, the use of buses for public transportation will help to decrease the emissions of the transport on the island.

#### 5.1.9.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

- Electrical consumption of the island:
  - 044\_CON-ELEC-ELC\_ELEC-ELEC\_ES-ELHIERRO\_01012018-31122018



- Wind generation
  - 047\_GEN-ELEC-WIN\_ELEC-ELEC\_ES-ELHIERRO\_01012018-31122018
- Thermal generation
  - 045\_GEN-ELEC-DIG\_ELEC-ELEC\_ES-ELHIERRO\_01012018-31122018
- Pumped-storage generation/consumption
  - 046\_GEN-ELEC-HYD\_ELEC-ELEC\_ES-ELHIERRO\_01012018-31122018

For the rest of the technologies, no real data is provided. In the case of solar photovoltaic generation, synthetic data has been specifically created for the expected solar photovoltaic installation of 80 kWp. In the case of the battery energy storage system and the hydrogen, the data series indicated below must be scaled or adapted to this scenario.

- Solar photovoltaic generation
  - 078\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-ELHIERRO\_01012005-31122016
- Battery energy storage system
  - 043\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-02022018
- Hydrogen generation
  - 063-GEN-HYDR-H2E-WIND-HYDR-PT-PORTO-01012023-31122023



## 5.1.10 Scenario 10

<b>CARRIERS</b>					Gas
					Hydrogen
				X	Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>					Industrial
				X	Commercial
				X	Residential
					Academic/Educational
<b>LOCATION</b>					Health
				X	Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind		Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
	CHP		Cool	X	Water
	Diesel		Pumped Hydro		Hydrogen
X	Heat pump		Hydrogen		Gas
	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Spain		<b>City</b>	Manzanares el Real	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



#### 5.1.10.1 Scenario Description

This scenario corresponds to a heating-cooling network that supplies residential, public, and commercial users. A water-source heat pump plant (district heating-cooling) works by extracting heat from a reservoir, i.e. a lake, and converting it into useful heat to warm the water in winter or to cool it in summer. The water loop is more efficient than air in transporting thermal energy. Also, the mass of the water provides thermal storage that reduces the electricity consumption of the heat pump plant.

The scenario is located in a small town where the users meet their heating needs with individual installations (natural gas boilers or air-source heat pumps). The aim of this scenario is the analysis of an energy hub formed by the users integrated into a heating-cooling network. To accomplish this goal, the individual boilers will be replaced by a district heating-cooling system supplied by a water-source heat pump. Also, new pipeline infrastructure is needed to create an open loop of water circulation between the heat pump plant and the reservoir. Moreover, a new pipeline infrastructure will connect the heating-cooling network with the users. The heat pump plant will be powered by electricity from the electric grid and PV generation from the buildings of the hub.

#### 5.1.10.2 Scenario location

Manzanares el Real is a small town situated in the northern area of Madrid (see Figure 50). It covers an area of 128.4 km<sup>2</sup> and, by 2021, a population of 9202 inhabitants. Manzanares el Real is in a mountain area close to the Manzanares river and the Guadarrama Mountains National Park and a few kilometres far from the reservoir “Embalse de Santillana”. The reservoir has a maximum flooded area of 1052 ha, and a distance between opposite shores of 4 km, with a total capacity of 91 Hm<sup>3</sup>. This reservoir is an important water supplier for Madrid and the rest of its community.



Figure 50. Scenario 10 – Scenario location.

The climate of Manzanares el Real is moderately continental, with quite cold, rainy winters and relatively hot, sunny summers (see Figure 51 and Figure 52). These conditions favour maintaining the mass water temperature of the reservoir in a stable range between 8°C (winter) and 20°C



(summer). Also, the town area is conducive to photovoltaic generation because monthly average hours of sunshine reach a minimum of 120 h in winter and a maximum of 200 h in summer, as shown in Figure 53.

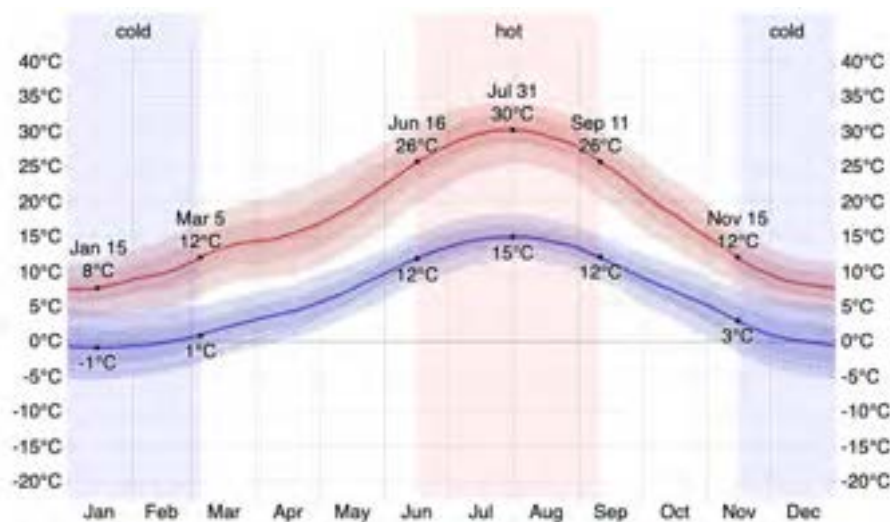


Figure 51. Scenario 10 - Temperature historic data [57].

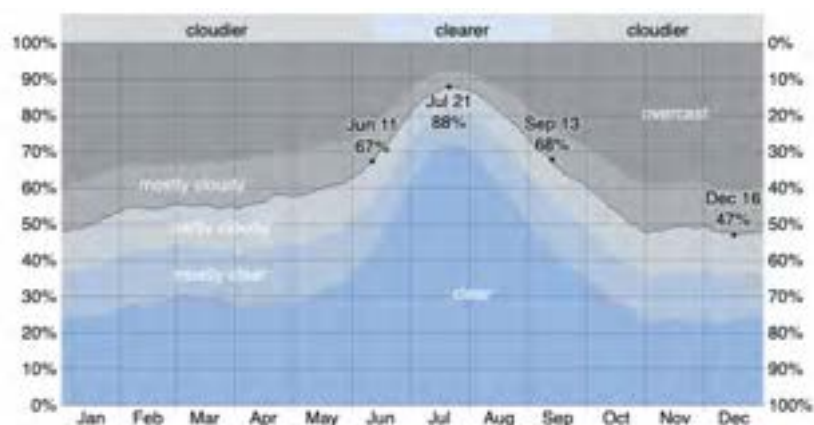


Figure 52. Scenario 10 - Cloud historic data [57].



Figure 53. Scenario 10 - Sun hours historic data [57].

Most of the users' buildings have rooftops compatible with the installation of PV systems, as can be seen in Figure 54. The energy produced by these PV systems will be used to power the heat pump



plant or supply the electrical loads of the users' buildings (e.g., lighting and appliances) or shared with other users (via collective self-consumption).



*Figure 54. Scenario 10 - Typical rooftops of scenario's users.*

#### 5.1.10.3 Scenario Diagram

The scenario considers two carriers for water and electricity to supply a heating-cooling network (see Figure 55). The water carrier is formed by an open-loop pipeline between the heat pump plant and the reservoir. The electricity consumption of the heat pump plant is supplied by the electricity network which is powered by the electric grid and the PV systems installed in the users' buildings. The heating-cooling network feeds the individual installations of each building according to its needs.



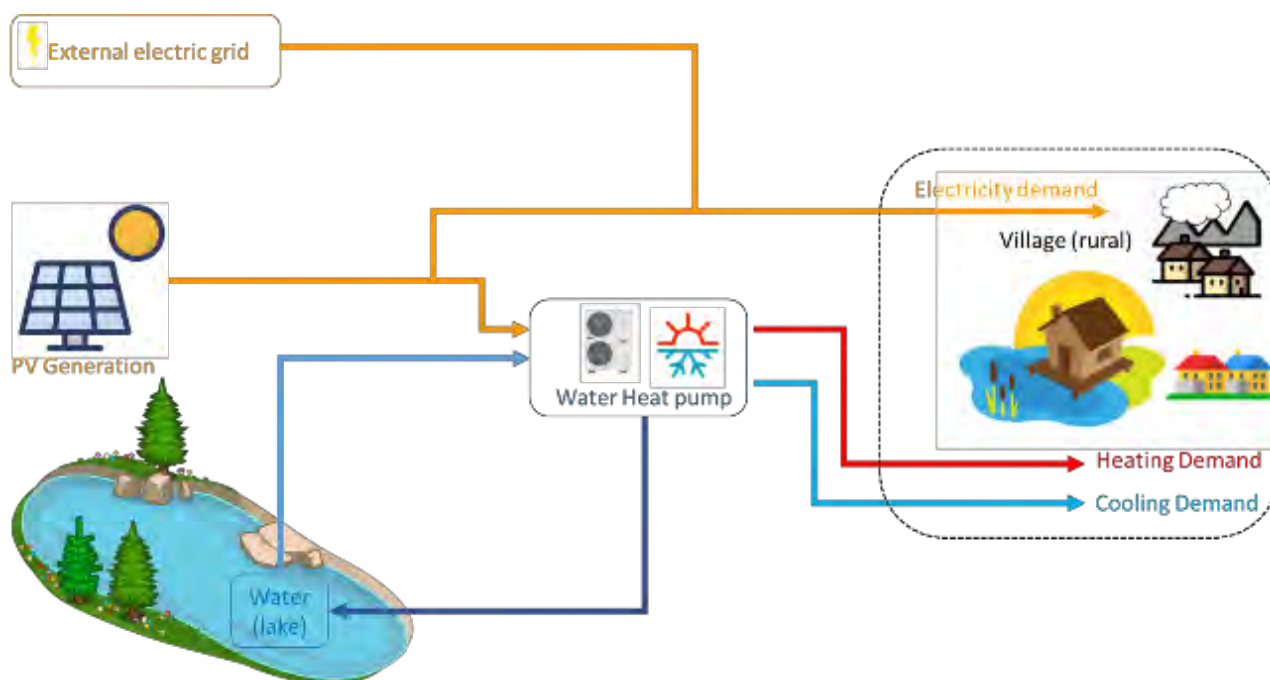


Figure 55. Scenario 10 - Scenario diagram.

It is assumed that the heat pump plant supplies the heating-cooling demand of the users' hub. To manage the energy needs of the heat pump plant, a transformer substation is to be installed. This substation includes a control system based on three-phase inverters that allows a bidirectional connection between the heat pump plant and the users of the energy hub by means of the electricity network. As the electric network connects all buildings in the hub, the users can import and export energy from and to them.

#### 5.1.10.4 Technical characteristics

The new heat pump plant that will power the Heating-Cooling network will have a transformation substation made up of two electric transformers (550 kVA each), electrical protections, and a control system based on three-phase inverters and a smart meter. The heat pump should be optimally sized to support peak heating-cooling demand.

The thermal energy is transported by two pipeline infrastructures; one of them is an open-loop between the heat pump plant and the reservoir, with a length of 20 km. The other one transports the water between the plant and the users. An EER of 35% is assumed [58].

The estimation of the thermal peak power of different users is presented in Table 12.

Table 12. Scenario 10 - Thermal power estimation

User	Estimated power
Government building 1 (400 m <sup>2</sup> )	80 kW
Medical centre (600 m <sup>2</sup> )	110 kW
Primary school (500 m <sup>2</sup> )	95 kW
Secondary school (600 m <sup>2</sup> )	110 kW



Commercial centre (800 m <sup>2</sup> )	140 kW
Sport centre (400m <sup>2</sup> )	80 kW
Group 1 of houses (900 m <sup>2</sup> )	160 kW
Group 2 of houses (700 m <sup>2</sup> )	125 kW
Total power	900 kW

#### 5.1.10.5 Energy management strategies

This scenario focuses on five specific objectives:

- Heat pump plant power optimisation.
- Maximizing the thermal energy production of the heat pump plant.
- Electric and thermal load forecasting of the energy hub.
- Photovoltaic capacity forecasting.
- Maximizing the energy self-consumption within the energy hub as a local energy community of the users involved.

Energy management strategies will consider reducing losses in energy conversion or transport, and costs.

#### 5.1.10.6 Regulatory aspects

In Spain, where the scenario is located, the installation of the heat pump plant must be approved by the electricity supply company, which is the one that authorizes the power to be installed and the type of connection necessary.

In the case of the use of water from the reservoir, authorization must be requested from the Ecological Transition Ministry, and compliance with environmental regulations must be guaranteed.

The Spanish Royal Decree 244/2019 [15] regulates the administrative, technical and economic conditions of the collective self-consumption of electric energy for different users (commercial, industry, homes etc.). In collective self-consumption, the distance between the generation and loads must be less than 500 m. Also, this normative only allows sharing generated power under static allocation coefficients. Meaning that the same coefficients are used during the hours of the year regardless of the demands of the users. However, it is expected that new regulations will allow the use of variable allocation coefficients and, therefore, the power-sharing between users can be adjusted to their different demand curves during the day or the year.

#### 5.1.10.7 Economic costs and benefits

The high initial capital costs of new pipeline construction constitute a major barrier to set-up the heating-cooling network. However, the water-source heat pump technology allows reducing the energy consumption of 30% compared to boiler-based systems [58]. According to the analysis presented in [20], [59], [60], the following set-up costs are estimated:

- Heat pump: 600 €/kW.



- Transformer substation and control system: 120.000 €.
- District heating-cooling network with an average diameter of 120 mm: 615 €/m.

#### 5.1.10.8 Impacts

The main environmental impact of the proposed scenario lies in reducing the energy consumption and CO<sub>2</sub> emissions by means of the heat pump plant performance. Also, the installation of PV distributed systems produces savings related to the increase in self-consumption and the system's CO<sub>2</sub> emissions. It is expected the reduction of the global energy consumption by 40-45% (heat pump plant) [58], [60] and individual users to reach savings of 35-40% from PV systems [20]. As a result, CO<sub>2</sub> emissions are expected to be reduced by 0.23 tons/year [61].

#### 5.1.10.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

Electrical consumption of users of the energy hub:

- 017\_CON-ELEC-ELC\_ELEC-ELEC\_ES-MADRID\_03022017-17052019\_3
- 040\_CON-ELEC-ELC\_ELEC-ELEC\_IT-Turin\_01012019-31122019

PV generation:

- 037\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-MADRID\_15072015-10072021

Thermal energy consumption of users of the energy hub:

- 041\_CON-THER-HVA\_HEAT-HEAT\_IT-TURIN\_01012019-31122019
- 042\_CON-THER-HVA\_COLD\_COLD\_IT-TURIN\_01012019-31122019



## 5.1.11 Scenario 11

<b>CARRIERS</b>				X	Gas
					Hydrogen
					Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>				X	Industrial
				X	Commercial
				X	Residential
					Academic/Educational
					Health
<b>LOCATION</b>					Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV	X	Batteries	X	Electric
	Wind	X	Heat	X	HVAC
	Hydro		Electric Vehicle		Electric Vehicle
X	CHP	X	Cool		Water
	Diesel		Pumped Hydro		Hydrogen
X	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
X	Absorption Chiller				
LOCATION					
<b>Country</b>	Italy		<b>City</b>	Turin	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>					Csa
					Cfb
					Dfb
					Dfc
				X	Cfa



#### 5.1.11.1 Scenario description

The scenario focuses on an Energy hub composed of four different end-users located in the city of Turin. The energy hub presents the following characteristics:

- the end-users considered in the case study under investigation belong to a hospital, a building with 10 office units, a hotel, and a cluster of buildings with 100 residential units,
- it consists of four multi-carrier micro-energy hubs, and each of them is used to cover the multi-energy demand of the associated building or a cluster of buildings. The energy hub is connected to external infrastructures such as the electricity distribution network and the gas network,
- each multi-carrier micro-energy hub is made up of a series of generation, conversion and storage technologies and the related software and hardware systems for the management, control, and monitoring of energy flows, and
- the multi-carrier micro-energy hubs are energetically interconnected and can interact with each other, sharing electrical and thermal energy, the latter via a district heating network, to meet the multi-energy needs (electricity, cooling) of the end-users.

Each micro-energy hub is composed of the following technologies:

- generation: CHP with a gas-fired internal combustion engine, a PV system, and a natural gas-fired auxiliary boiler,
- conversion: an absorption chiller and a reversible electric heat pump, and
- storage: battery and heat/cold storage.

The scenario compares the energetic and economic performance of the energy hub operating under optimized operational strategies with respect to one of the conventional energy supply systems typically used in Italy. As for the conventional system, the national electric grid is used to satisfy the electrical load of the energy hub's end-users and for feeding the electrical chiller to cover the cooling demand, whereas the gas boilers are used to satisfy the thermal demand.

#### 5.1.11.2 Scenario location

The energy hub is in the Italian climatic zone E, in the city of Turin. Precisely, it is in north-western Italy at the foot of the Alps (see Figure 56).

Turin features a mid-latitude, four seasons humid subtropical climate. In Turin, summers are warm and humid, winters are very cold, and the weather is partly cloudy all the year-round. Over the course of the year, the temperature typically varies from -3°C to 28°C, and it rarely goes below -5°C or beyond 32°C. The warm season lasts for 3.1 months, namely from June 7th to September 11th, with an average daily high temperature above 25°C. July is the hottest month of the year in Turin, with an average high temperature of 28°C and a low one of 18°C. The cold season lasts for 3.4 months, namely from November 18 to February 28, with an average daily high temperature below 11°C. January is the coldest month of the year in Turin, with an average low temperature of -3°C and a high one of 6°C [62].





Figure 56. Scenario 11 – Scenario Location.

According to the Italian law, for the climatic zone E, the heating season (i.e., the period in which space heating systems can be switched on) ranges from 15<sup>th</sup> October to 15<sup>th</sup> April, whereas no rules are fixed for the range of the cooling season [63].

In Figure 57 and Figure 58, the average solar irradiance for winter and summer are shown, respectively. The average is computed considering the hourly solar irradiance from 2005 to 2016 of the days in January for the winter and in July for the summer.

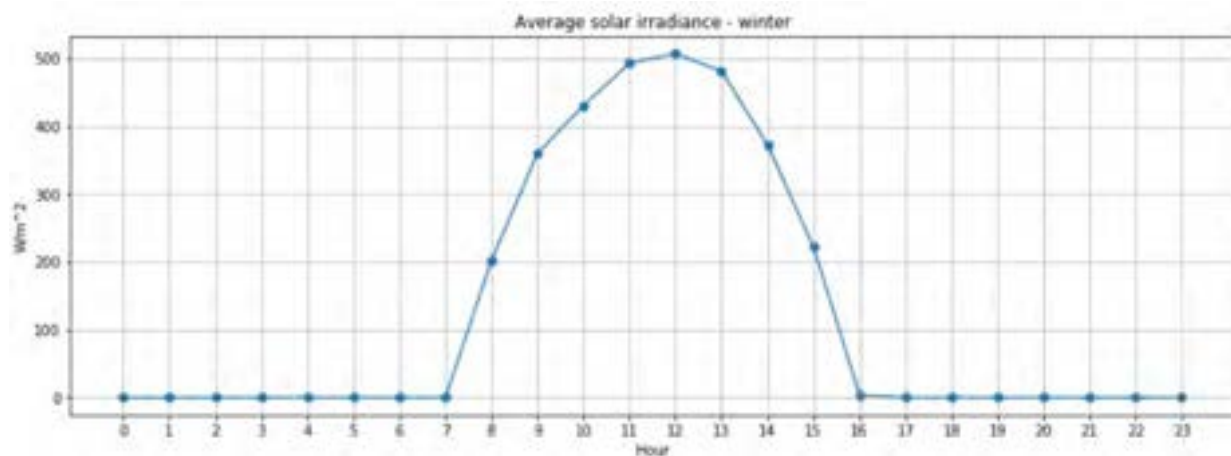


Figure 57. Scenario 11 - Irradiance historic data for winter.



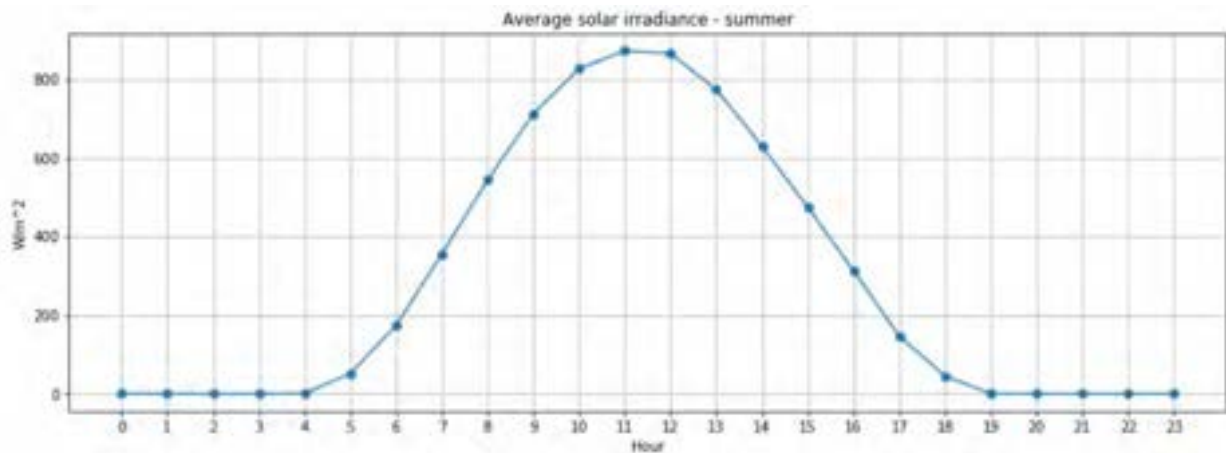


Figure 58. Scenario 11 - Irradiance historic data for summer.

#### 5.1.11.3 Scenario diagram

The scenario provides three carriers for electricity, heat, and cooling, plus the natural gas used to feed both CHPs and boilers of the four micro-energy hubs (see Figure 59). Also, solar irradiance is considered for PV systems.

For each end-user, the energy needs are met as follows:

- the electricity needs can be met by the electricity distribution network, CHP, PV system, and battery of the associated micro-energy hub, as well as by CHPs of the other micro-energy hubs through the pre-existing local network,
- the thermal energy needs can be met by the CHP, heat pump, boiler, and heat storage of the associated micro-energy hub, as well as by CHPs of the other micro-energy hubs through the district heating network, and
- the energy needs for cooling can be met by the absorption chiller, heat pump and cold storage of the associated micro-energy hub. The absorption chiller of each micro-energy hub can be powered by both the thermal energy supplied by the CHP and the auxiliary boiler of the associated micro-energy hub, and also, by the thermal energy supplied by CHPs of the other micro-energy hubs through the district heating network.



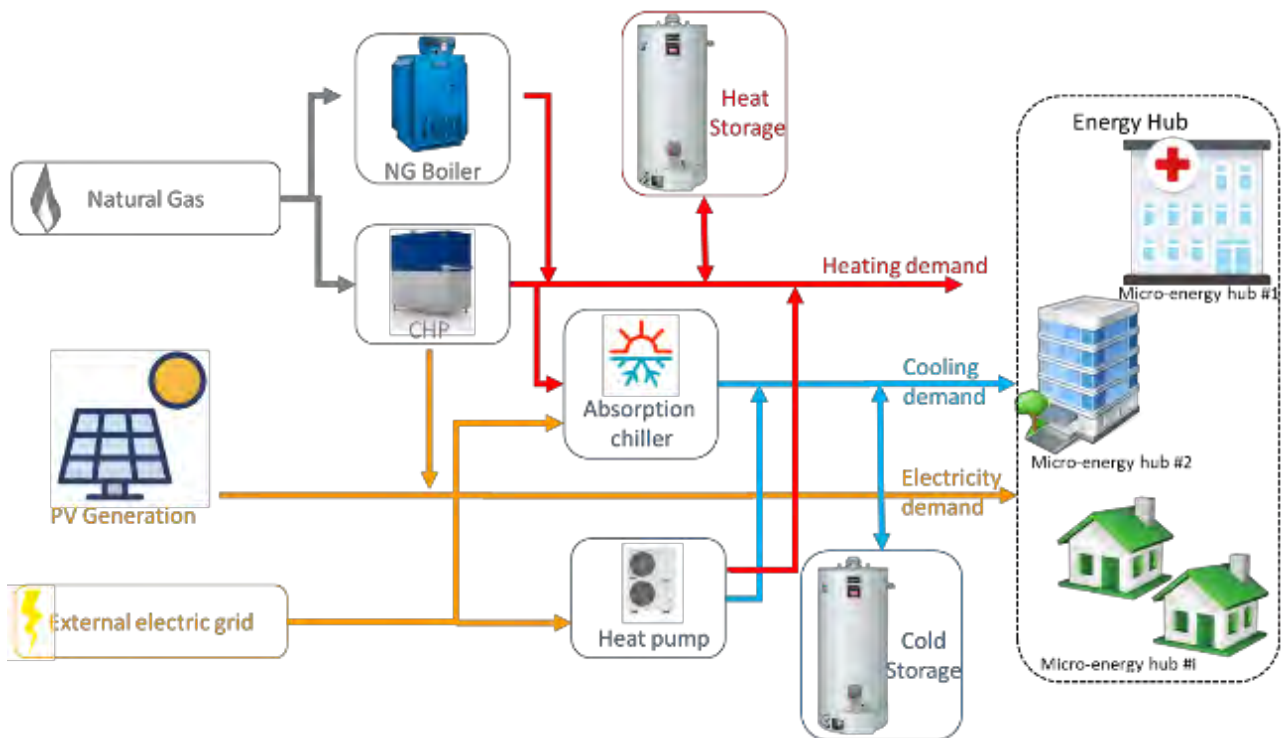


Figure 59. Scenario 11 – Scenario diagram.

PV production is directly linked to solar irradiance that has an hourly profile. Consumptions planned in this scenario are related to the electric and heat demand of the end-users and to the natural gas used to feed CHPs and auxiliary boilers. Each micro-energy hub has its own consumption.

#### 5.1.11.4 Technical characteristics

The electric network and the gas network provide electricity and gas, respectively, to each micro-energy hub investigated in this scenario. Electricity and thermal consumptions of each micro-energy hub are synthetic databased on real aggregated data.

In detail, for the electricity demand, the cold, mid-cold, and mid-hot season was assumed to be of 273 days, ranging from the 1<sup>st</sup> of September to the 31<sup>st</sup> of May, while the hot season was assumed to be 92 days, ranging from the 1<sup>st</sup> of June to the 31<sup>st</sup> of August. Therefore, the hourly electricity demands per each representative season day have been evaluated as the average of the hourly mean values of the electricity demands in the corresponding hour of all the days in the respective season.

For the thermal demand, the hourly energy per each representative day of the cold season has been evaluated as the average of the hourly mean values of the heating demands in the corresponding hour of all days in the winter season.

For the cooling demand, the hourly energy per each representative day of the hot season day has been evaluated as the average of the hourly mean values of the cooling demands in the corresponding hour of all days in the summer season.



The overall electric, heating and cooling demand of the energy hub is reported in Table 13.

Gas consumption results from the operational optimisation of the energy hub according to economic and/or energetic objectives. For the hospital, the total yearly NG consumption resulting from the optimisation under economic objectives is equal to 1,227,919 m<sup>3</sup>, while the ones resulting from the optimisation under environmental objectives are equal to 68,777 m<sup>3</sup>. In both cases, the NG consumption is zero during the hot season.

Technical data of the technologies in the energy hub are reported in Table 14. The maximum and minimum State of Charge (SOC) of all the batteries installed in the energy hub correspond to 80% and 20% of their capacity, respectively.

The overall thermal efficiency of the district heating network is assumed to be equal to 90%.

Table 13. Scenario 11 - Energy demand of the energy hub.

Season	Electricity (kWh)	Total heating (kWh)	Cooling (kWh)
Winter	1040	3684	0
Summer	968	452	1858

Table 14. Scenario 11 - Technical data of the technologies in the energy hub.

End-user	Technology	Size	Efficiency	
			Electrical	Thermal
Hospital	CHP NG ICE	950 kWe	0.34	0.48
	Natural gas boiler	265 kW	n/a	0.9
	PV	3700 m <sup>2</sup>	0.14	n/a
	Heat Pump	1000 kWth	n/a	COP <sup>SH</sup> =3.5 COP <sup>SC</sup> =3.0
	Absorption chiller	260 kW	n/a	COP=0.8
	Battery	250 kWh	$\eta^{Ch} = \eta^{Disch}=0.85$	n/a
	Thermal storage	200 kWh	n/a	$\varphi_{TES} = 0.05$
Offices	CHP NG ICE	340 kWe	0.34	0.48
	Natural gas boiler	50 kW	n/a	0.9
	PV	1300 m <sup>2</sup>	0.14	n/a
	Heat Pump	1000 kWth	n/a	COP <sup>SH</sup> =3.5 COP <sup>SC</sup> =3.0
	Absorption chiller	40 kW	n/a	COP=0.8
	Battery	100 kWh	$\eta^{Ch} = \eta^{Disch}=0.85$	n/a



End-user	Technology	Size	Efficiency	
			Electrical	Thermal
	Thermal storage	100 kWh	n/a	$\varphi_{TES} = 0.05$
Hotel	CHP NG ICE	260 kWe	0.33	0.54
	Natural gas boiler	50 kW	n/a	0.9
	PV	1000 m <sup>2</sup>	0.14	n/a
	Heat Pump	125 kWth	n/a	$COP^{SH}=3.5$ $COP^{SC}=3.0$
	Absorption chiller	40 kW		$COP=0.8$
	Battery	80 kWh	$\eta^{Ch} = \eta^{Disch}=0.85$	n/a
	Thermal storage	100 kWh	n/a	$\varphi_{TES} = 0.05$
Cluster of residential buildings	CHP NG ICE	380 kWe	0.34	0.48
	Natural gas boiler	230 kW	n/a	0.9
	PV	1500 m <sup>2</sup>	0.14	n/a
	Heat pump	670 kWth	n/a	$COP^{SH}=3.5$ $COP^{SC}=3.0$
	Absorption chiller	210 kW	n/a	$COP=0.8$
	Battery	80 kWh	$\eta^{Ch} = \eta^{Disch}=0.85$	n/a
	Thermal storage	150 kWh	n/a	$\varphi_{TES} = 0.05$

#### 5.1.11.5 Energy management strategies

This scenario focuses on two objectives:

- minimization of the daily net energy cost
- minimization of expected daily CO<sub>2</sub> emissions of the energy hub.

The four multi-carrier micro-energy hubs are energetically interconnected and can interact with each other, sharing electrical and thermal energy via the internal electrical network and the district heating network, respectively.

#### 5.1.11.6 Regulatory aspects

The regulatory framework represents a fundamental step for the installation of energy conversion technologies from renewable sources. In Italy, there have been many regulations in the country and to enact the European directives in the last three decades. Many of them have helped the spread of some of the most important technologies (for example, photovoltaic panels and wind turbines) in order to reach the targets (especially as regards the electricity sector) set to increase the use of renewable resources, the reduction of CO<sub>2</sub> emissions and the increase of energy efficiency.



Photovoltaic panels were certainly one of the technologies encouraged, especially in the period from 2008 to 2010, both for the feed-in-tariff scheme and for the reduced capital investment favoured by scale economies and scientific research. However, since 2013, the pricing scheme has been definitively cancelled, and the spread of this technology has suffered a sharp slowdown due to the increase in the payback times. Currently, for photovoltaic plants with a capacity greater than 20 kW, an “Autorizzazione Unica” is required according to Legislative Decree n°. 387/2003. A simplified authorization instead (provided by Legislative Decree n°.28 / 2011) is required for plants below this threshold unless they fall into other specific areas, indicated by the Ministerial Decree of 10 September 2010, for which, on the other hand, the “Autorizzazione Unica” can be applied. It is worth noting that many regions in Italy have adopted specific measures linked to the peculiarities of the territories to encourage or prevent the spread of PV panels in particular areas [64].

As regards the heating sector, the regulations adopted are certainly more complex and are constantly evolving because it represents one of the weak links in the energy transition process. Among the technologies proposed for the heating sector, CHP is certainly one of the most widespread, especially in industrial areas or residential areas where a district heating network is already present. The legislation in Italy (Legislative Decree 4 July 2014, no. 102) aims to essentially establish the characteristics of the cogeneration process, the identification of cogeneration technologies, the calculation of production from cogeneration, the method of determining the efficiency of the cogeneration process and the possibility to access to the support scheme (e.g. Certificati Bianchi) [65].

Finally, as regards the use of electric batteries, the regulatory framework is the Directive 2006/66 / EC (the Batteries Directive), last amended in 2018. This legislation essentially refers to the limitation of the carbon footprint of batteries, increasing the recycling rate of batteries and addressing the raw material problems of the batteries [66].

#### 5.1.11.7 Economic costs and benefits

The scenario compares the economic performance of the energy hub operating under optimized operational strategies with respect to a conventional energy supply system typically used in Italy. As for the conventional system, the distribution network is used to satisfy the electrical load of the energy hub’s end-users and to feed the electrical chiller used to cover the cooling demand.

From a comparison with the conventional supply system, it emerges that the daily energy costs of the energy hubs operating according to optimized operational strategies are reduced by 75% during the cooling season and in a range that goes from 70% to 80% during the heating season [67].

A recap of capital and operative costs for the different technologies is resumed in Table 15 [68].



Table 15. Scenario 11 - Costs information for the involved technologies [68].

Technology	Size range	Costs	
		Capital	O&M
CHP NG ICE	20-5000 kW <sub>e</sub>	840-1495 €/kW	0.008-0.023 €/kWh
Natural gas boiler	10-2000 kW	100 €/kW	0.011-0.019 €/kWh
PV	-	2000 €/kW	0.010 €/kWh
Heat Pump	10-5000 kW <sub>th</sub>	460 €/kW	0.0025 €/kWh
Absorption chiller	10-5000 kW	230-510 €/kW	0.002 €/kWh
Battery	-	350 €/kWh	0.005 €/kWh
Heat and cold storage	-	20 €/kWh	0.0012 €/kWh

#### 5.1.11.8 Impacts

The scenario pretends also compare the environmental performance of the energy hub operating under optimized operational strategies to that of the conventional energy supply system typically used in Italy.

From a comparison with the conventional supply system, it emerges that the daily CO<sub>2</sub> emissions of the energy hub that operates according to operational strategies optimized under environmental objectives are reduced by 24% during the cooling season and by 35% during the heating one [64].

#### 5.1.11.9 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used:

Electrical consumption of the energy hub:

- 040\_CON-ELEC-ELC\_ELEC-ELEC\_IT-Turin\_01012019-31122019

Thermal consumption of the energy hub:

- 041\_CON-THER-HVA\_HEAT-HEAT\_IT-TURIN\_01012019-31122019

Cooling consumption of the energy hub:

- 042\_CON-THER-HVA\_COLD\_COLD\_IT-TURIN\_01012019-31122019

Solar irradiance

- 051\_GEN-ELEC#THER-PVE#CSP\_IRRA-IRRA\_IT-TURIN\_01012005-31122016

CHP Natural gas consumption for the hospital:



- 085\_CON-NGC-NGC-NGC-NGC-IT-TURIN-01012019-31122019
- 086\_CON-NGC-NGC-NGC-NGC-IT-TURIN-01012019-31122019



## 5.1.12 Scenario 12

<b>CARRIERS</b>					Gas
					Hydrogen
					Water
				X	Electricity
				X	Heat
					Cooling
<b>SECTOR</b>				X	Industrial
				X	Commercial
				X	Residential
					Academic/Educational
					Health
<b>LOCATION</b>				X	Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV	X	Batteries	X	Electric
	Wind		Heat	X	HVAC
	Hydro	X	Electric Vehicle	X	Electric Vehicle
X	CHP	X	Cool		Water
	Diesel		Pumped Hydro		Hydrogen
X	Heat pump		Hydrogen		Gas
X	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	NG Reforming				
	Fuel Cell				
	Absorption Chiller				
LOCATION					
<b>Country</b>	Portugal		<b>City</b>	Lisbon	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



#### 5.1.12.1 Scenario description

This scenario focuses on an urban district: Parque das Nações, a parish of the city of Lisbon, the capital of Portugal. The parish has 22350 inhabitants and a total area of 5.4 km<sup>2</sup>, occupied by residential and tertiary/services buildings, with a residual number of industrial buildings.

It is a renovated part of the city, laid out after the 1998 Lisbon World Exposition, near the river, and counts with a big shopping mall, many office buildings, an oceanarium, the biggest exhibition centre in Portugal, a hospital, schools, residential buildings, hotels, a train station, a marina, etc.



Figure 60. Scenario 12 - Parque das Nações.

The city of Lisbon is a signatory of the Covenant of Mayors and has developed a SECAP which has been in force since 2018, committing to a goal of a 60% reduction in CO<sub>2</sub> emissions by 2030 and being carbon-neutral by 2050. Thus, several measures were designed, namely regarding the increase of energy efficiency and PV in buildings and fostering sustainable methods of mobility, notably through more public EV charging stations, municipality fleet with EVs and in 2050, internal combustion vehicles are not allowed. Concerning the industry, in 2030, it is expected a final energy consumption decrease of 10% compared to 2016 [69]. In general, the energy consumption per capita should be kept until 2030.

Parque das Nações is currently served by an electrical grid and a district heating and cooling (DHC) grid. There is also a public EV mobility grid.

The DHC is entirely confined within the district and powered by a local trigeneration DHC gas-fired powerplant, and the electrical grid has two well-defined interconnection points. Thus, Parque das Nações can be considered an Energy Hub. Every building or condominium in the parish is usually large and has its own electrical secondary substation and DHC substation, as well as some locally managed PV generation and Home Energy Management Systems, so each one of these buildings/condominiums can be considered a micro-Energy Hub. For simulation purposes, many of these  $\mu$ EH can be considered as desired.

This scenario intends to pick up on the current energy infrastructure status of Parque das Nações and extrapolate an ambitious view for the horizon of 2050.



In this regard, there are some assets that can have an important role to contribute to those objectives, which will be described in detail in the next chapters: there is still a lot of rooftop area available for distributed PV generation, and almost all the buildings/condominiums have individual garage parking places available to install EV chargers, and there is a landfill and a wastewater treatment plant in the northern part of the district. Both can be used to produce biogas that can fuel the DHC powerplant. As of today, only the wastewater treatment plant is already producing biogas, but it is not currently being used as input to the trigeneration plant.

#### 5.1.12.2 Scenario location

As aforementioned, this scenario is in Parque das Nações, a parish of the city of Lisbon the (see Figure 61).



Figure 61. Scenario 12 – Scenario Location.

Parque das Nações is in the eastern part of the city, by the Tagus River estuary, practically at sea level. Lisbon has mild to warm, moderated temperatures; winters are very mild for its latitude, influenced by the Portugal Current, a weak current by-product of the Gulf Stream, average highs during this season vary between 15 and 16°C. Lisbon has the mildest winter nights out of any major European city, ranging between 8 and 10°C. Summers are warm to hot; regions east of the Tagus Estuary usually average around 30°C maxima in July and August. Summer nights are often independent of the location, averaging a comfortable 16–19°C. For this reason, cooling needs usually surpass heating needs.



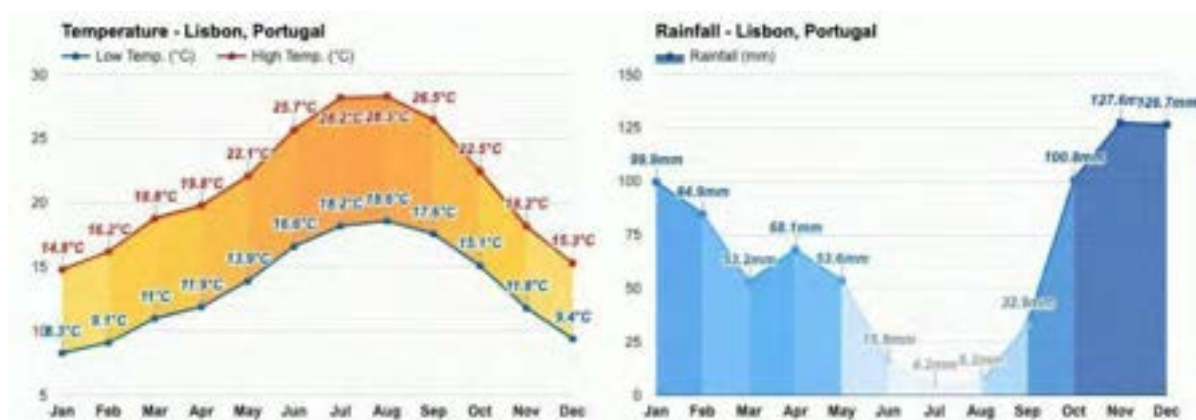


Figure 62. Scenario 12 – Weather historic data.

A general overview of the district can be seen in Figure 63.



Figure 63. Scenario 12 - Parque das Nações overview.

In Figure 64, a diagram of the DHC main grid that feeds Parque das Nações (blue colour), and some other assets, like the DHC power plant (yellow), PV generation already installed (purple) and the wastewater treatment plant (orange) are shown.



Figure 64. Scenario 12 - Parque das Nações DHC grid and plant, PV generation and water treatment plant

### 5.1.12.3 Scenario diagram

The following diagram depicts the complete scenario and connection between all carriers and technologies involved in the Parque das Nações Energy Hub. The existing state is depicted in solid lines, and 2050 foreseen connections are depicted in dashed lines/hollow arrows. Practically, the technology implementation presented in Figure 65 is already in place as of today, 2021-22. The ones



that are not deployed yet are: the biogas utilization in the DHC plant, the V2G chargers and the home Battery Storage systems.

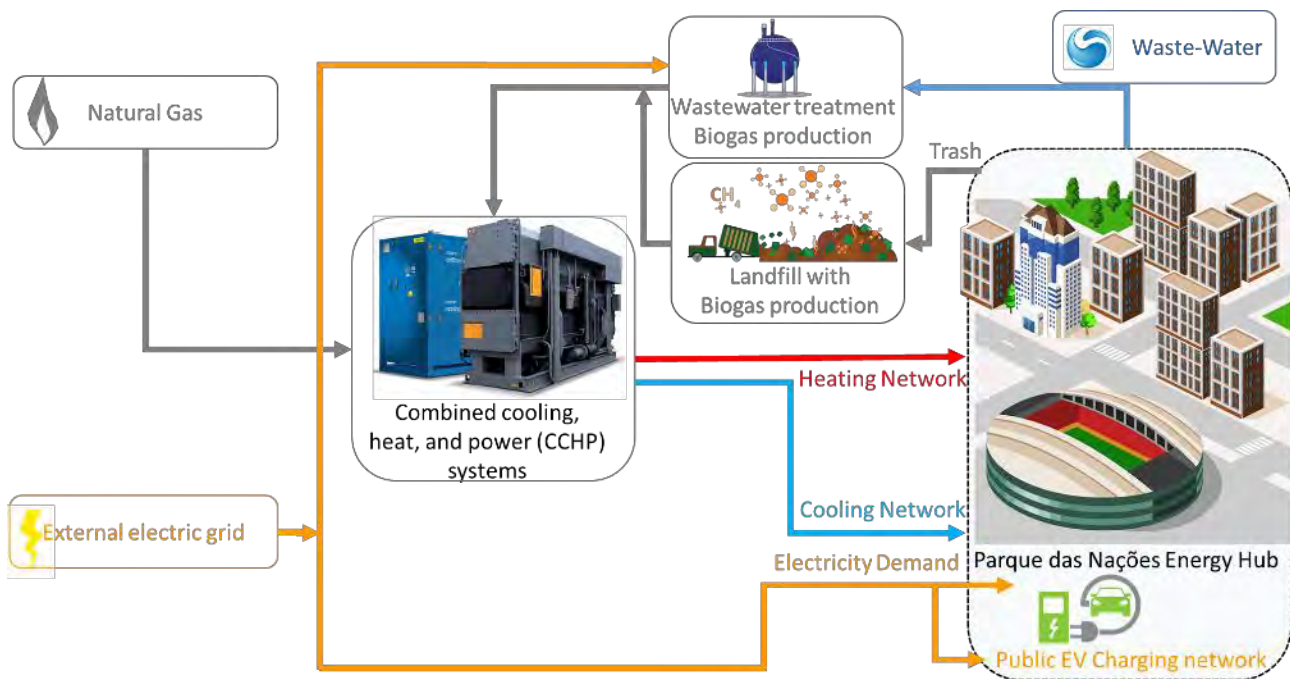


Figure 65. Scenario 12 - Scenario diagram.

Each building/condominium can be considered a  $\mu$ EH. Despite each one having its own characteristics, every  $\mu$ EH can be characterized by the same schematic with electricity, heating, and cooling, with the variation between different  $\mu$ EH being basically regarding consumption profiles and volumes.

Figure 66 presents the carriers, technologies, and connections inside one of the  $\mu$ EH.

#### 5.1.12.4 Technical characteristics

The technical information related to the elements included in the scenario is detailed in this section.

The electricity distribution network of Parque das Nações is supplied by two main 60/10 kV substations with a total installed power of 80 MVA and a maximum peak consumption of 54 MW in 2020, and it is totally underground, with 12.618 LV Consumers, 57 MV industrial and services clients. These two substations supply a 10 kV MV underground network which connects to 208 secondary substations, installed mostly inside the buildings/condominiums, which transform from 10 kV to 400/230 V. These main assets are expected to be essentially unchanged by 2050. The DSO is mostly investing in grid digitalization and remote management and control. A tender to monitor the national LV network will be launched in 2025. The estimated yearly electrical consumption of Parque das Nações is 255 GWh.

As of mid-2021, a total of 70 public charging ports in 20 different locations are available at Parque das Nações, with power between 3.7 and 50 kW. None are of the V2G type at present, but by 2050,



it is expected that the number of public charging ports will be at least 500, with at least 100 being V2G type.

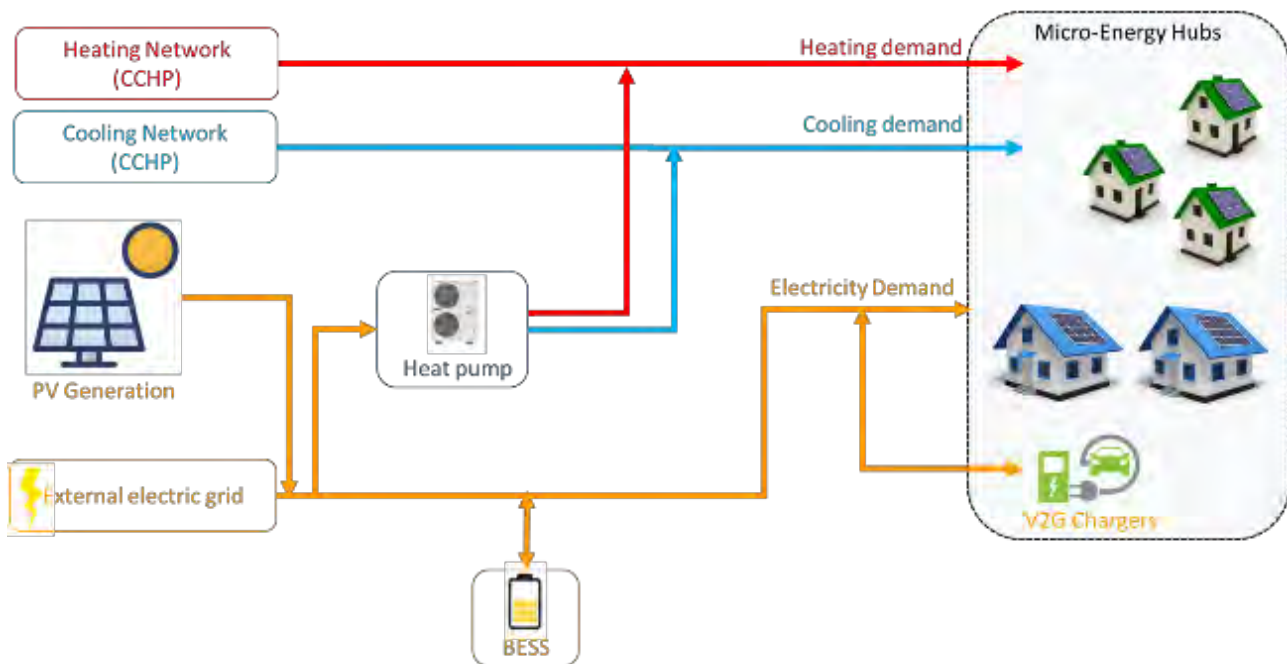


Figure 66. Scenario 12 - Parque das Nações Condominium  $\mu$ EH diagram.

The DHC power station comprises a gas turbine burning natural gas and some chillers capable of generating:

- 35 MW cooling power (chilled water @ 4°C).
- 29 MW heating power (hot water @ 90°C).
- 5 MW electrical power.

The DHC plant includes a 25000 m<sup>3</sup> chilled water storage, corresponding to a buffer of 140 MWh of cooling at 20 MW (short-term thermal storage). The DHC network is distributed to 150 buildings through a network of pipelines with 90 km of extension, part of which is installed in technical galleries. Each condominium has a DHC substation, which basically is a heater-exchange system between the DHC grid and the building heating and cooling grid.

The wastewater treatment plant also produces biogas, with a production capacity of ~126 Nm<sup>3</sup>/h. The landfill, at the moment, does not produce biogas, but in this scenario, it is considered so. The wastewater treatment plant is a major prosumer, with an annual consumption of around ~4 GWh of electricity.

Most of the buildings/condominiums in Parque das Nações have flat rooftops and good conditions to install PV generation. For this analysis, the maximum available rooftop power that can be installed has been estimated to be 25 MWp, which at this location can generate 36 GWh/year. At present, only 1 MWp is installed.



Most buildings/condominiums also have individual parking garages, where companies and residents can install private EV chargers. At least 3000 private EV chargers are expected by 2050, which is equivalent to an average of 20 in each condominium (some will be private, others will be shared).

There is currently a residual number of homes in Parque das Nações that include Home Energy Management Systems (HEMS) and BESS systems. By 2050, it is expected that the number will increase, but not as much as the EV chargers and EVs. For a residential BESS system, we can consider a 7 kW/12.5 kWh unit at the building level or a 1.2 kW/2 kWh at the apartment level.

#### *5.1.12.5 Energy management strategies*

This section includes all energy management strategies and modules foreseen. The Parque das Nações EH operation will focus on the following main objectives:

- Minimizing the importation of electricity and natural gas from the upstream external networks.
- Maximizing the usage of RES resources and thus, minimizing overall CO<sub>2</sub> emissions.
- Maximize flexibility in order to minimize costs for end-users.

To accomplish these objectives, there are several strategies/functionalities that can be in place and have to be simulated, for example:

- Renewable forecasting (PV generation)
- Electric and thermal load forecasting.
- Demand-side management.
- Energy market forecasting.

#### *5.1.12.6 Regulatory aspects*

All Portuguese regulatory aspects related to the new scenario were considered. As mentioned before, practically all the technology implementation, presented in Figure 65 and Figure 66, is already installed. Solar PV, BESS systems, and V2G can be used easily at present on a self-consumption basis, according to the Law Decree no. 162/2019. Solar PV systems in buildings and condominiums are currently going through a boom, particularly due to state incentives which can reach 85%. But, to export electricity to the public grid, at present, one must be registered as a producer and make a contract.

Local Energy Communities were also introduced by that Law Decree as a type of “collective self-consumption”. Nevertheless, the concept has still no practical implementation, and a new law is pending to be published in 2022. This new law is expected to introduce a practical framework for the implementation of LECs. It is unclear, at present, if the legislation will include provisions for business models, for example, P2P trading, or if the LECs will be allowed to fully manage themselves in this regard. Moreover, there is not currently a legal framework for demand-side management, but some demonstration pilots have taken place in the past, including in Parque das Nações, with some homes being managed by the DSO.



### 5.1.12.7 Economic costs and benefits

Overall technology costs can be extracted from D2.2: Technical solutions for multi-carrier integrated systems under the LEC concept: A review» and «Renewable power generation costs in 2020» [20].

Regarding  $\mu$ EH, the technologies that are expected to grow are:

- PV: ~1000 €/kWp
- BESS Systems: 100-200 €/kWh
- Heat pumps: CAPEX between 450 €/kW to 850 €/kW for systems with a capacity of 7-20 kW. Installation costs begin from 300 €/kW. OPEX is 3 c€/kWh.
- Solar thermal: ~1000 €/kW
- EV chargers: 600-1,100 € per charger.

Regarding  $\mu$ EH investments, in addition to the technology costs mentioned, it is worth considering in the analysis the state incentive of 85% up to 2500€ per end-user for the installation of PV, BESS systems, heat pumps and solar thermal. This incentive has been in place for some time, and it is expected to continue in 2022.

The costs at the EH level is mainly to create the infrastructure to take the biogas from the wastewater treatment plant and the landfill and to, inject this biogas into the natural gas to be burnt at the DHC powerplant, and also for expand of the public EV grid:

- Infrastructure and conversion of DHC power plant turbine for biogas: ~500 k€ estimated.
- Public EV chargers and infrastructure: 3 – 7 kW (public): 3,400 €
  - 11 – 22 kW (public): 4,500 €.
  - 50 kW: 31,000 €.
  - 150 kW: 75,000 €.
  - 250 – 350 kW: 150,000 – 200,000 €.

The benefits for the LEC are expected to especially come from the investments at the  $\mu$ EH level, which are co-financed by the state. With an optimized operation of the Parque das Nações enabled by the eNeuron toolbox, ROI should occur fast, and both energy costs for end-users and CO<sub>2</sub> emissions are expected to decrease. The benefits should be felt outside the LEC also due to decreased consumption and investment in assets by the DSO and by the possibility of exporting energy and providing ancillary services.

### 5.1.12.8 Impacts

The impacts of the implementation of this LEC using optimisation provided by eNeuron toolbox can be very substantial. Especially regarding CO<sub>2</sub> emission levels, it is expected that this LEC will contribute to the Lisbon SECAP objective, which has been in force since 2018, committing to a goal of a 60% reduction in CO<sub>2</sub> emissions by 2030 and being carbon-neutral by 2050. This can happen, especially if the Parque das Nações LEC can prove to be energy net-zero or even export renewable electricity to the upstream network.



### 5.1.12.9 Database linkage

Unfortunately, there are still no specific time series obtained from real data of the scenario. This is because smart meters and the required data infrastructure are non-existing as of the time of the writing of this deliverable and are currently in the process of being acquired and installed. Usual profiles for the different generation technologies and for the different demand patterns can be considered, with the respective scaling to meet the main numbers. Nonetheless, some possible eNeuron Database time series that can be used for the scenario generation are:

μEH level:

- Solar PV:
  - 057\_GEN-ELEC-PVE-IRRA-ELEC-IT-ANCONA-01012018-31122018
  - 078\_GEN-ELEC-PVE-IRRA-ELEC-ES-ELHIERRO\_01012005-31122016
  - 057\_GEN-ELEC-PVE-IRRA-ELEC-IT-ANCONA-01012018-31122018
- Battery Storage:
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
- V2G:
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
  - 088\_STO-ELEC-BAT-ELEC-ELEC-ES-MADRID\_03022017-03022017
- Heat Pump:
  - 070\_CON-HVAC-HEP-ELEC-NONE\_PL-BYDGOSZCZ3\_01012021-31112021
- Electricity consumption
  - Residential:
    - 038\_CON-ELEC-ELC-ELEC-ELEC-IT-TURIN\_01012019-31122019
  - Commercial:
    - 052\_CON-ELEC-ELEC-ELEC-ELEC-IT-ANCONA-01012019-31122019
  - Industrial:
    - 044\_CON-ELEC-ELC-ELEC-ELEC-ES-ELHIERRO\_01012018-3112201
- Heat consumption:
  - 067\_CON-HVAC-BEL-ELEC-NONE\_PL-BYDGOSZCZ31\_01012021-31122021
- Cold consumption:
  - 054\_CON-THER-HVA-COLD-COLD-IT-ANCONA-01012019-31122019

EH level:

- DHC plant:
  - 066\_GEN-ELECTHERM-CHP-NG-ELECTHERM-IT-ANCONA-27022006-27022006
  - 092\_CON-ELEC-CHI-ELEC-NONE-\_CY-NICOSIAA\_01012021-31122021
- Public EV charger:
  - 087\_STO-ELEC-BAT-ELEC-ELEC-ES-MADRID\_03022017-03022017
  - 088\_STO-ELEC-BAT-ELEC-ELEC-ES-MADRID\_03022017-03022017



## 5.2 Pilot Scenarios

The pilot scenarios have been defined in a similar way to the general ones, but they focus on the specific pilots of the eNeuron project (Portugal, Norway, Poland, and Italy). Moreover, they address specific use cases for every scenario with concrete impacts and energetic strategies. Pilots' scenarios have been addressed in such a way that the eNeuron toolbox will be used to design and to take investment decisions for its finalization and to take short-term decisions during operation.



## 5.2.1 Portuguese Pilot – Lisbon Naval Base

<b>CARRIERS</b>				X	Gas
					Hydrogen
				X	Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>				X	Industrial
				X	Commercial
				X	Residential
					Academic/Educational
<b>LOCATION</b>					Health
				X	Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV	X	Batteries	X	Electric
	Wind	X	Heat	X	HVAC
	Hydro	X	Electric Vehicle	X	Electric Vehicle
	CHP		Cool	X	Water
	Diesel	X	Pumped Hydro		Hydrogen
X	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
X	Solar thermal				
	Electrolyser				
	Fuel Cell				
	Electric Chiller				
	Absorption Chiller				
X	NG Boiler				
	NG Reforming				
LOCATION					
<b>Country</b>	Portugal		<b>City</b>	Almada	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



### 5.2.1.1 Scenario description

This scenario focuses on the Lisbon Naval Base campus, property of the Portuguese Navy, where one of the pilot demos of the eNeuron project will be located. Within its perimeter the Naval Academy, the Naval Technologies School, the Portuguese Shipyard Arsenal do Alfeite S.A., the Marine Corps Base, and other Portuguese Navy units are also located.

Accordingly, the Base can be considered divided into “units” with very different profiles: residential (messes/canteens, living quarters), tertiary (offices, sports centre) and industrial (ship docks, workshops, etc.). These “units” are relatively independent and can be considered as micro-Energy Hubs ( $\mu$ EHs). These units are supplied by different carriers and private grids, which interface with the public grids at specific, well-defined points. Thus, the Lisbon Naval Base can be characterized as an Energy Hub (EH).

The Lisbon Naval Base has the following grids/carriers at the EH level: electricity, water, and natural gas. At the  $\mu$ EH level, the following carriers are also present: heat and cooling.

Regarding the main energy assets, at the EH level, there will be a centralized large-scale PV system, water storage tanks and pumps. Still, at the EH level, there are significant consumer units, with different profiles, like workshops, offices, and ship docks.

At the  $\mu$ EH level, some of the units will have generation, consumption, and storage, namely three:

- The Sports Centre “CEFA” will have PV and Solar Thermal generation, Natural Gas boilers, Domestic Hot Water (DHW) storage, Battery Energy Storage System (BESS), and an EV charger in the Directorate of Transports.
- The Residential Mess will have Solar Thermal generation, Natural Gas boilers, DHW storage and heat pump HVAC.
- The Canteen will have PV and Solar Thermal generation, Natural Gas boilers, DHW storage and V2G charging.

Building/Home Energy Management Systems (B/HEMS) will also be installed. These main assets are all expected to be in operation by summer2022. Their technical details will be presented in the “Technical Characteristics” section.

Three Use Cases were elaborated to be demonstrated in the Portuguese pilot, which is presented in Figure 67. These use cases are fully independent and divided, but at the same time, they facilitate each other.



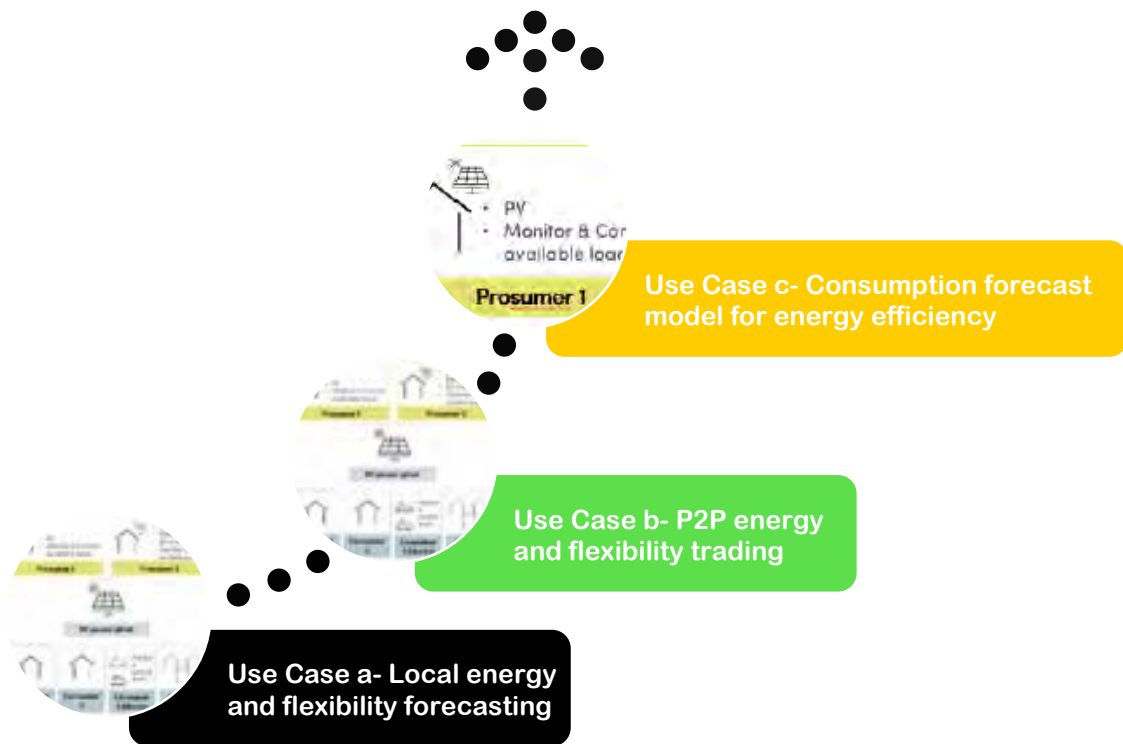


Figure 67. Portuguese Pilot - Use Cases

▪ Use case a: *Maximization the use of renewables*

Use Case a will provide the basis for an optimisation of the energy system to maximize the use of renewables by forecasting:

- PV generation.
- Flexible elements and loads' demand (water pump motors, DHW, EV chargers etc.).

The objective of this use case is to create models for the accurate generation and consumption forecast, and also, to optimize the management of flexibility elements/variable loads in order to enable the means to maximize the usage of energy generated by renewable sources and to minimize total energy costs for the LEC.

▪ Use case b: *Economic optimization to reduce the total energy cost per  $\mu$ EH*

Regarding Use Case b, it will optimize the energy system economically, namely, to reduce total energy costs for each  $\mu$ EH and for the whole LEC, based on virtual trading between peers (considering purchasing/selling prices for each peer). CO<sub>2</sub> footprint cost may also be used as an optimisation parameter.

▪ Use case c: *Intelligent energy efficiency recommendations*



Regarding the last Use Case, data gathered by smart meters and NILM<sup>9</sup>-like devices will be used to learn patterns of electric equipment usage and to be used as the base to provide intelligent energy efficiency recommendations such as:

- Replacement of equipment (higher efficiency).
- Modification of non-flexible equipment usage profiles/schedules due to consumption/PV generation profiles.
- Identification of possible additional flexible loads (i.e., loads that can have some degree of regulation without compromising their usage, like pumps, ovens, etc.).

These Use Cases will ultimately lead to significant environmental and economic benefits.

#### 5.2.1.2 Scenario location

As previously mentioned in Scenario 04 but repeated in this Section for readability issues, this scenario is located in the Lisbon Naval Base, which, despite the name, is located in the city of Almada, on the southern bank of the Tagus River estuary (see Figure 69).



Figure 68. Portuguese Pilot - Scenario Location.

Almada has a similar climate to Lisbon, namely mild to warm, moderated temperatures, winters are very mild for its latitude, the influence of the Portugal Current, a weak current by-product of the Gulf Stream, average highs during this season vary between 15 and 16°C. Lisbon has the mildest winter nights out of any major European city, ranging between 8 and 10°C. Summers are warm to hot; regions east of the Tagus Estuary usually average around 30°C maxima in July and August.

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<sup>9</sup> Non-intrusive load monitoring



Summer nights are often independent of the location, averaging a comfortable 16–19°C. For this reason, cooling needs usually surpass heating needs.

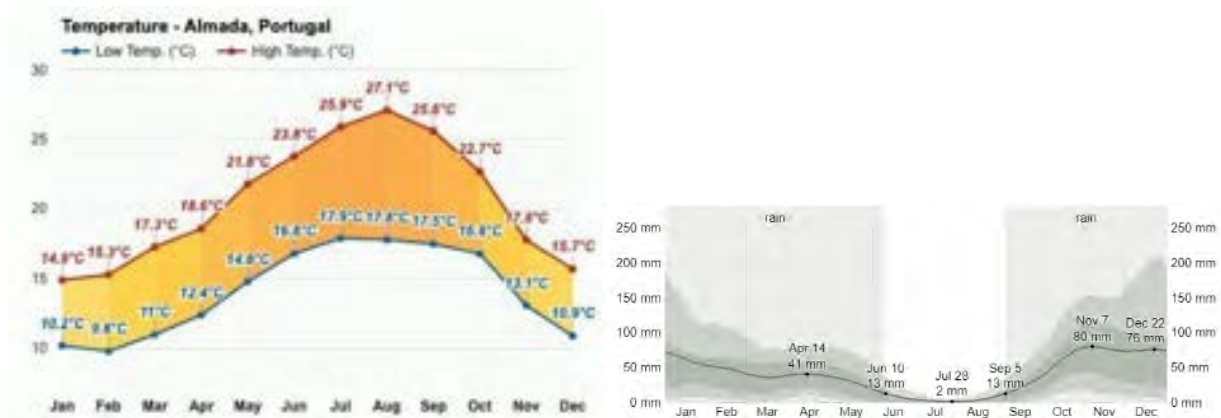


Figure 69. Portuguese Pilot – Weather historic data - Source: weather-atlas.com

The location of the main “units”, which are the  $\mu$ EH that will be part of the Portuguese demo pilot, are presented in Figure 70: Canteen, PV generator, Workshop and Sports Centre.



Figure 70. Portuguese Pilot - Location of the main assets of the eNeuron Portuguese Pilot - Source: Google Maps.

### 5.2.1.3 Scenario diagram

Figure 71 depicts the complete scenario overview and connection between all carriers and technologies that will be involved in the Lisbon Naval Base Energy Hub demo pilot.

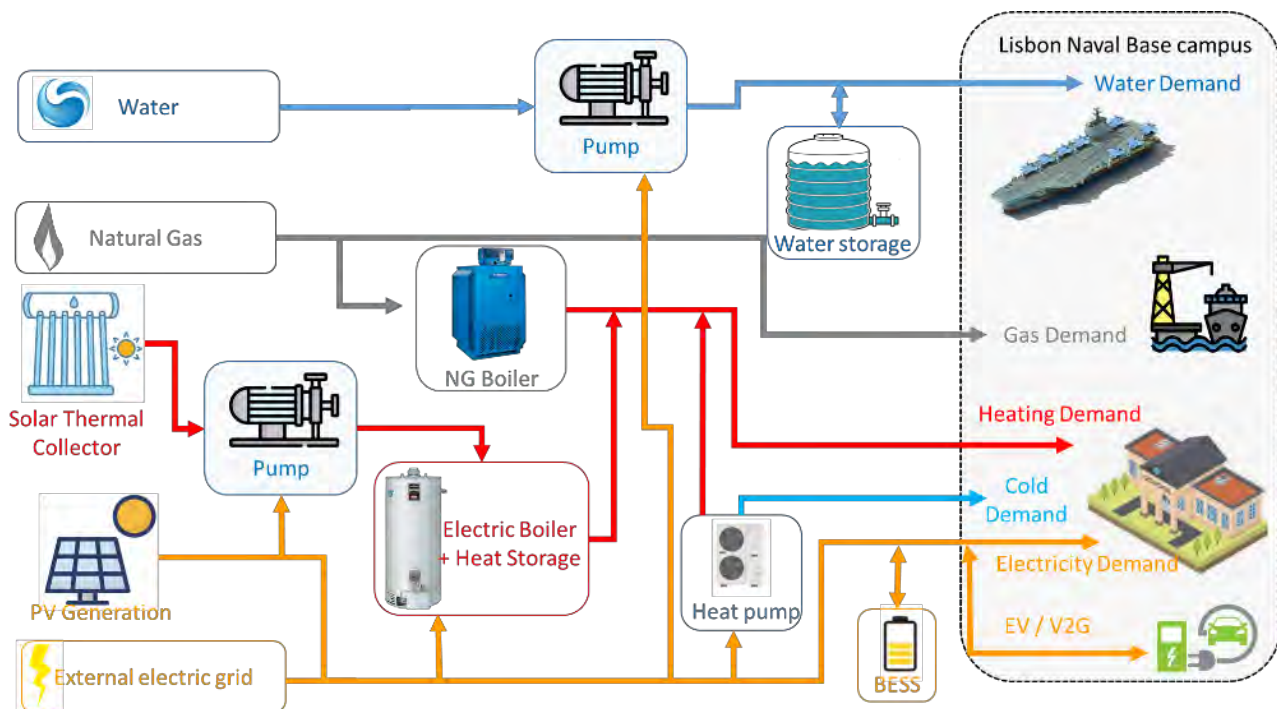


Figure 71. Portuguese Pilot – Diagram scenario.

Figure 72 depicts the Lisbon Naval Base pilot scenario at Energy Hub (EH) Level. The carriers at the EH level will be water, electricity and natural gas. The shared generation will be the solar PV system, and shared storage will be water storage. The water carrier is self-supplied from a local well.

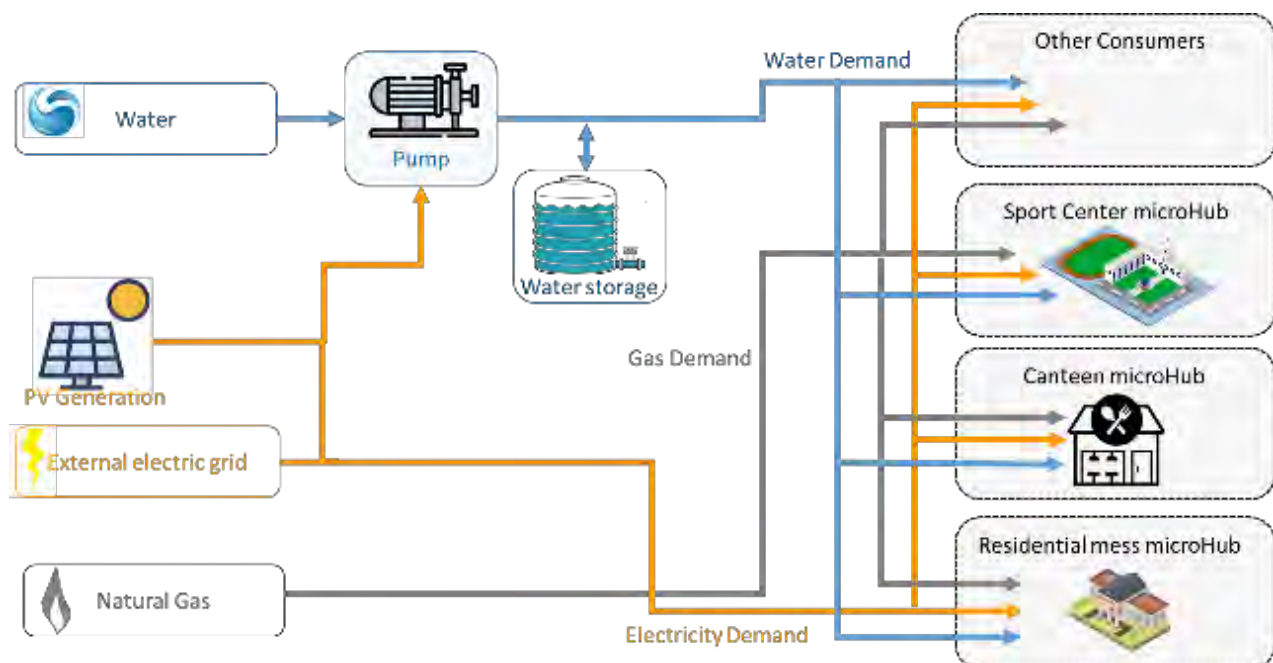


Figure 72. Portuguese Pilot - Lisbon Naval Base – EH level diagram.



Figure 73 shows the «Sports Centre + DT»  $\mu$ EH level scenario. Additionally, to the EH carriers, there will be a heat carrier, supplied by natural gas boilers and a solar thermal system, and with storage consisting of DHW tanks. There will also be PV generation and EV consumption and a Battery Energy Storage System (BESS).

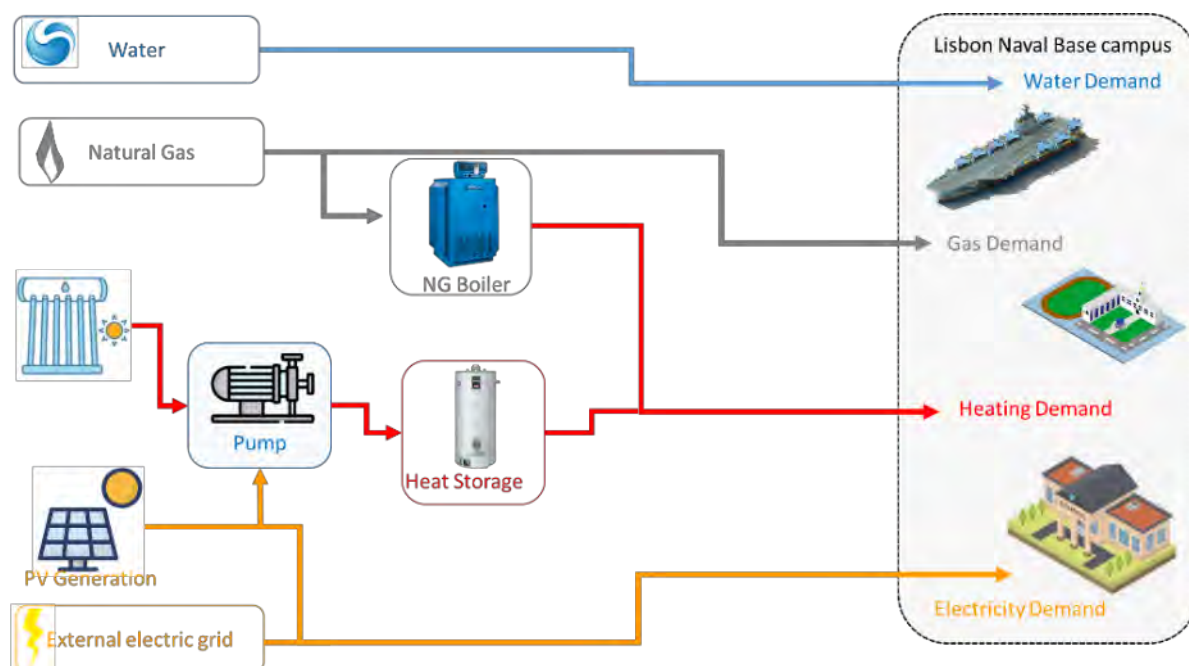


Figure 73. Portuguese Pilot - Lisbon Naval Base – «Sports Centre + DT»  $\mu$ EH level diagram.

Figure 74 depicts the «Residential Mess»  $\mu$ EH level scenario. Additionally, to the EH carriers, there will be a heat carrier and a cooling carrier, supplied by Natural Gas boilers, a solar thermal system and heat pumps, and storage consisting of DHW tanks.

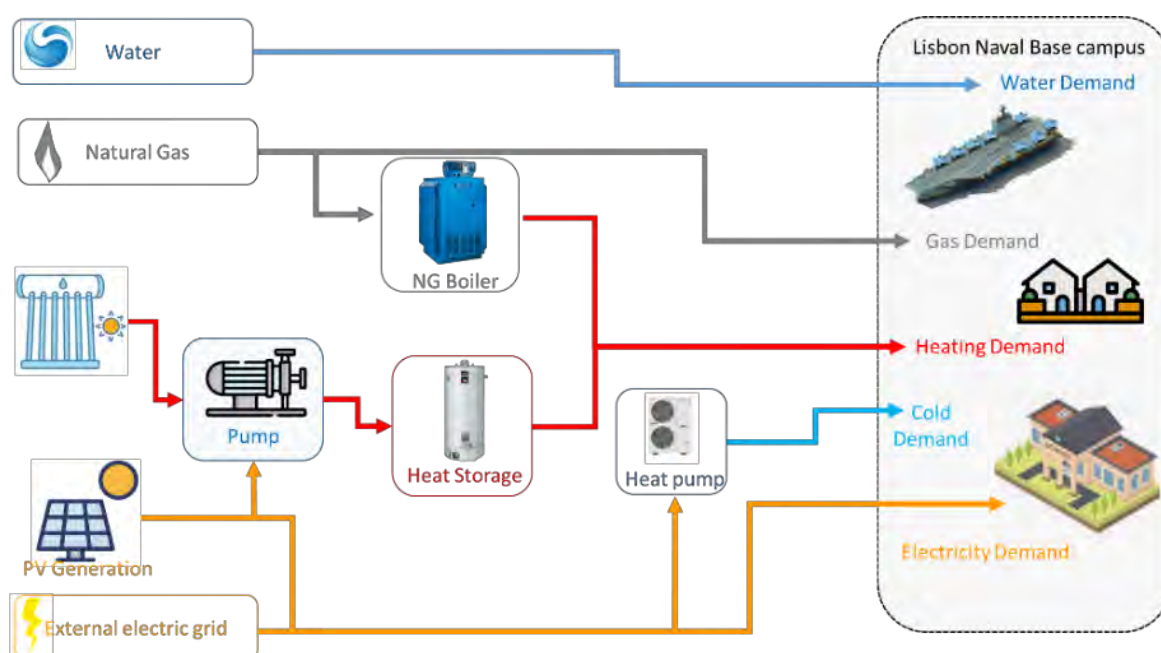


Figure 74. Portuguese Pilot - «Residential Mess»  $\mu$ EH level diagram.



Finally, Figure 75 depicts the «Canteen»  $\mu$ EH level scenario. Additionally, to the EH carriers, there will be a heat carrier, supplied by Electric boilers and a Solar Thermal system, and with storage consisting of DHW tanks. There will also be PV generation and V2G EV storage/consumption.

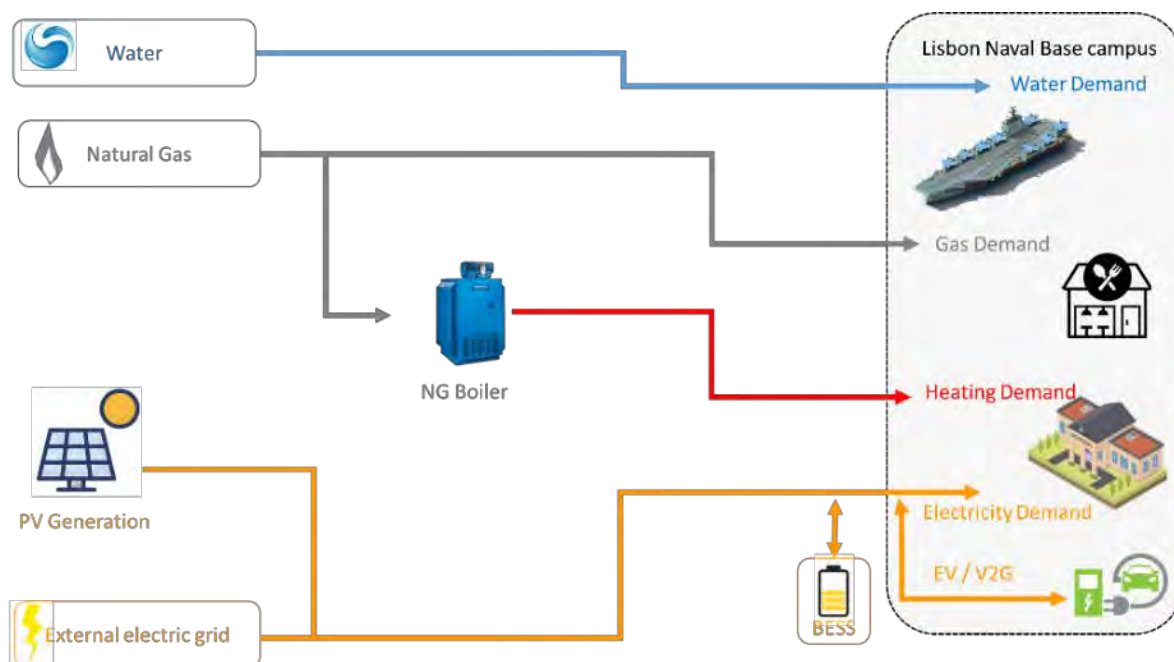


Figure 75. Portuguese Pilot - «Canteen»  $\mu$ EH level diagram.

#### 5.2.1.4 Technical characteristics

The most important grid to be considered in this scenario is the electrical grid because it interfaces with all the other carriers, and it is where the largest power flows occur.

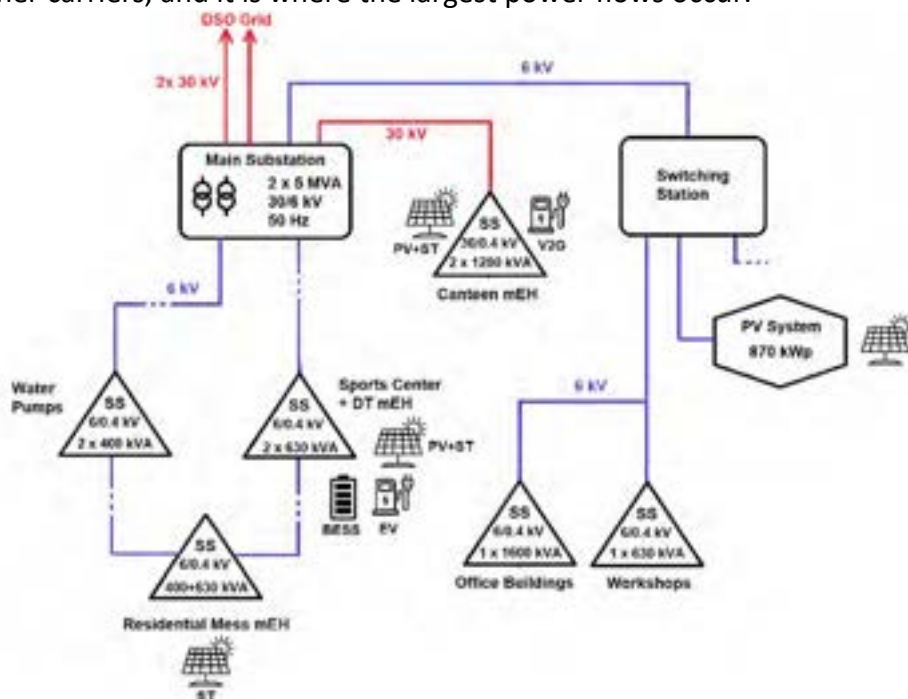


Figure 76. Portuguese Pilot - Electrical grid.



The coupling point to the electrical grid is a 30 kV/6 kV main substation with an apparent power of 2 x 5 MVA. Despite this, there is a secondary substation fed at 30 kV, with 2 x 1.2 MVA installed power. All the MV and LV connections are made with buried insulated cables. All cables are monopolar type, XPLE insulation, and aluminium core with varying core cross-sections. The transformers in the SS fed at 6 kV have nominal powers between 400 and 1600 kVA, and each SS serves one or two units, as shown in Figure 76. There is a 60 Hz sub-grid that is fed by 3.5 MVA dynamic converters, which are used to feed the warships.

This grid has a peak annual load of around 6 MW and total annual electricity consumption of around 25 GWh. The consumption is not expected to increase significantly in the following years. It may even decrease due to efficiency gains of equipment replacement.

The installed PV system will total of nearly 1 MWp (870 kWp centralized + ~100 kWp decentralized (μEH level)), which at this location can generate up to 1.4 GWh/year.

Moving on to the «units», or μEH level, the main assets are detailed in the tables below.

*Table 16. Portuguese Pilot - CEFA (Sports Centre)*

CEFA (Sports Centre) – Main Assets		
Tech.	Quant.	Power/Capacity
PV	120 x 440 Wp	52.8 kWp
Solar Thermal	60	60x2.58m <sup>2</sup>
Nat. Gas. Boilers	2	300 kW
DHW tanks	2	3,000l (~250 kWh)

*Table 17. Portuguese Pilot - Canteen*

Canteen – Main Assets		
Tech.	Quant.	Power/Capacity
PV	90 x 460 Wp	~41.4 kWp
Solar Thermal	30	30x2.58m <sup>2</sup>
Electric Boilers	2	300kW
DHW tanks	2	3,000l (~250 kWh)

*Table 18. Portuguese Pilot - Residential Mess*



Residential Mess – Main Assets		
Tech.	Quant.	Power/Capacity
Solar Thermal	70	70 x 2.58 m <sup>2</sup>
Nat. Gas. Boilers	2	225 kW
DHW tanks	3	7000l (~380 kWh)
HVAC	2 ext. / 16 int.	31.5 + 37.5 kW

As aforementioned, these units will have H/BEMS systems that can cooperate with the eNeuron toolbox. Until 2022, there was only one EV charging station at the Lisbon Naval Base with 22 kW nominal power. By mid-2022, a 22 kW V2G EV charger will be installed. As of mid-2022, a BESS will also be connected to the Sports Centre's electrical grid, with an estimated rating of around 50 kW/100 kWh.

Regarding the water carrier, there are 2 x 110 kW pumps to take the water from the well to the supply water tanks/towers. The biggest water tanks have a capacity of 2 x 4,850 m<sup>3</sup>.

#### 5.2.1.5 Regulatory aspects

All regulatory aspects related to the Portuguese Pilot were considered and are already addressed at the time of writing this document. The Lisbon Naval Base LEC has the advantage of having its own private grids, with single-point interfaces with the public grids. Accordingly, the EH and  $\mu$ EH can be much more flexibly managed, as long as the requirements at the interface points are met.

Solar PV, BESS systems, and V2G can be used easily at present on a self-consumption basis, according to the Portuguese Law Decree no. 162/2019. However, in order to export electricity to the public grid, at present, one has to be registered as a producer and make a contract. This is not expected to happen because the overall Lisbon Naval Base consumption is expected to always surpass local generation, given the actual configuration presented in this document.

#### 5.2.1.6 Economic costs and benefits

Overall technology reference costs can be extracted from D2.2: «Technical solutions for multi-carrier integrated systems under the LEC concept: A review» [70] and «Renewable power generation costs in 2020» [20]:

- Solar Thermal: ~1,000 €/kW
- PV: ~1,000 €/kWp
- BESS: 100-200 €/kWh
- EV chargers:
  - 3 – 7 kW (public): 3,400 €
  - 11 – 22 kW (public): 4,500 €
  - 50 kW: 31,000 €
  - 150 kW: 75,000 €



- 250 – 350 kW: 150,000 – 200,000 €
- HVAC heat pumps: CAPEX between 450 €/kW to 850 €/kW for systems with a capacity of 7-20 kW. Installation costs begin from 300 €/kW. OPEX is 3 c€/kWh.
- Costs related to sensors and communication:
  - Smart meters: 50-75 €
  - RS485 concentrator: 50-75 €

The benefits for the LEC are expected to be very significant and threefold: economical, environmental, and strategical (to reduce dependence on external sources). With an optimized operation of the Lisbon Naval Base LEC enabled by the eNeuron toolbox, ROI should occur fast, and both energy costs for end-users are expected to reduce a minimum of 8%, whereas CO<sub>2</sub> emissions are expected to decrease a minimum of 9%.

The benefits should be felt outside the LEC also due to decreased consumption and investment in assets by the DSO.

#### 5.2.1.7 Impacts

The impacts of the implementation of this LEC using optimisation provided by eNeuron toolbox can be very substantial. The direct impacts can be measured by the Key Performance Indicators (KPIs) distributed by the three Use Cases:

Use Case a:

- KPI 30 - Reduction in energy spending (pilot level).
- KPI 9 - Increase in self-sufficiency.
- KPI 43 - Overall satisfaction (concerning eNeuron local energy system).

Use Case b:

- KPI 30 - Reduction in energy spending (pilot level).
- KPI 12 - Reduction in daily and annual CO<sub>2</sub> emissions.
- KPI 6 - Flexible energy traded and managed.

Use Case c:

- KPI 33 - Awareness of eNeuron Energy efficiency measures
- KPI 13 - Energy savings for the consumers
- KPI 7 - Flexible energy unlocked

#### 5.2.1.8 Database linkage

Unfortunately, there are still no specific time series obtained from real data of the scenario. This is because smart meters and the required data infrastructure are non-existing as of the time of the writing of this deliverable and are currently in the process of being acquired and installed. Usual profiles for the different generation technologies and for the different demand patterns can be



considered, with the respective scaling to meet the main numbers. Nonetheless, some possible eNeuron Database time series that can be used for the scenario generation are:

At the EH level:

- PV generation
  - 078\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-ELHIERRO\_01012005-31122016

At the  $\mu$ EH level:

- PV generation
  - 078\_GEN-ELEC-PVE\_IRRA-ELEC\_ES-ELHIERRO\_01012005-31122016
  - 057\_GEN-ELEC-PVE-IRRA-ELEC-IT-ANCONA-01012018-31122018
- Solar thermal generation
  - 084\_GEN-HVAC-CSP\_IRRA-NONE\_PL-BYDGOSZCZ4\_01012021-31122021
- Heat pump (kW)
  - 070\_CON-HVAC-HEP\_ELEC-NONE\_PL-BYDGOSZCZ3\_01012021-31122021
- Natural gas boiler
  - 058\_CON-NGC-NGC-NGC-NGC-IT-SAVONA-01012019-31122019
- Electric boiler
  - 067\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ31\_01012021-31122021
  - 068\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ32\_01012021-31122021
- BESS storage
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
- V2G storage
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
  - 088\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017
- Electricity consumption
  - Residential:
    - 038\_CON-ELEC-ELC\_ELEC-ELEC\_IT-TURIN\_01012019-31122019
  - Residential, office, commercial aggregated:
    - 040\_CON-ELEC-ELC\_ELEC-ELEC\_IT-Turin\_01012019-31122019
  - Residential, Industrial and Commercial aggregated:
    - 044\_CON-ELEC-ELC\_ELEC-ELEC\_ES-ELHIERRO\_01012018-3112201
- EV mobility consumption
  - 087\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017
  - 088\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017
- HVAC consumption
  - 039\_CON-THER-HVA\_HEAT+COLD-HEAT+COLD\_IT-TURIN\_01012019-31122019
- Natural Gas
  - 053\_CON-NGC-NGC-NGC-NGC-IT-ANCONA-01012019-31122019



## 5.2.2 Norwegian Pilot – Skagerak Energilab

CARRIERS				
				Gas
				Hydrogen
				Water
		X		Electricity
				Heat
				Cooling
SECTOR				
				Industrial
		X		Commercial
		X		Residential
				Academic/Educational
				Health
LOCATION				
				Inland
				Island
		X		North Europe
				Centre Europe
				South Europe
TECHNOLOGIES				
Generation		Storage		Consumption
X	PV	X	Batteries	Electric
	Wind		Heat	HVAC
	Hydro		Electric Vehicle	Electric Vehicle
	CHP		Cool	Water
	Diesel		Pumped Hydro	Hydrogen
	Heat pump		Hydrogen	Gas
	Natural Gas		Electric boiler	
	Electric			
	Solar thermal			
	Electrolyser			
	Fuel Cell			
	Electric Chiller			
	Absorption Chiller			
	NG Boiler			
	NG Reforming			
LOCATION				
<b>Country</b>	Poland	<b>City</b>	Bydgoszcz	
Type of geographic area (city, rural, ...)			City	
Climate Zone - European Köppen-Geiger classification:				Csa
<ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>			X	Cfb
				Dfb
				Dfc
				Cfa



### 5.2.2.1 Scenario description

Skagerak Energilab was initiated in 2016 in collaboration with Odd football club.



Figure 77. Norwegian Pilot – Pilot image.

Following an extensive construction project, Skagerak Arena (see Figure 77) is now equipped with Norway's most advanced test facility for exploring flexibility solutions for future power production, energy storage, distribution, and consumption. The plant is unique in that it is the largest solar energy plant combined with energy storage in Norway. The facility is built on one of the most visited sports arenas, and the project contributes significantly to the dissemination of knowledge to grid companies, suppliers to the grid, the solar energy industry, research environments and the general public.

Due to its both technical and functional content, Skagerak Energilab has become an attractive pilot facility for research activity shortly after completion. The facility is part of several important national and international projects.

The project's innovation goals are linked to utility value for the entire value chain from energy production to consumption. Functionality related to DSO is continuously explored through the control system's functionality and extensive data capture. The purpose is to enable grid companies to adopt new technology and meet a greater prevalence of decentralized production and the introduction of energy storage in the power grid. The realization of Skagerak Energilab in this way helps to increase and accelerate the commercial use of flexibility. Optimal utilization of local resources will result in a significant reduction in climate emissions and power consumption.

Skagerak Energilab is a project that consists of 3 phases:

- Development/concept study.
- Construction.
- Operation, Maintenance and R&D activities.



The construction phase of Skagerak Energilab began in the second quarter of 2018. The PV system was completed and was taken over as a partial delivery in January 2019. Due to the design phase for the control system and delivery of battery containers being delayed, installation of battery containers did not start until the first quarter of 2019. The plant was opened on 23 June 2019, but formally Skagerak Nett/Lede did not take over ownership of the energy storage and control system until 20 December 2019. This marked the completion of the construction project.

Table 19 provides an explanation for all the use cases planned for implementation on the pilot.

*Table 19. Norwegian Pilot – Use cases.*

	Title	Explanation
1	Green Electricity for Local Customers	This operation is like a Virtual Microgrid assuming the PV and ESS are connected to the same grid.
2	High Reliability of Supply	Emergency power supply for safe supply during matches based on ESS. The scenario allows grid disconnection and reconnection without a break, maintaining the power supply of the critical loads.
3	Frequency regulation (primary)	This scenario means that the ESS is used as frequency regulation. With an ESS available, the inverter can be programmed to deliver frequency support to the grid and thereby increase stability. This means that the inverter emulates frequency droop characteristics and will respond to the Grid Frequency Fluctuations like a Virtual Generator (VGM Mode).
4	Green EV charging (assessment)	Based on an on/off signal from the EV charger, the ESS shall discharge a predefined power value equal to the power value of the EV charger. The scenario simulates that the battery is supplying the EV charger with energy from PV systems.
5	Flexibility traded in the local flexibility market for solving voltage problems in the local distribution grid (assessment)	Based on signals from the flexibility market, the amount of reactive power is regulated (increased/reduced dependent on too low or too high voltage)  the active power is regulated or  the active and reactive power is regulated to constant load (referred the substation or transformer station)
6	Improved voltage quality (at the customer)	Based on meter data from the customer's connection point to the grid, the amount of reactive power is regulated (increased/reduced dependent on too low or too high voltage)  the active power is regulated or  the reactive power is regulated (referring to the voltage)
7	Reduced grid tariff costs through peak shaving	The monthly peak load is reduced, so the customers get lower grid costs – compared to "normal" consumption.



At the moment, it is not clear whether all of these can be implemented in the eNeuron toolbox. Running these use cases can be done within the existing topology configurations, i.e., no modifications are needed.

However, the eNeuron toolbox will be used to assess how the present configuration can be extended in the future. Among possible options, the project considers adding EV charging stations and H<sub>2</sub> electrolyser(s) coupled with long-storage. This may also consider the utilisation of waste heat from H<sub>2</sub> infrastructure.

#### 5.2.2.2 Scenario location

The scenario is located in Skien, Norway (see Figure 78). Skagerak Energilab is a full-scale test facility for technical solutions and innovative ideas about what future power and grid services may look like, with a focus on local renewable energy production, energy storage and consumption. In other words, it is a virtual microgrid conveniently located at Skagerak Arena in Skien, and it is already built and in function. The site is located at geographical coordinates 59.2114° N and 9.5900° E.



Figure 78. Norwegian Pilot - Scenario Location.

#### 5.2.2.3 Scenario diagram

The Norwegian demo is deployed at a functioning football stadium, the so-called "Skagerak Energy Lab". The installation combines a big-scale (800 kWp) PV system with a battery energy storage system, BESS (1 MWh) and power electronics allowing several operational modes for the unit, including fully islanded operation. The adjacent area includes several commercial and household end-users and several EV charging units (see Figure 79).



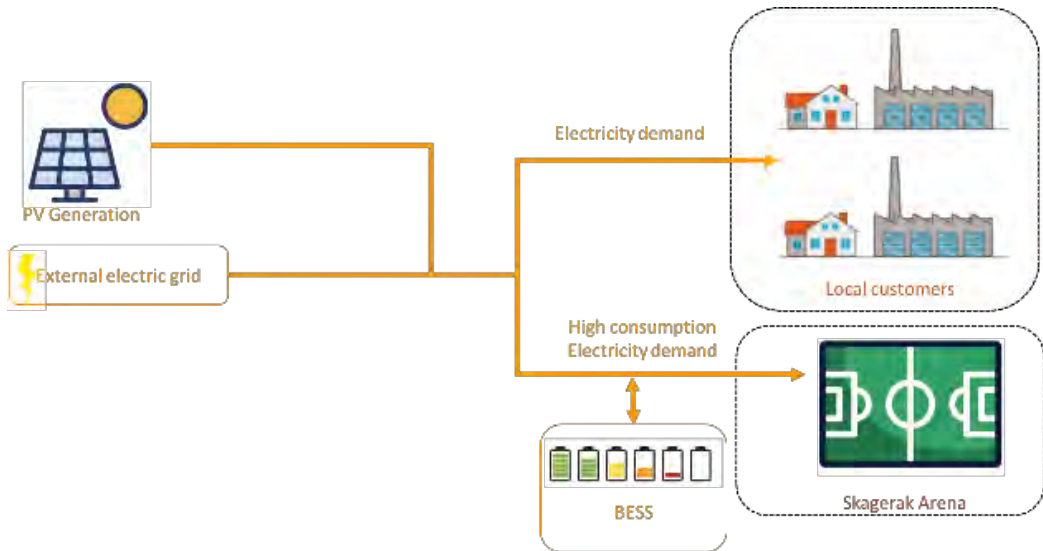


Figure 79. Norwegian Pilot - Scenario diagram for the Norwegian Pilot.

5.2.2.4 Technical characteristics

Skagerak Energilab is currently a completed and active full-scale research arena for testing and developing future sustainable energy production and distribution of significant size and degree of innovation. The plant's activities and extensive data collection contribute to significant competence development in Norwegian companies and the technology environment. Skagerak Energilab is installed at Skagerak Arena in Skien and consists of the following:

Solar production:

Area	4300 m <sup>2</sup>
Number of modules	2700
Type of modules	Polycrystalline (REC295TP2 and REC300TP2)
Installed generation capacity	800 kWp
Average annual generation	660 MWh

Energy storage:

Power	800 kW
Energy	1 MWh

Control system:

MicroScada is adapted with project-specific functionalities in accordance with innovation goals for research and development. The functional requirements of the project are represented in the control system's 20 different configurable operating modes. This means that each scenario has a



customized function button in our MicroScada control system, and we have in total 20 of these different operation modes to explore.

### Data capture, analysis, and measurements:

Skagerak Energilab collects a total of about 1,700 data signals that are stored continuously for R&D purposes. This gives the project participants unique opportunities to explore hypotheses, analyse and validate findings and support considerations.

Skagerak EnergiLab is a fully functional installation which includes the following main components:

- 10.4 kV distribution system with both TN (400 V) and IT (230 V) system.
- 1 Li-Ion battery system with 16 racks and 9 modules per rack / 1 MWh and a power rating of 800 kW.

The average charging efficiency of the battery system is 96.18%, and the average discharging efficiency of the battery system is 96.18%.

- One PV system (2,700 panels) with a power rating of 800 kWp and a normal annual generation of 660 MWh. The solar panels have an efficiency of 18%.
- Three aggregated load points, one of them is floodlight. Load PV side is 250-300 kW in the summer and 300-400 kW in the winter on average. This load is primarily the food store (Kiwi) located at the arena. Time series can be exported from Azure.
- One 230 V bus, two 400 V buses and thirteen 10.4 kV buses

In summary, Table 20 shows the description of all pilot assets:

*Table 20. Norwegian Pilot – Assets.*

Asset	Description
Local grid	230 V IT-nett (Consumers/Loads under S914) and 400 V TN (PV), 400 V TN-nett (battery)
Battery system	1 MWh/800 kW Li-ion, supplied by Samsung. Owned by Lede.
Control system	MicroScada
PV	2700 panels of types REC295TP2 and REC300TP2 with an installed power of 800 kWp.  Calculated energy production is 660,000 kWh in a normal year.
Weather station	VSN800 Weather Station, ABB
Household customers	Number of private customers: 42  (two housing cooperatives)
Commercial customers	Stores, offices, school, gym (nine in total)
Skagerak Arena	Soccer stadium



The overall layout of the microgrid is presented in Figure 80.

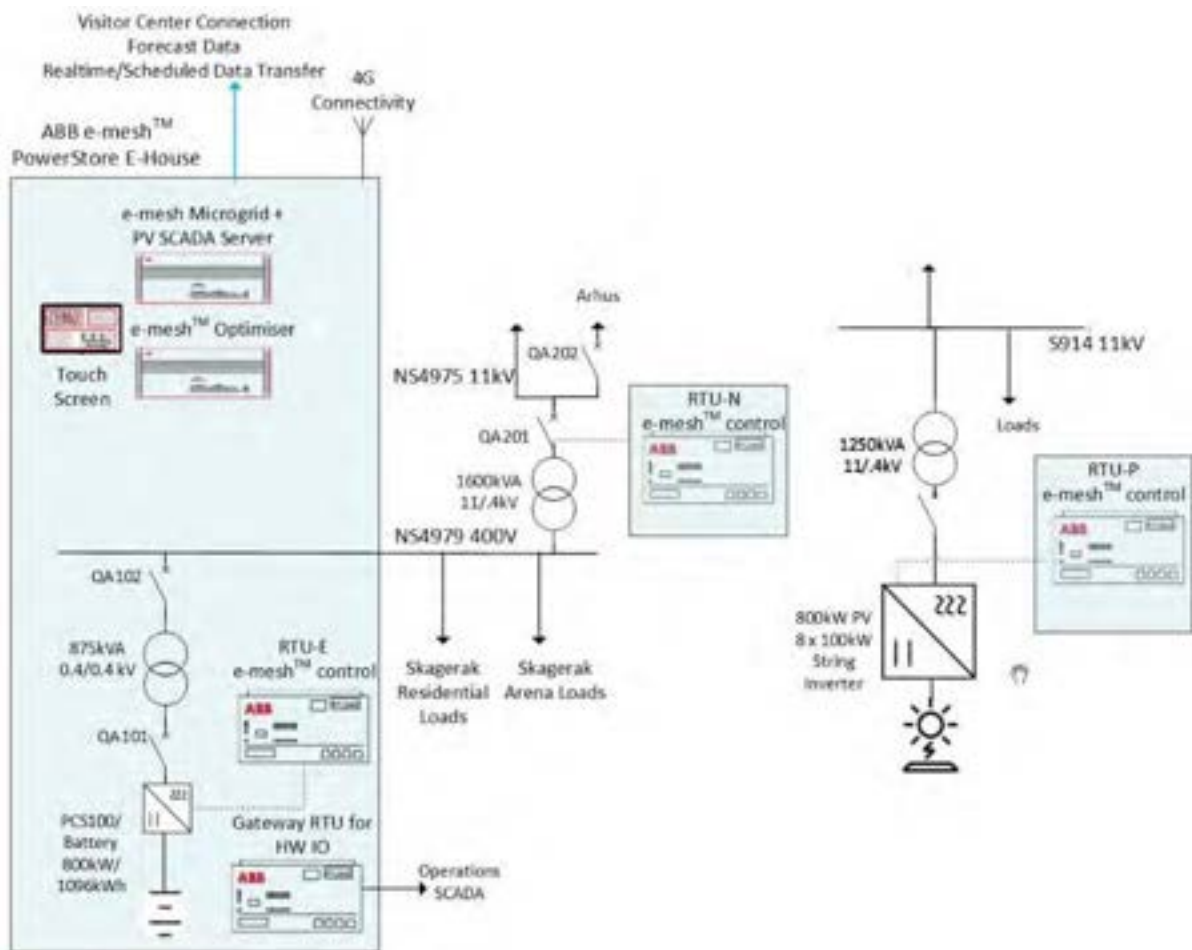


Figure 80. Norwegian Pilot - Overall layout of the Skagerak Microgrid.

- Generation characteristics for the PV:
  - Area: 4300 m<sup>2</sup>.
  - Number of PV panels: 2,700.
  - Installed generation capacity: 800 kWp.
  - Normal annual generation: 660 MWh.
- Consumption characteristics and estimated power
  - P1: Office consumption with significant-high peak loads (up to 800 kW) during soccer matches (see Figure 81).



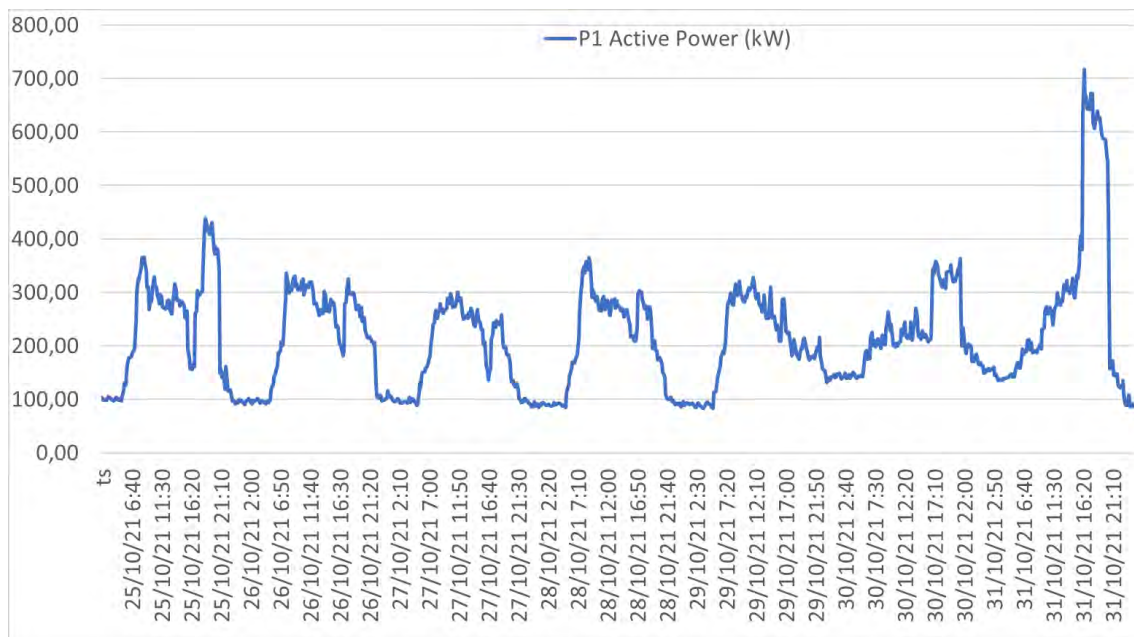


Figure 81. Norwegian Pilot - P1 Load (Week with a soccer match on Sunday).

- P2: Standard household profiles (see Figure 82)

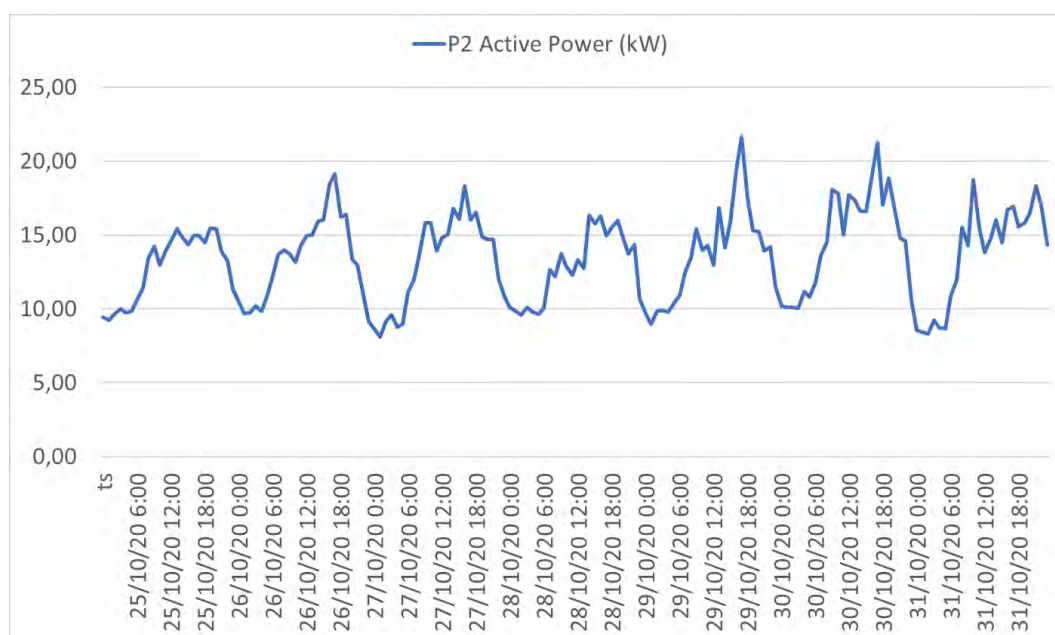


Figure 82. Norwegian Pilot - P2 Loads (Week autumn).



- Loads PV side: Convenience/Grocery Stores (see Figure 83).

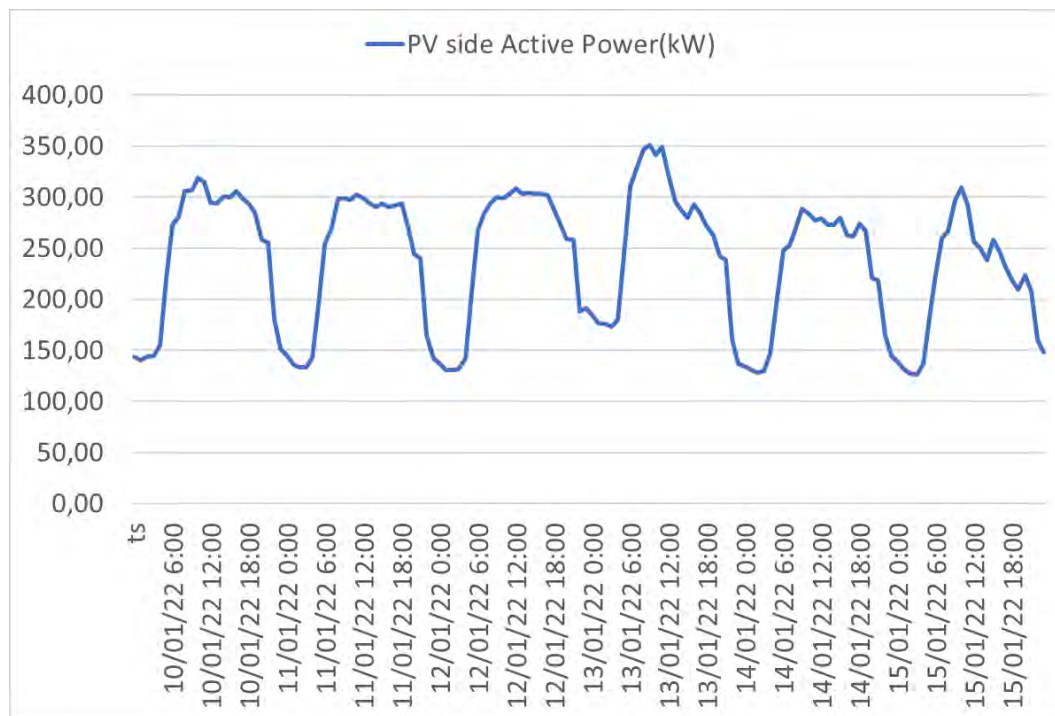


Figure 83. Norwegian Pilot - Loads PV side (Week winter season – stores are closed on Sunday).

Time series for the three characteristic load profiles are available from the Azure data storage available at the pilot. The installation is electricity-only. Some of the connected end-users have district heating, but this is outside the scope of the present project. Therefore, the pilot is an accomplished, fully operational installation. In relation to the pilot and testing of eNeuron toolbox, the project will model and explore the alternative extension possibilities, including alternative energy technologies such as long-term hydrogen storage.

#### 5.2.2.5 Regulatory aspects

Several regulatory limitations described in [68] and [69] are applicable to the Norwegian pilot, including the following.

The existing limitations related to using diesel-powered generation and the forthcoming environmental restrictions encouraged the Norwegian Pilot Operator to invest in BESS together with PV panels and power electronics:

- According to IEM Directive 2019/944 [73], DSOs are not allowed to own and operate energy storage facilities. However, this Directive is still in transposing process in Norway, and the outcome of the process remains unclear. Thus, ownership and operation of energy storage are not yet defined, especially considering that the energy storage is essentially used for operational purposes, i.e., improved reliability and quality of supply.

The future of the installation, especially the potential extensions, should consider the present and forthcoming limitations:



- Ownership of charging stations for EVs is not allowed for the DSOs and thus an external operator for the station(s) has to be involved.
- Limitations related to ownership of hydrogen infrastructure, which may allow optimal utilisation of the PV panels, i.e., electrolyser(s) and storage facilities. It is an open question whether it will be treated as a natural monopoly or commercial activity. If latter, the development and operation should be transferred to another company.
- The same applies to the use of the generated hydrogen; there are two main alternatives or combinations of these:
  - Use of hydrogen for fuelling of H<sub>2</sub> vehicles: Potential limitations of ownership and operation should be considered.
  - Use of hydrogen for the operation of CHP generating electricity and heat for local use. In general, this may be challenging, considering that as DSO, the operator of the Norwegian pilot cannot produce electricity. However, following the forthcoming regulation in Norway, Active Customers can share among them up to 500 kW of self-produced electricity at the same property. This potentially opens possibilities for the development of a local multi-energy hub.

#### 5.2.2.6 Economic costs and benefits

The total costs for building Skagerak Energilab were about 30 MNOK (approx. 3,000 k€). This includes the total costs of implementing PV, battery, and control systems at the arena. The battery was specified in 2017 and purchased a year later. The battery costs have since decreased significantly. Extensions related to Skagerak Energilab will only be simulated based on the already existing site. No new hardware implementation cost will apply in relation to the eNeuron project.

#### 5.2.2.7 Impacts

The following impacts are foreseen for the listed business cases:

	Business case	Impacts
1	Green Electricity for Local Customers	Increased use of green electricity (produced by PV panel), reduced import of electricity to the area (reduced grid losses?)
2	High Reliability of Supply	Improved quality of supply, faster start-up and no noise and emissions
3	Frequency regulation (primary)	Reduced deviation of frequency and increased stability in the power system (on a system level).  Increased RES hosting capacity.
4	Green EV charging (assessment)	Reduced load variations in the local grid – fewer voltage deviations.  Improved service to the EV owners.



	Business case	Impacts
5	Flexibility traded in the local flexibility market for solving voltage problems in the local distribution grid (assessment)	Improved voltage quality
6	Improved voltage quality (at the customer)	Improved voltage quality
7	Reduced grid tariff costs through peak shaving	Reduced grid costs (for the customer) Reduced peak load (in the distribution grid?) Increased grid capacity for other customers in the area Reduced need for investing in increased grid capacity (for the DSO)

#### 5.2.2.8 Database linkage

The Norwegian pilot does not link to the eNeuron Database but makes use of all real-time monitored data that cannot be included because of confidentiality issues.

In total, the pilot collects about 1700 signals from the control system, which can be exported via API. The use cases and business models to be implemented will be developed into operation modes in the control system.

Therefore, each scenario will have a customized function button in the MicroScada control system, with a total of 20 of these different operation modes to explore. Nonetheless, the use cases cover services that enable the investigation of both technical and commercial aspects of optimisation within future energy communities. These scenarios and the data series collected from testing will be used as the basis for further development of the eNeuron toolbox.



## 5.2.3 Polish Pilot – City of Bydgoszcz

<b>CARRIERS</b>				X	Gas
					Hydrogen
					Water
				X	Electricity
				X	Heat
					Cooling
<b>SECTOR</b>					Industrial
				X	Commercial
					Residential
				X	Academic/Educational
<b>LOCATION</b>					Health
					Inland
					Island
					North Europe
				X	Centre Europe
					South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind	X	Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
X	CHP		Cool		Water
X	Diesel		Pumped Hydro		Hydrogen
X	Heat pump		Hydrogen	X	Gas
	Natural Gas		Electric boiler		
	Electric				
X	Solar thermal				
	Electrolyser				
	Fuel Cell				
	Electric Chiller				
	Absorption Chiller				
	NG Boiler				
	NG Reforming				
LOCATION					
<b>Country</b>	Poland		<b>City</b>	Bydgoszcz	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>					Csa
					Cfb
				X	Dfb
					Dfc
					Cfa



### 5.2.3.1 Scenario description

The scenario focuses on the eight buildings of the town of Bydgoszcz in Poland. Each building will be treated as a micro-energy hub ( $\mu$ EH). The hardware devices will be installed at the level  $\mu$ EH to collect energy data and events from PV, heat pumps, CHP, etc., and to transmit control commands where possible. Data from devices installed at  $\mu$ EH will be transmitted to the central application coordinating the operation of  $\mu$ EHs and managing the entire EH (The Energy Hub). The central application will coordinate the micro energy hubs so that they can act together and provide several functions having as objective maximization of local resources and optimal grid flexibility. The EH presents the following characteristics:

- end-users: eight buildings with different functions: City Hall, swimming pool, school, animal shelter, sports facilities, cultural and living facilities (description is presented in the scenario location),
- generation: PV, CHP, backup power generator, and
- demand-side flexibility (flexible resources): heat pumps, heat storage, electric boiler, electric furnace.

Their technical details will be presented in the “Technical Characteristics” section. The relations in The Energy Hub are shown in Figure 84.

Each  $\mu$ EH has its own energy consumption. There are flexible sources in several  $\mu$ EHs. Based on energy demand forecasts, PV forecasts and the optimisation target (use case), a schedule for the operation of flexible sources will be prepared.

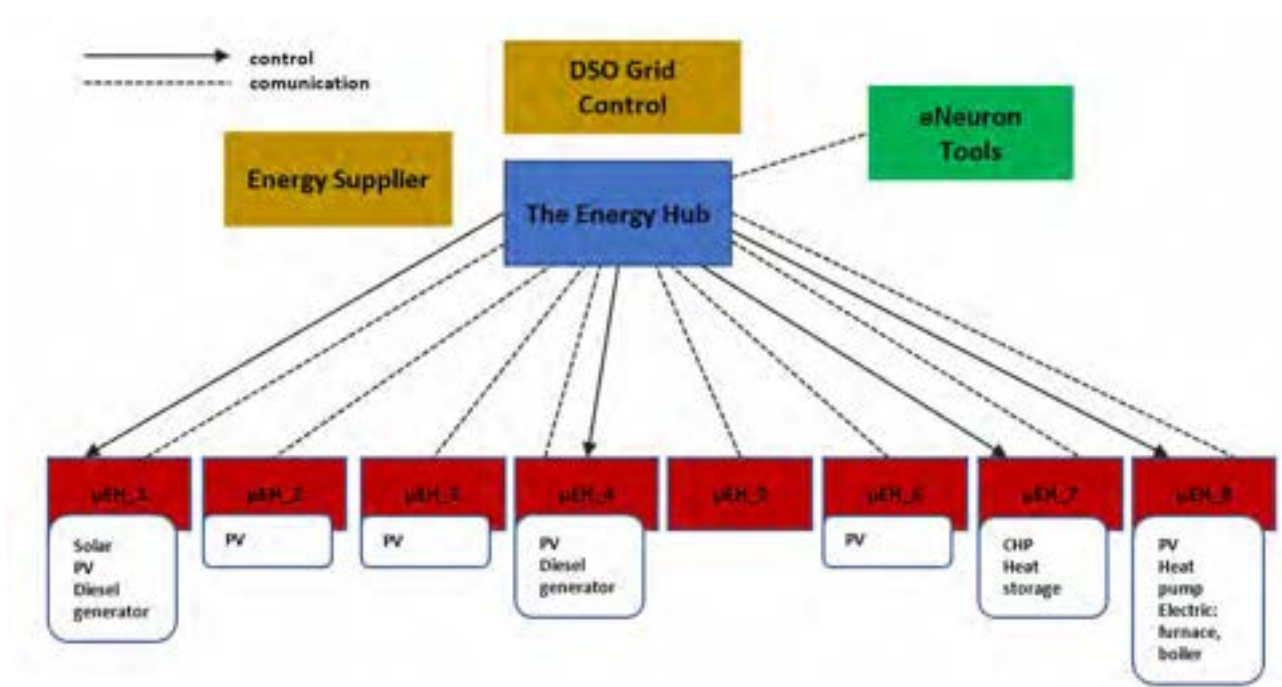


Figure 84. Polish Pilot - Energy Community Relations in the Polish Pilot.



Two cases are considered within the pilot:

- Use case 1: *Maximization of use of local generation in the Energy Hub*

The assumption of the use case is the maximization of the local electricity consumption generated by own resources (installed in eight buildings) in order to optimize the energy balance of the energy hub. The aim of optimisation is to reduce the supply of electricity from external sources (e.g., distribution networks), which is expected to reduce electricity costs. Flexible resources will be used for optimisation.

In order to implement use case 1, PV generation forecast, Power demand forecast, and the availability of flexible resources (power, energy) are required.

Based on the forecasts of the demand for power/generation in the Energy hub, a day-ahead energy balance (e.g., 24 hours) can be obtained. If there is an excess of local energy, the change of the flexible resource operation profile should be analysed depending on the PV profile. Historical data on electricity consumption in individual buildings and weather forecasts (insolation) can be used to build a forecast model.

- Use case 2: *Grid flexibility management*

PV panels connected to the distribution network can cause several multiple problems, e.g., voltage de-regulation (too high voltage at high generation). By using controllable resources within the energy hub (generation/demand), the quality and safety of the energy supply can be improved. The pilot covers the area of the city of Bydgoszcz and its major energy nodes, connected to both LV and MV grids. All current P, Q, V, and I measurements are available directly from substations or indirectly from the SCADA system and AMI system so that near real-time energy flow tracking management is achievable and can be superimposed over detailed GIS map. This will deliver full insights into MV operation in a visual way.

In use case 2, it is expected that for a selected part of the MV network (including at least one  $\mu$ EH), the possibility of changing the voltage profile of the distribution network by changing the generation and load will be analysed. A fragment of the MV grid model will be developed (including technical data on the distribution grid and power flow). Based on the forecasts of the power demand /generation in a selected  $\mu$ EH, the possibilities of the impact of flexibility resources on, for example, a change in the voltage profile in a selected part of the MV grid will be analysed.

### 5.2.3.2 Scenario location

The energy hub will be formulated in the city of Bydgoszcz (see Figure 85).





Figure 85. Polish Pilot - Scenario Location.

The buildings are connected to the DSO (ENEA Operator), which is a partner in the project. The location of the buildings is shown in Figure 86. In most cases, buildings are equipped with PV panels. Therefore, it is important to know the conditions of insolation in Bydgoszcz. Annual insolation values are presented in Figure 87 [19].



Figure 86. Polish Pilot - Location of buildings.



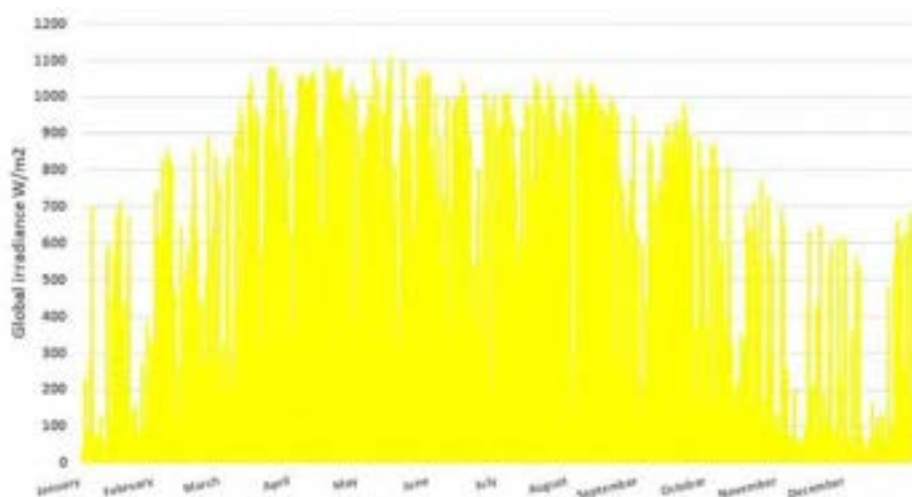


Figure 87. Polish Pilot – Irradiance historic data [19].

### 5.2.3.3 Scenario diagram

The scenario provides information about energy carriers such as electricity and natural gas. Depending on the installed devices and energy needs, different carriers are required for each building ( $\mu$ EH):

- Electricity, natural gas: School Complex no. 28 with swimming pool (No. 7).
- Electricity: Bydgoszcz City Hall building ( $\mu$ EH no. 1), Łuczniczka Sports and Entertainment Complex ( $\mu$ EH no. 2), Zawisza Sports and Entertainment Complex ( $\mu$ EH no. 3), Astoria Recreation Centre ( $\mu$ EH no. 4), Palace of Youths in Bydgoszcz ( $\mu$ EH no. 6), Animal Shelter in Bydgoszcz ( $\mu$ EH no. 8); Primary School No. 9 ( $\mu$ EH no. 5).

In the Energy Hub, electricity is partially supplied by the network grid, while the rest is produced by means of PV panels (8 units of which two are planned, power installed 280 kWp) and CHP (1 unit, 40 kW<sub>e</sub>). Some PV panels are used as off-grid (see Table 21). In buildings where PV is connected to the network, the surplus of electricity can be sent to the grid.

Gas is used by the CHP, and the electricity obtained from it is consumed locally. The thermal energy produced by the CHP is consumed locally, and the excess is stored in a heat storage system. CHP is a flexible source where the electricity generation can be adjusted in the range of 20-40 kW<sub>e</sub>.

Each  $\mu$ EH has its own energy consumption. The buildings are equipped with smart meters that record, among others, 15 min energy consumption profiles. These measurements will be used for load forecasts.

The heat pump, electric furnace, and electric boiler provide an additional source of flexibility that can be used as needed. They can be turned on, considering the technical limitations of the installation, when there is excess energy in the Energy Hub. In contrast, the use of diesel generators (backup power generators in Figure 88) is conditioned by the price of electricity from the grid.



Figure 88 shows the energy carriers diagram in the Polish pilot scenario, representing both energy carriers and conversion technologies. The presented drawing is illustrative because the energy carriers and conversion technologies for each  $\mu$ EH will be different (see Table 21 for the replacement of installed devices).

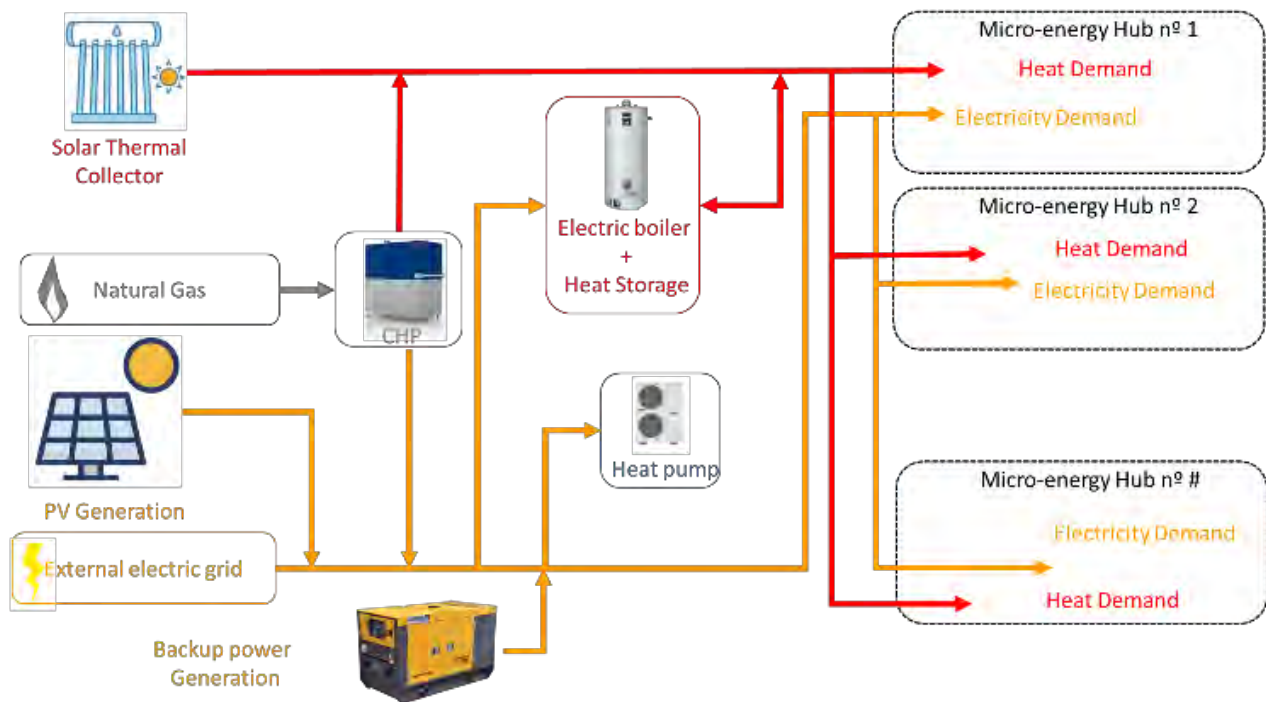


Figure 88. Polish Pilot - Energy carriers' diagram in the Polish pilot, representing both energy carriers and conversion technologies in the Scenario.

#### 5.2.3.4 Technical characteristics

The electric network provides electricity to each building which is equipped with smart meters registering 15 minutes' energy consumption profiles and 10 minutes' phase voltage profiles. The measurements will be automatically sent to the energy hub central level with a delay time of 15-30 minutes. The total annual electricity consumption for all buildings is presented below (Figure 89). The total demand for electricity is characterized by predictable consumption both during the week (Figure 90) and the day (Figure 91).

Although some individual buildings ( $\mu$ EH), e.g., City Hall and schools, have a predictable demand for electricity, some others, such as sports and cultural facilities, are characterized by very high variability in their demand (Figure 92).



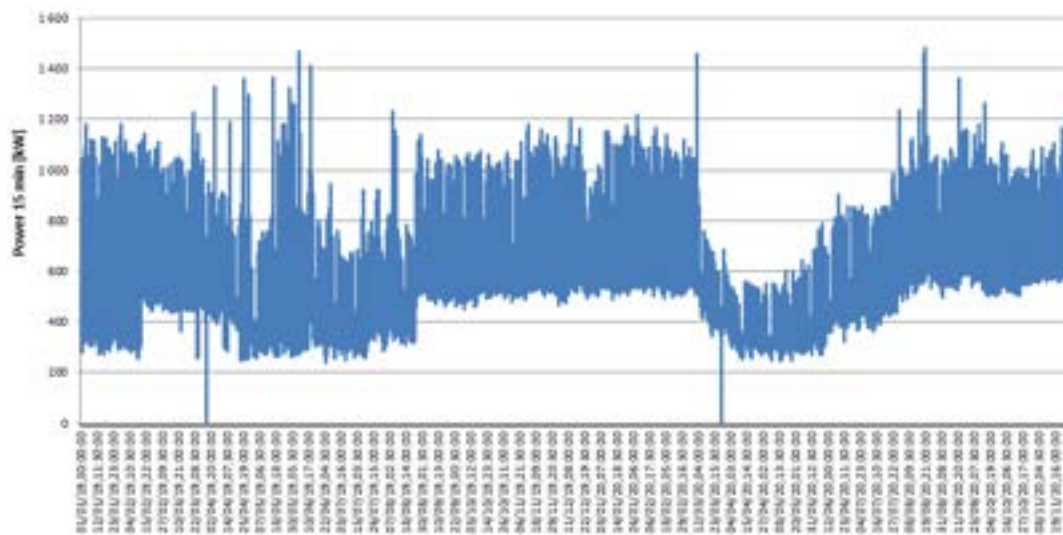


Figure 89. Polish Pilot – Historic data of electric power demand of the EH.

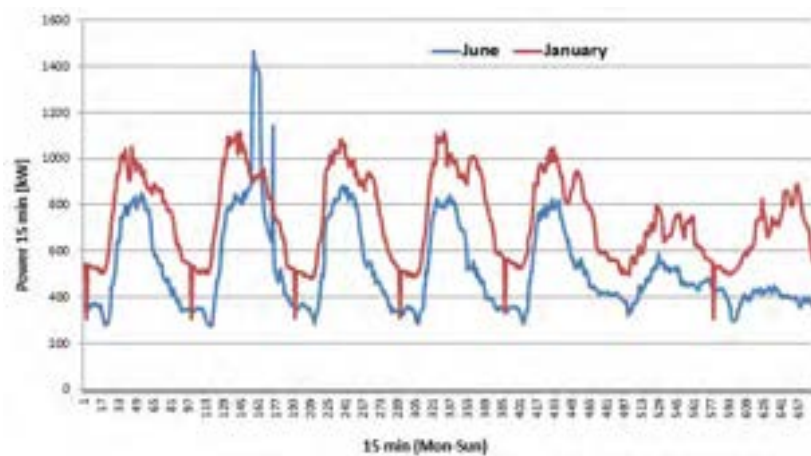


Figure 90. Polish Pilot –January and June weekly historic data of electric power demand of the EH.

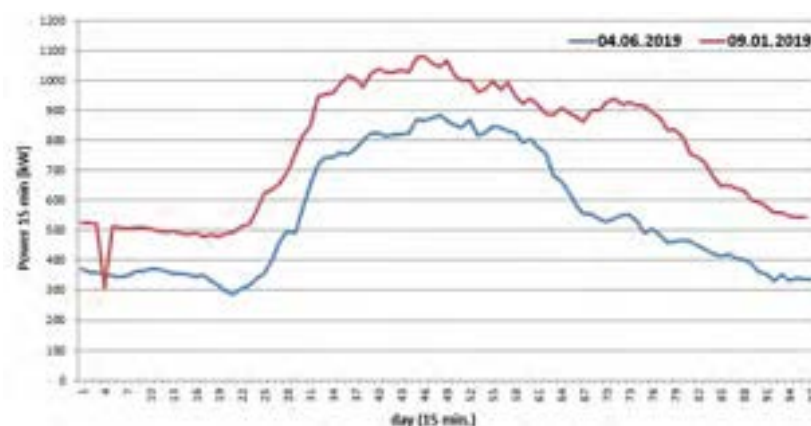


Figure 91. Polish Pilot - Daily electric power demand of the EH.



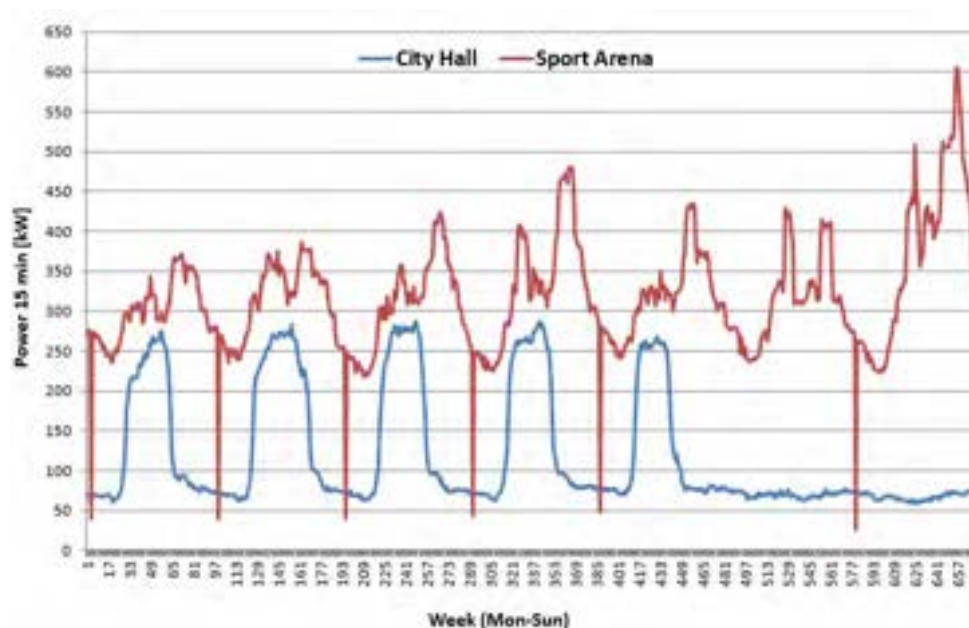


Figure 92. Polish Pilot – Typical week variability of power demand in the selected buildings.

Mainly PV systems are installed in the buildings; only one of the buildings is passive, although there are flexible resources in a few buildings. The description of the devices installed in each  $\mu$ EH is shown in Table 21.

Table 21. Polish Pilot - Technical data of technologies in the  $\mu$ EH.

No. $\mu$ EH	End-user	Technology	Size	Efficiency		Grid connection
				Electrical	Thermal	
1	Bydgoszcz City Hall building	PV	10.5 kWp	-	-	Off-grid**
		Solar Collector	12.5m <sup>2</sup>	-	-	-
		Diesel generator	180 kVA (144kW) 80 kVA (66kW)	n/a	-	Off-grid**
2	Łuczniczka Sports and Entertainment Complex	PV (40 kWp) – ongoing*	40 kWp	-	-	Off-grid**
3	Zawisza Sports and Entertainment Complex	PV (50 kWp) – ongoing*	50 kWp	-	-	Off-grid**
4	Astoria Recreation Centre	PV	143 kWp	-	-	Off-grid**
		Diesel generator	667.4kVA, 4 kVA (533.4kW, 4 kW)	n/a	-	-



No. μEH	End-user	Technology	Size	Efficiency		Grid connection
				Electrical	Thermal	
5	Primary School No. 9	passive users with no DER	-	-	-	-
6	Palace of Youths in Bydgoszcz	PV	18 kWp			On-grid
7	School Complex no. 28 with swimming pool	CHP	2 x (20 kW <sub>e</sub> /38.7kW <sub>th</sub> )	32%	64%	Off-grid**
		heat storage	957 l	-	n/a	-
8	Animal Shelter in Bydgoszcz	PV	18 kWp			On-grid
		3xheat pumps	5.97 kW <sub>e</sub> /20.63kW <sub>th</sub>	-	COP=3.5	-
		electric furnace	24 kW	-	n/a	-
		electric boiler:				-
		electric heater	2x9 kW	-	n/a	-
		tank:	500 L, 800 L	-	n/a	-

\*Finish June-September 2022

\*\*There is no possibility of power transmission from PV to the network grid (blockers are installed). These sources are not adapted to island operation, and in the event of a power failure, they are turned off.

#### 5.2.3.5 Regulatory aspects

In Poland, the Act on Renewable Energy Sources (RES Act) defines two forms of local energy community, the so-called clusters and energy cooperatives. The energy cluster is an association of entities with various legal statuses. Cluster agreement concerns the production and demand balancing, distribution, or trade of energy from renewable sources or other fuel/energy sources. The area of the cluster's operation should be a distribution network with grid voltage below 110 kV operating within one county or five municipalities.

#### 5.2.3.6 Economic costs and benefits

As for the future expansion of the facility, the current costs and benefits are being considered:

Costs:

- Purchase of the specialized equipment.
- Operation and maintenance of each device.
- Purchase of the communication and metering devices.
- Engagement and incentives given to the users.



## Benefits:

- Increased energy security within the microgrid.
- Reduction of peak consumption.
- Savings related to the increase in self-consumption (reduced grid tariffs for local flows and energy prices).
- Active role of the users within the residential premises.

## Projected cost:

- Industrial computer 5,000€ (2 units = 12,000€).
- Control with communication modem approximately 4,000€ (probably 6-7 units, currently at the stage of arrangements).
- adaptation of local EMS (BMS) to the needs of the project; local modification, e.g., purchase of devices (cost unknown/negotiations with system suppliers).

## 5.2.3.7 Impacts

The formation and functioning of Energy Hub should provide environmental, economic, and social benefits for its members - the shareholders or local areas in which they operate, in particular:

- Reduction of greenhouse gas emissions, which is due to local production by the cogeneration system and PV panels (Use case 1).
- Obtaining an independent source of heat and electricity (backup for the facility). The installation is not independent of external sources but gives the opportunity to reduce energy bills (Use case 1).
- Increase of penetration of RES in the local generation mix (Use case 1).
- Observability improvement of the LV grid supplying the micro hubs (Use case 2).
- Improvement of power quality in the field of voltage profiles of LV grid supplying the micro hubs (Use case 2).
- Increase in hosting capacity of the LV grid connected to the micro hubs (Use case 2).

## 5.2.3.8 Database linkage

For the simulation of this scenario, the following time series of the eNeuron Database can be used, divided by  $\mu$ EH.

- For the Bydgoszcz City Hall building:
  - PV system:
    - 073\_GEN-ELEC-PVE\_IRRA-NONE\_PL-BYDGOSZCZ\_01012021-31122021
  - Solar collector:
    - 084\_GEN-HVAC-CSP\_IRRA-NONE\_PL-BYDGOSZCZ4\_01012021-31122021
  - Diesel generator:
    - 081\_GEN-ELEC-DIG\_FUEL-NONE\_PL-BYDGOSZCZ4\_01012021-31122021
  - Electrical consumption:
    - 092\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021
- Łuczniczka Sports and Entertainment Complex:



- PV System:
  - 074\_GEN-ELEC-PVE\_IRRA-NONE\_PL-BYDGOSZCZ5\_01012021-31122021
- Electrical consumption:
  - 094\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021
- Zawisza Sports and Entertainment Complex
  - PV system:
    - 075\_GEN-ELEC-PVE\_IRRA-NONE\_PL-BYDGOSZCZ6\_01012021-31122021
  - Electrical consumption:
    - 095\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021
- Astoria Recreation Centre:
  - PV system:
    - 082\_GEN-ELEC-PVE\_IRRA-NONE\_PL-BYDGOSZCZ1\_01012021-31122021
  - Diesel Generator:
    - 080\_GEN-ELEC-DIG\_FUEL-NONE\_PL-BYDGOSZCZ1\_01012021-31122021
  - Electrical consumption:
    - 093\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021
- Primary School No. 9
  - Passive users without DER:
    - 079\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012019-30112020
- Palace of Youths in Bydgoszcz
  - PV System:
    - 073\_GEN-ELEC-PVE\_IRRA-NONE\_PL-BYDGOSZCZ\_01012021-31122021
  - Electrical consumption:
    - 096\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021
- School Complex no. 28 with swimming pool
  - CHP:
    - 072\_GEN-HVAC-CHP\_ELEC-NONE\_PL-BYDGOSZCZ2\_01012021-31122021
  - Heat storage:
    - 067\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ31\_01012021-31122021
  - Electrical consumption:
    - 091\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021
- Animal Shelter in Bydgoszcz
  - PV system:
    - 076\_GEN-ELEC-PVE\_IRRA-NONE\_PL-BYDGOSZCZ3\_01012021-31122021
  - Heat pumps:
    - 070\_CON-HVAC-HEP\_ELEC-NONE\_PL-BYDGOSZCZ3\_01012021-31122021
  - Electric furnace:
    - 067\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ31\_01012021-31122021
  - Electric boiler:
    - 067\_CON-HVAC-BEL\_ELEC-NONE\_PL-BYDGOSZCZ31\_01012021-31122021
  - Electric consumption:
    - 090\_CON-ELEC-ELC\_NONE-NONE\_PL-BYDGOSZCZ\_01012021-31122021



## 5.2.4 Italian Pilot – UnivPM Campus

<b>CARRIERS</b>				X	Gas
					Hydrogen
					Water
				X	Electricity
				X	Heat
				X	Cooling
<b>SECTOR</b>					Industrial
					Commercial
					Residential
				X	Academic/Educational
					Health
<b>LOCATION</b>					Inland
					Island
					North Europe
					Centre Europe
				X	South Europe
TECHNOLOGIES					
Generation		Storage		Consumption	
X	PV		Batteries	X	Electric
	Wind	X	Heat		HVAC
	Hydro		Electric Vehicle		Electric Vehicle
X	CHP		Cool		Water
	Diesel		Pumped Hydro		Hydrogen
	Heat pump		Hydrogen	X	Gas
X	Natural Gas		Electric boiler		
X	Electric				
	Solar thermal				
	Electrolyser				
	Fuel Cell				
X	Electric Chiller				
X	Absorption Chiller				
X	NG Boiler				
	NG Reforming				
LOCATION					
<b>Country</b>	Poland		<b>City</b>	Bydgoszcz	
Type of geographic area (city, rural, ...)				City	
Climate Zone - European Köppen-Geiger classification: <ul style="list-style-type: none"> <li>▪ Csa: Temperate with dry, hot summer (Mediterranean).</li> <li>▪ Cfb: Temperate without dry season and warm summer.</li> <li>▪ Dfb: Temperate continental climate/humid continental climate without dry season and with warm summer.</li> <li>▪ Dfc: Cold, without dry season and with cold summer.</li> <li>▪ Cfa: Humid subtropical climate</li> </ul>				X	Csa
					Cfb
					Dfb
					Dfc
					Cfa



#### 5.2.4.1 Scenario description

This scenario focuses on the Università Politecnica delle Marche (UnivPM). UnivPM is composed of different campuses; among them, the Monte Dago site is a multi-energy microgrid since it currently presents several energy conversion technologies and internal energy networks that connect each building within site (e.g. an MV electric cabinet for the electricity import-export, a CCHP unit (CHP unit + absorption chiller) connected to a district heating and cooling network within site, and PV panels). Furthermore, electrical chillers are also installed in the buildings of the Monte Dago site. Regarding storage units, electric batteries will be installed in the near future, as well as Electric Vehicles (EVs) charging stations where EVs. Besides being charged, the Vehicle-to-Grid (V2G) possibility will be explored, and they can also be used as energy storage to provide flexibility to the internal microgrid of the Monte Dago site along with external electric batteries.

Different operating data of the technologies previously mentioned have been monitored to have a figure of their energy production according to the energy demand of the site.

The present scenario considers hourly data of both energy demand of the Monte Dago site, as well as the energy production from: i) natural gas boilers, ii) a CCHP unit, iii) electric chillers, and iv) PV panels. The thermal energy produced by both natural gas boilers and the CCHP plant is distributed among different buildings through a local district heating network. Such a network is also connected to various electric chillers situated in several buildings, enabling the capability of fulfilling the cooling demand. As previously said, the previous four technologies have been already installed on the site, while both electric batteries and EVs' charging stations will be installed afterwards.

#### 5.2.4.2 Scenario location

The Monte Dago site, which is located in Ancona which is located in the Marche Region (centre of Italy) at an altitude of 140 m above sea level, has been chosen for the current scenario (see Figure 93).



Figure 93. Italian Pilot - Scenario Location.



Most of the buildings host similar activities (e.g., teaching, research, laboratories, administration, and secretariat). A and B are the road accesses to the site. Three faculties are in the Monte Dago site: i) Faculty of Engineering (buildings 4, 5, 8, 9, 10, and “Blocco Aule Sud” (BAS)), ii) Faculty of Science (buildings 1, 2, and 3), and iii) the Faculty of Agriculture (buildings 6 and 7).



Figure 94. Italian Pilot - Map of the Monte Dago site (thermal power plant is highlighted in red).

Since the Monte Dago site is located at the geographical coordinates 43° 34' 53" N 13°30' 10" E, the lowest and the highest values of direct solar radiation are equal to 0.7517 kW/m<sup>2</sup> (21<sup>st</sup> of December) and 1.025 kW/m<sup>2</sup> (21<sup>st</sup> of June), respectively. Figure 95 shows the number of hours when the sun is shining each day, which is the number of hours between sunrise and sunset each day.

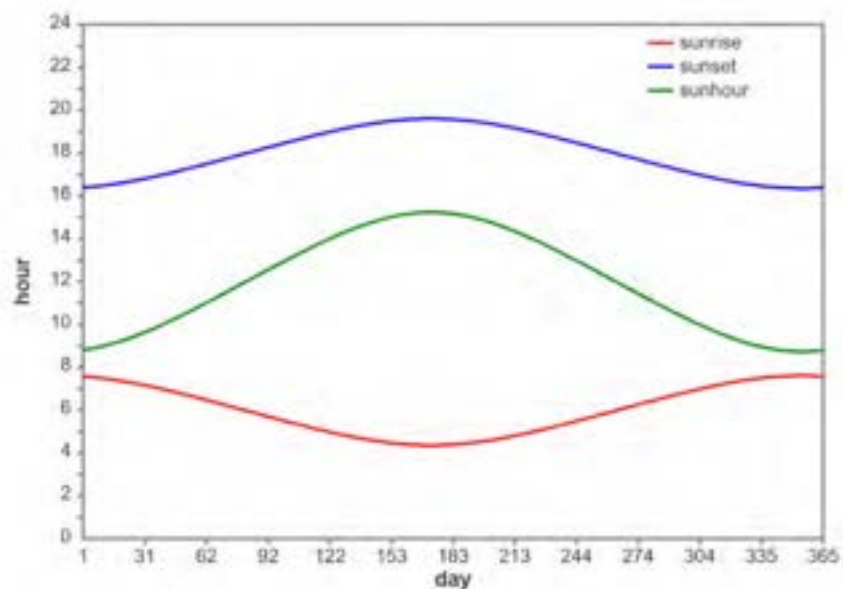


Figure 95. Italian Pilot – Sun hours' historic data.

The city of Ancona is the capital of the Marche Region, and it is in the centre of Italy close to the Adriatic Sea (East coast). The climate of Ancona is Mediterranean. Winter, from December to February, is relatively cold. The rains are quite frequent (few snowfalls), but generally not abundant.



Summer, from June to August, is hot and sunny. Spring and autumn are mild and variable with sunny periods.

#### 5.2.4.3 Scenario diagram

The present scenario investigates four energy carriers: electricity, natural gas, heating, and cooling. The electricity demand of the Monte Dago site is partially covered by the electricity withdrawn from the national grid and partially covered by the CHP unit and PV panels. The produced electricity can also be injected into the national electric grid through an MV electric cabinet when there is a surplus of energy production. The PV generation depends on the weather conditions and the day/night cycle as well. To integrate this kind of intermittent source, electric batteries will be installed in the near future on the site and proposed in this Scenario, which will provide flexibility to the internal electric grid. Furthermore, EVs' charging stations will be installed in the parking areas of the Monte Dago site as well. Along the same line, EVs will provide further flexibility to the microgrid due to the management of the charging/discharging phases of their batteries, since there will be a two-way electricity flow passing through the EVs' charging stations.

A thermal power station is installed in the Monte Dago site, which provides thermal energy to all the facilities within the campus. It is composed of boilers and a CCHP, where the latter produces thermal energy recovered from the exhaust gases or cooling thermal energy through absorption chillers. The CCHP unit is connected to a district heating and cooling network within the Monte Dago site that provides thermal energy to the buildings within site, as highlighted in Figure 94. Furthermore, such network is also connected to various electric chillers situated in several buildings, by enabling the capability of fulfilling the cooling demand. Regarding energy storage, electric batteries will be installed within site to provide flexibility to its microgrid. In addition, EVs' charging stations can provide further flexibility by considering EVs as a source/storage of electricity due to the two-way electricity flow passing through the EVs' charging stations.

Figure 96 shows the energy carriers and the technologies involved in the Monte Dago site.

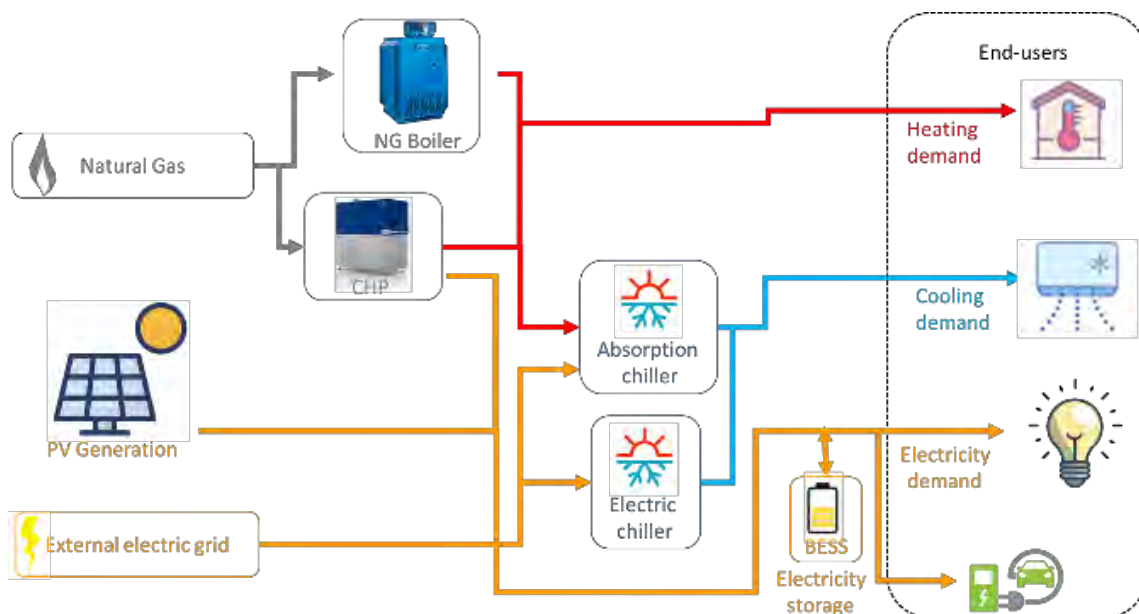


Figure 96. Italian Pilot – Scenario diagram.



#### 5.2.4.4 Technical characteristics

##### Electric network

The electric network provides electricity to each building of the Monte Dago site, which is analysed in this scenario, with an average efficiency equal to 94%. The yearly electricity demand in 2021 has been measured, and it was equal to 5.62 GWhe/year (with a power peak of 1.37 MWe). The average electricity consumption is constant throughout the year, with a daily variability due to the presence of both weekdays and weekends. However, in both the spring and autumn seasons, there is a considerable drop in the electricity demand.

##### Heating and cooling network

Heating and cooling energies are provided to each building of the Monte Dago Site with an average efficiency of 82%. The yearly thermal energy demand in 2021 has been measured, and it was equal to 3.95 GWhth/year (with a power peak of 1.22 MWth). The peak of the thermal energy demand occurs on the first day after the Christmas holidays since all the activities in the Monte Dago site restart. Therefore, a considerable amount of heat is required to warm up all the rooms.

As for cooling energy demand, it is present only from July to September with a gap in August due to the summer holidays. The yearly cooling energy demand in 2021 has been measured, and it was equal to 0.50 GWhth/year (with a peak at 1.33 MWth).

##### Gas network

The gas network refers to the national pipelines since the natural gas is withdrawn from them. The average efficiency of the gas distribution pipelines is equal to 99%. The natural gas is used to feed both natural gas boilers and the CHP unit. The fuel consumption is measured by a flow meter installed upstream of the thermal power plant in the Monte Dago site. The natural gas consumption in 2021 was equal to about 1,300,000 m<sup>3</sup>/year.

##### CCHP unit - 600 kWe/700 kWth (heating)/400 kWth (cooling)

The CCHP unit (CHP unit + absorption chiller) is installed in the thermal power plant located in the Monte Dago site, and it provides part of the electrical and thermal/cooling energies needed by the campus, mainly to buildings 1, 2, 3, and BAS showed in Figure 94.

Figure 97 shows the energy flow through the CCHP technology under investigation.

The CHP unit has an electric efficiency of 42% and a thermal efficiency of 48.4%, thus achieving overall efficiency of 90.4%. Two absorption chillers (water-lithium bromide-based) are present in the site under investigation: the smallest one provides a cooling power of 150 kWth with an average COP of 0.75, while the largest one provides a cooling power of 250 kWth with an average COP of 0.75.



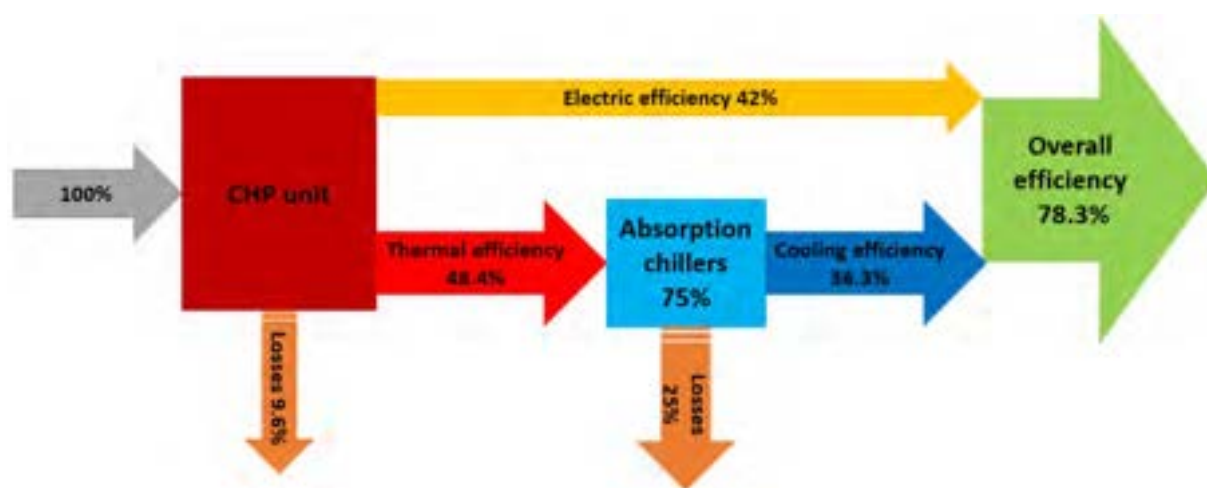


Figure 97. Italian Pilot - Energy flow through the CCHP technology that is under investigation.

### Natural gas boilers - 8 MWth

The natural gas boilers are installed in the thermal power plant located at the Monte Dago site, and they provide part of the thermal energy needed by the campus. The thermal efficiency of the natural gas boilers is equal to 91%.

### Electric chillers - 900 kWth

The electric chillers are installed in several buildings located within the Monte Dago site, and they provide part of the cooling energy needed by the campus. The overall electricity consumption by the electric chillers is about 12 GWhe/year.

### PV panels - (20 kWep)

So far, there is only a small PV system within the Monte Dago site that has been used for research purposes: however, this plant will be widened soon. The current solar production of this PV system is about 21 MWhe/year. The average efficiency of the PV system is equal to 19%.

#### 5.2.4.5 Regulatory aspects

As already mentioned, the incentives provided by the Italian Energy Service Management under Italian Government policy were initially proportional only to the energy produced by the PV system. A subsequent considerable decrease in the PV module price in the period 2010–2012 [24] induced the Italian Government to reduce year-by-year the feed-in-tariff contribution for PV energy production. The regulatory framework introduced by the Italian Government in July 2013 [25], definitively closed the feed-in-tariff scheme in Italy, and no further incentives can be obtained for PV energy production.

In the heating and cooling sector, RES can be present in different forms (e.g., biomass, geothermal, etc.). However, most of the heating and cooling needs in the EU are still satisfied using fossil fuels and, for this reason, the decarbonisation of the heating and cooling sector has been considered a



priority in the upcoming years. Up to now, the promotion of highly efficient cogeneration and district heating are considered among the main pathways to achieving decarbonisation of the sector, as reported in [74].

Regarding electric batteries [75], the Directive 2006/66/EC (the Batteries Directive), last amended in 2018, is the main legal act regulating batteries at the EU level. The directive applies to all types of batteries. In addition, the Directive 2019/944 IEM established common rules for the generation, transmission, distribution, energy storage, and supply of electricity, together with consumer protection provisions, with a view to creating truly integrated, competitive, consumer-centred, flexible, fair, and transparent electricity markets in the Union. The Directive 2019/944 IEM aims to ensure affordable, transparent energy prices and costs for consumers, a high degree of security of supply, and a smooth transition toward a sustainable low-carbon energy system. It lays down key rules relating to the organization and functioning of the Union electricity sector, in particular rules on consumer empowerment and protection, open access to the integrated market, third-party access to transmission and distribution infrastructure, unbundling requirements, and rules on the independence of regulatory authorities in the Member States. This Directive also sets out modes for the Member States, regulatory authorities, and transmission system operators to cooperate towards the creation of a fully interconnected internal market for electricity that increases the integration of electricity from renewable sources, free competition, and security of supply.

Categories of battery also include the ones involved in the automotive batteries (excluding traction batteries for electric cars) that can be used as second-life batteries for the energy sector. The primary objective of the Directive 2006/66/EC was to minimize the negative impact of batteries and waste batteries on the environment while ensuring the smooth functioning of the internal market; in particular:

- Reduce the use of such substances in batteries.
- Ensure the proper management of waste batteries.

Under the extended producer responsibility principle, producers of batteries and producers of other products that incorporate a battery became responsible for the waste management of batteries that they placed on the market, in particular the financing of collection and recycling schemes.

Regarding EVs [76], the Directive 2014/94/EU Directive Alternative Fuel Initiative in Italy (DAFI) assesses the deployment of alternative fuels infrastructure. The main objective is to reduce the dependence on oil and mitigate the environmental impact in the transport sector. The decree also establishes that when the Italian public authorities' current fleet of cars, buses, and service vehicles, is worn out and needs replacement, the public authorities will be obliged to make sure that at least 25% of the fleet will consist of EVs, hybrid vehicles, compressed natural gas (CNG), liquid propane gas (LPG), and liquefied natural gas (LNG) vehicles. Furthermore, according to the DAFI, by 31 December 2017, municipalities had to update their building regulations to meet requirements on the deployment of alternative fuels infrastructure. From 1 June 2017, new buildings and those ones which have been significantly renovated must provide connection points for EVs' charging. Currently, there are no official data available on compliance with these DAFI building regulations. In order to further deploy the use of renewables and energy storage in the near future, these technologies can be embedded to constitute the so-called Local Energy Communities (LECs), which are legal entities involved, among other things, in power production, distribution, and use. Their



main goal is to provide environmental, economic, and social benefits to the local community. These entities can be then allowed to participate in the electric market as an aggregator when an overall power of at least 1 MW is reached [77]. The definition of the LEC is also embedded in the term “citizen energy communities” that is provided by the Directive 2019/944 IEM. Indeed, the Directive 2019/944 IEM assesses this community as a legal entity that: i) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises; ii) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and iii) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles; and may provide other energy services to its members or shareholders.

#### 5.2.4.6 Economic costs and benefits

The site of Monte Dago currently consists of an MV electric cabinet for the electricity import-export, a CCHP unit connected to a district heating and cooling network, and PV panels.

Regarding the storage units, electric batteries will be installed in the near future, as well as EVs' charging stations where EVs, besides being charged, can be used as energy storage as well.

To have a better insight into the economy of scale of the technologies previously mentioned, their costs are listed and reported hereinafter:

- CCHP
  - Total installed cost: 3,500 €/kWe [28]
  - Levelized cost of electricity: 0.01 €/kWh [28]
- PV panels
  - Total installed cost: 778.01 €/kWe [20]
  - Levelized cost of electricity: 0.05 €/kWh [28]
- Electric batteries (about 70 kWh capacity, to be confirmed)
  - Total installed cost: 500 €/kWh [78]
- EVs' charging stations (#2 with at least 25 kW capacity (bidirectional) per each, to be confirmed)
  - Total installed cost: 500 €/kWe [79]
  - Cost of electricity: market pricing (contracts with DSOs)
- Electric chillers
  - Total installed cost: 600 €/kWth [70]
  - Cost of electricity: market pricing (contracts with DSOs)

In order to monitor the operating data of the previous technologies, the following measuring infrastructure has been installed at the Monte Dago site:

- One LoRaWan antenna was installed in the Faculty of Engineering (building 11, see Figure 94), whose range is about 6 km as the crow flies



- Total installed cost: 725 €
- 14 acquisition cards for the data monitoring and acquisition of CCHP, PV, electric batteries, and EVs' charging stations
  - Total installed cost: 768 € per each

Benefits from this scenario can be found mainly in i) the gaining of ECCs that lead to economic revenues by the deployment of the use of RESs, and ii) energy efficiency interventions as well.

#### 5.2.4.7 Impacts

This scenario has several goals to be achieved, which can be divided into Use Cases (UCs) and Business Models (BMs).

Use Cases (UCs):

The main objective of the Italian pilot is to define the optimal mix of energy assets to be installed in the micro energy hubs, which will also take into account the achievement of 50% Renewable Energy Systems (RESs) by 2030 (1) (UC1, KPI 15) in the Monte Dago site. By constituting the optimal mix of energy assets, the maximization of the self-consumption (UC2, KPIs 8 and 9) will be achieved since a LEC will be created with the Monte Dago site in the upcoming years, favouring the deployment of new DERs technologies and renewables and thus reducing the energy withdrawn from the national grid.

Up to now, the Monte Dago site presents different energy conversion technologies such as natural gas boilers, a CCHP unit, electric chillers, and PV panels. Possibly, the PV panels' capacity will be widened to achieve the goal previously mentioned, keeping an eye on the installation of other green technologies in the future. Indeed, the implementation of new green technologies will also lead to the minimization of CO<sub>2</sub> emissions (UC3, KPI 12), which is one of the main goals declared by the European Union (EU) in the following deadlines in the years 2030 and 2050 (in this last case, a net-zero emission should be achieved).

Furthermore, the installation of both batteries and EVs' charging stations will increase the flexibility of the local DSO (UC4, KPIs 6 and 7). Then, a proper energy management strategy (e.g., a day-ahead operation program) will be used to optimally schedule energy assets through the eNeuron toolbox, as well as through AI and a data-driven model. As a further result, this strategy will lead to the minimization of total primary energy input to the Monte Dago site (UC5, KPI 1).

For the sake of clarity, further KPIs information is listed below:

- KPI 1 - Reduction in primary energy demand and consumption;
- KPI 6 - Flexible energy traded and managed;
- KPI 7 – Flexible energy unlocked;
- KPI 8 - Self-sufficient;
- KPI 9 - Increase in self-sufficiency;
- KPI 12 - Reduction in daily and annual CO<sub>2</sub> emissions;
- KPI 15 - Increase of penetration of RES in the local generation mix.



#### 5.2.4.8 Database linkage

For the simulation of this scenario, several eNeuron Data series can/must be used. Specifically:

- Electricity consumption:
  - 052\_CON-ELEC-ELEC-ELEC-ELEC-IT-ANCONA-01012019-31122019
- Thermal and cooling energy consumption (from natural gas boilers and CHP):
  - 055\_CON-THER-HVA-HEAT-HEAT-IT-ANCONA-01012019-31122019
  - 054\_CON-THER-HVA-COLD-COLD-IT-ANCONA-01012019-31122019
- Natural gas consumption:
  - 053\_CON-NGC-NGC-NGC-NGC-IT-ANCONA-01012019-31122019
- CCHP unit:
  - 066\_GEN-ELECTHERM-CHP-NG-ELECTHERM-IT-ANCONA-27022006-27022006
- PV generation:
  - 057\_GEN-ELEC-PVE-IRRA-ELEC-IT-ANCONA-01012018-31122018
- Electric batteries:
  - 064\_STO-ELEC-BAT-ELEC-ELEC-IT-ANCONA-24072021-25072021
- EVs:
  - 087\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017
  - 088\_STO-ELEC-BAT\_ELEC-ELEC\_ES-MADRID\_03022017-03022017



## Conclusions

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This deliverable has addressed the definition of 16 scenarios (12 generals and 4 based on pilots) for their simulation through the eNeuron toolbox. Moreover, within this deliverable, the mathematical models of technologies and flexible electrical distribution grid models have been also provided. These can be seen as the key elements of the scenario's simulation in the next tasks of WP5.

For the scenarios' design, the eNeuron Database has been created to support the time series needed for future simulations, with an initial proposal of 93 inputs and size of 1.5GB. Some of these time series are based on real monitored data, and some others are synthetic based on models.

Regardless of the typology, the sector or technologies included in the scenario, most of the impacts raised by the scenarios focus on the reduction of carbon footprint and on accelerating the transition towards a carbon-neutral economy in Europe. Unfortunately, as already mentioned in eNeuron public deliverable D2.3 "Limitations and shortcomings for optimal use of local resources", the legislation to implement all scenarios and use cases depend on the technology and country. For example, local PV generation is highly dependent on each country. However, because of the new EU regulations to promote local and collective self-consumption, the scenarios do not envisage any regulatory limitation related to the local PV generation. On the contrary, there is neither a common EU framework nowadays, in terms of compulsory regulations or prescriptions, for the installation of hydrogen generation-electrolyser and their interconnection to the electricity grids or to the transport sector. Therefore, each country relies on specific national regulations. All scenarios have taken into account these limitations.

The same problems arise when designing Renewable Energy Systems (RES) in the scenarios. RES penetration in the electricity sector has attracted most of the attention due to the availability of relatively more mature technologies like PV. However, most of the heating and cooling needs in the EU are still satisfied using fossil fuels. For this reason, heating and cooling technologies have been incorporated into several scenarios.

In the scenarios, some cost amortizations have not fully been estimated because of the lack of government policies and regulations, but also because of technological issues. Once again, hydrogen is a special case for pilots because it may be stored at a higher density through different technologies, but few of these have reached commercial maturity for large-scale applications. Therefore, some of the technologies differ in approach among the pilots. In any case, most of the investment and operating costs of the technologies included in the scenarios have been mainly extracted from the eNeuron public deliverable D2.2: "Technical solutions for multi-carrier integrated systems under the LEC concept: A review" and the "Renewable power generation costs in 2020" IRENA report. Furthermore, the eNeuron toolbox is pointed by the scenarios as a mean to finish dimensioning the use cases.

Regardless of these contingencies, every scenario has been designed with the aforementioned aspects in mind, defining different use cases to simulate, in the case of the pilots, and linking to the eNeuron Database, being ready for the simulation in the following tasks of WP5.



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