PEM ELECTROLYSERS FOR OPERATION WITH OFFGRID RENEWABLE INSTALLATIONS

First assessment on monitor and model: alignment with requirements and objectives

Deliverable D2.7

GRANT AGREEMENT
700359

D2.7 First assessment on monitor and model: alignment with requirements and objectives

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Abstract summary

As a European project handled by an international consortium, ELY4OFF project is divided into several tasks to be carried on by partners. After one year of project, the objective of this report is to evaluate the progress of each specific task related to the demonstration system development and installation. Compliance with the design specifications and requirements is also analyzed.

Progress evaluation showed that the electrolyser system development is on-going and in agreement with initial planning and specifications. On the demonstration site, PV panels have to be installed and the construction at FHA's is progressing and start-up is anticipated at the beginning of 2018. Furthermore, others required equipment such as batteries, fuel cell and hydrogen storage are already ready to be used. Power electronics development also appears on time, whereas great progress is expected soon for the control and communication system design and development.

The second objective of this report is to give an overview of the computer model of the system that was developed during first 6 months of the project and illustrate its ability to contribute to the design and evaluation of the system. The system model is detailed as an assembly of its different components and the associated sub-system models, parameters and the overall energy management strategy. Then, the model is used through simulations cases occurring in 2 different locations and submitted to two different hydrogen loads, aiming to observe impacts of these input data on results. This model will be used in future task to achieve techno-economic studies.

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I. Context of D2.7 report

I.1 WP2 presentation and objectives

Deliverable 2.7 is part of work package 2 which aims at "providing a clear definition of technical, regulatory and safety aspects for an electrolysis system as a solution for completely off-grid areas in stand-alone operation" as mentioned in the project Grant Agreement [1]:

Specific objectives of WP2 are:

1. Compilation of regulations, codes and standards, aligned with the system demonstration and developed business cases;
2. Analysis of end user requirements;
3. Development of a set of system specifications and capabilities of an electrolysis system working off grid;
4. Update of the objectives to be monitored in the validation and demonstration phase;
5. Life Cycle Cost analysis: a base line and update of the improvements;
6. Sensitivity analysis of the main parameters affecting LCC and alignment with business cases".

Within WP2, report D2.7 main objectives are:

(i) To evaluate the progress of demonstration related tasks and validate that current developments are in line with specifications identified in WP2 technical reports ;
(ii) To give an overview of the computer model of the system that was developed during first 6 months of the project and illustrate its ability to contribute to the design and evaluation of the system.

I.2 WP2 previous reports

I.2.1 D2.1: RCS study for demonstrative case

Report D2.1 ("RCS study for demonstrative case"), delivered at month 3 and written by FHA was defined as following in the Grant Agreement [1]:

"A literature search about national and local regulations will be developed as first step and local/national regulators will be consulted when necessary to assess and compile all the information regarding the installation and running of the off-grid system."

This report listed equipment to be used for ELY4OFF project, and also RCS (please see Appendix 1 for RCS updates) that it will be required to follow (Figure 1):

	RD 842/2002 of 18 September, where Electrical Low Voltage Regulation and Technical Instructions are approved.
	RD 3275/1982 of 12 November approves the Regulation on technical conditions and safety guarantees in power plants, substations and transformer centres.
	RD 614/2001 of 8 June, on minimum standards for the protection of the health and safety of workers from electrical risk.
PED	**RD 2060/2008** of 12 December, transposed from European Pressure Equipment Directive 97/23/EC
CTE	**RD 314/2006** of 17 March, Technical Building Code
	RD 2267/2004 of 3 December, Fire Safety Regulation in Industrial Facilities. **RD 1942/1993** of 5 November, that approves the Regulation on Fire Protection Installations
	RD 400/1996 of 1 March, transposing Directive 94/9/CE on Equipment and Protective Systems intended for use in potentially explosive atmospheres. **RD 681/2003** of 12 June, transposing Directive 1999/92/CE of minimum requirements for improving the protection of the health and safety of workers in explosive atmospheres.
	RD 1254/1999 of 16 July, transposing Directive 96/82/CE, on measures to control the risks inherent in major accidents involving dangerous substances

Finally, the following standards are also of application:

UNE – ISO 14687: Hydrogen fuel. Product specification

UNE – ISO 15916: Basic considerations for the safety of hydrogen systems

Figure 1: RCS to respect according to [2]

Report D2.1 also defined mains actions to do in order to satisfy the project needs:

a. Transformation of PV generation from being connected to the grid to be isolated.

b. Modification of the connection of the PV generation to feed PEMWE.

c. Update of metallic hydride compression system, and its connection.

d. Batteries and power electronics related to HSS (Hybrid Storage System).

I.2.2 D2.3: System capability requirements

Report D2.3 ("System capability requirements"), delivered at month 7 and written by FHA with the contribution of other partners was defined as following in the Grant Agreement [1]:

"Deliverable 2.3 will be devoted to summarizing in one document all the technical requirements and boundary conditions of each subsystem to be developed."

Several elements of D2.3 are presented in the present document in order to evaluate if components of the system are currently designed in accordance with D2.3 expressed requirements and specifications.

I.3 D2.7: First assessment on monitor and model: alignment with requirements and objectives

I.3.1 D2.7 report description according to the Grant Agreement

Report D2.7 ("First assessment on monitor and model: alignment with requirements and objectives"), to be delivered by the end of month 14 (May 2017) was defined as following in the Grant Agreement [1].

"A continued monitoring of the specific technical developments will be carried out in this deliverable, which will consist in following the correct implementation of the previous work developed in WP2 during first 14 months."

I.3.2 D2.7 report objectives

The objectives of this report, as expressed in the Grant Agreement description, are:

(i) To evaluate the progress of demonstration related tasks and validate that current developments are in line with specifications identified in WP2 technical reports ;

(ii) To give an overview of the computer model of the system that was developed during first 6 months of the project and illustrate its ability to contribute to the design and evaluation of the system

The methodology followed during the construction of this document in order to fulfill these objectives is described in the following section.

I.3.3 Methodology

To achieve objectives mentioned above, main technical requirements expressed in report D2.3 by ITM, FHA, EPIC Power and Inycom regarding equipment they are in charge of are checked. Then, a comparison with the expected progress by the Grant agreement Gantt planning is realized.

In the second part of this document, the computer system model developed with Odyssey, a simulation software developed by CEA which allows to study energetic systems, is presented and its capabilities are illustrated through simulation scenarios.

To sum up, the methodology to fulfil the report objectives is the following:

- Evaluation of technical progress and compliance with the Gantt planning for each partner of the project ;

- Validation of the ability of the developed model to simulate the behaviour of the system and contribute to the design, sizing and strategy definition of ELY4OFF system.

In order to evaluate the technical progress and compliance with the Gantt planning, each section (each section is dedicated to one partner) is organized as following:

- **Initial planning** of partners development tasks: the objective of this section is to evaluate the expected percentage of progress according to the starting date, the ending date and the current month of the partner task(s) (current month taken as end of April).
- **Compliance with D2.3**: the objective of this section is to validate if on-going developments are in line with specifications and design information provided in D2.3. this evaluation is realized using a table composed gathering the following information:
    - *D2.3 information*: information from D2.3
    - *Planned value*: information value according to D2.3.
    - *Planned value confirmation* (have to be filled by the partner): planned value confirmation (is the planned value still valid?).
    - *Comments* (filled by the partner): add eventual comments, for example if the planned value is already implemented, or the reason why it is no more valid etc.

In Table 1 below are illustrated these explanations about compliance with D.2.3. Texts in *italic* are filled by partners. After *Compliance with D2.3* table is an additional blank table allowing partners to write any additional information.

D2.3 information	Planned value	Planned value confirmation	Comments
Any type of information n°1	Value planned in D2.3	*Confirmation of the planned value*	*Already implemented or any other comments*
Any type of information n°...	Value planned in D2.3	*Confirmation of the planned value*	*Already implemented or any other comments*
Any type of information n°n	Value planned in D2.3	*Confirmation of the planned value*	*Already implemented or any other comments*

Table 1: Example of a Compliance with D2.3 table

Note: for ITM, main requirements regarding the electrolysis system mentioned in the Grant agreement are also evaluated in this section.

- **Indicators evaluation**: the objective of this section is to estimate the on-going progress of the partner task(s), and evaluate the risk of delay for future developments. This is realized using a table composed of the following columns:

- *Task*: Considered task
- *Initial planning*: expecting progress in the task according to the initial planning
- *Estimated real progress* (filled by partners): partners estimation about the real progress on the task
- *Risks analysis: Compliance with Gantt* (filled by partners): comparison between the initial planning progress and the real progress estimation
- *Risks analysis: Expected evolution* (be filled by partners): task evolution estimation (green smiley=no problems in view ; red smiley=critical problems in view)
- *Risks analysis: Compliance with D2.3* (be filled by partners): show if any changes were made since D2.3 report. Can be filled by yes/no or a percentage of compliance
- *Comments* (filled by partners): add any comments

In Table 2 below are illustrated these explanations. Texts in *italic* were filled by each partner for the developments task they are in charge of.

Tasks	Initial planning	Estimated real progress	Risks analysis			Comments
			Compliance with Gantt	Expected evolution	Compliance with D2.3	
3.1	35%	*Estimation of the real progress*	*Real progress >35% → Ok Real progress <35% → No*	*Choose one* 	*"Yes" or "No" depending on the planned value confirmation (can be a %)*	*Any comments*

Table 2: Example of an Indicators table

I.3.4 ELY4OFF Gantt

The following Gantt planning (Figure 2) was proposed in the project Grant agreement [1]. In this report, the progress evaluation is realized for highlighted tasks.

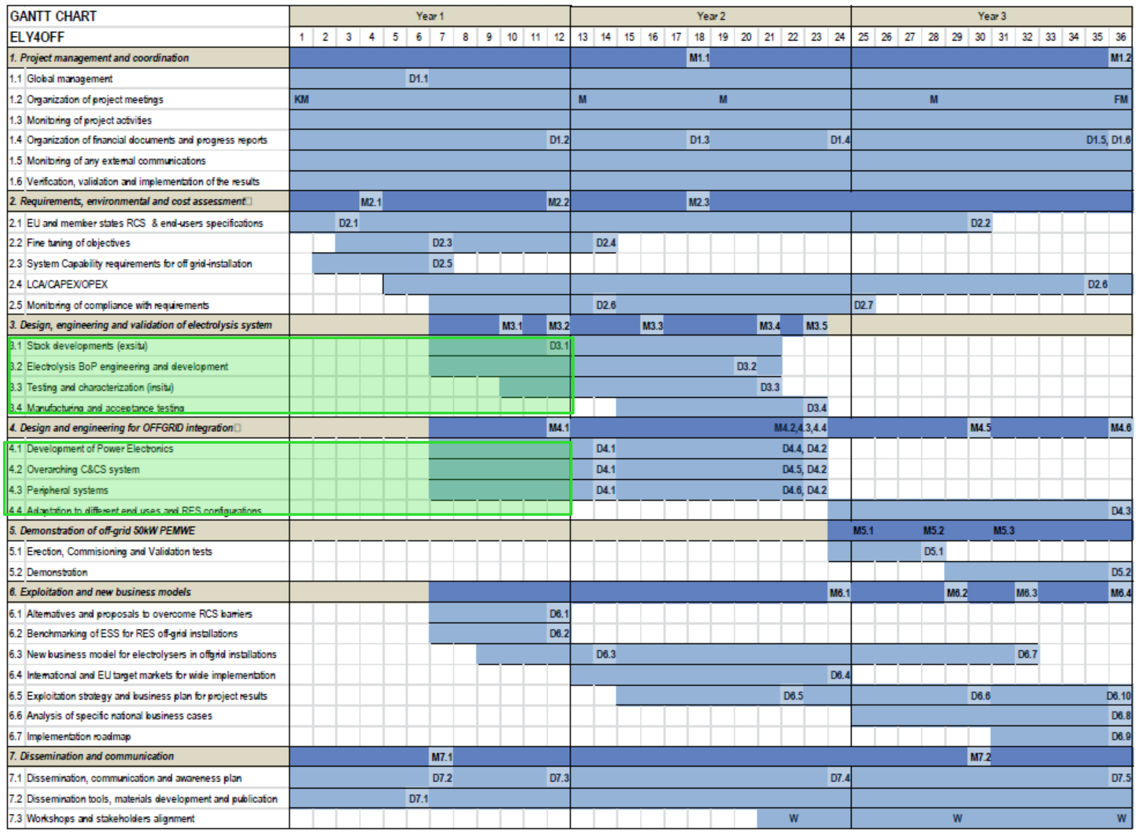


Figure 2: ELY4OFF Gantt planning [1]

II. Evaluation of tasks progress and compliance with Gantt

Figure 3 and comments below were presented in report D2.3 [3], to illustrate the different technologies to be commissioned in ELY4OFF project and the partner in charge of their development.

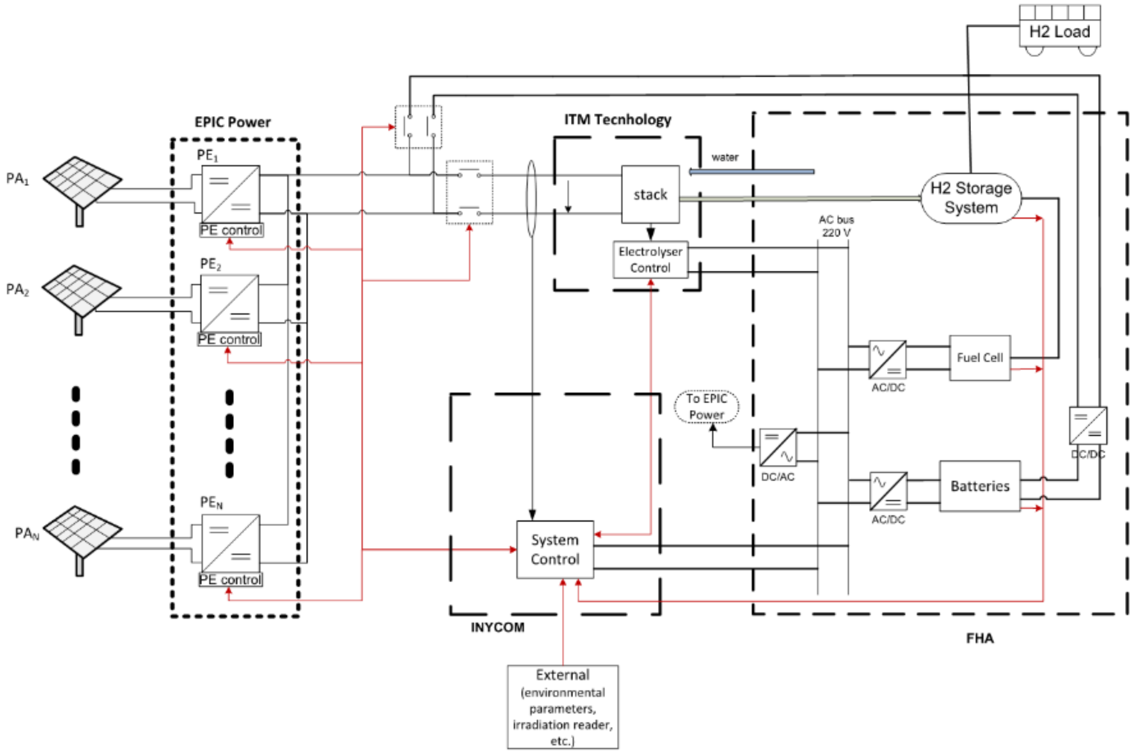


Figure 3: Technologies to be used in ELY4OFF and partner in charge of their development [3]

As it can be observed, the different subsystems are the following ones [3]:

Note: Please keep in mind that information below are originated from report D2.3. One of the objective of this document is to identify if any modification was made.

- **PV generator**: this is a crucial element as it is the only electrical power source for the system. In the proposal it was foreseen a size of 80 kWp of power. 60 kWp PV plant is already installed in FHA facilities.

- **Power electronics**: Scope by EPIC Power, the main challenge consists in the development of the necessary architecture to couple the electrolyser to RE source (PV), focusing on improvements of efficiency and enhanced flexibility over the state of art.

- **Electrolysis System** (PEMWE, or Polymer Electrolyte Membrane Water Electrolyser): supplied by ITM, the main challenge consists in improvements in order to maximize average hydrogen yield and minimize the need for back-up power during off periods. It will be developed and fabricated at ITM facilities, then shipped and installed at the demonstration site. The elements to be considered are: stack, control system, and auxiliary (pump, fans, chiller, dryer and electrical heater). 50 kW.

- **Peripheral Systems**: scope by FHA, formed by the rest of the elements of the demo installation. It is composed by a Hybrid Storage System (it will supply energy during periods of cloudy weather or during the night) and the required elements for distributing the hydrogen to customer. The main challenge is to find the appropriate size that allows to back-up the rest of the elements when there is no source of power, while fulfilling the expected amount of hydrogen to the 'customer'. The elements to be considered are:
  - H2 storage system: formed by tanks (different pressures), a metal hydride vessel and a compressor, the stored H2 will be sent to the final application or to the Fuel Cell.
  - Fuel Cell: it will use part of the H2 stored to supply electricity to the elements requiring it in moments of necessity.
  - Batteries: they will supply electricity as backup to the system in moments of necessity.
  - Power electronics: converters that allow supplying electricity stored in the batteries and in the Fuel Cell to consumers, as well as the charge of the batteries.

- **Overarching Control and Communication System**: studied by INYCOM, the main challenge consists on the design of new control strategies able to operate in an off-grid system, optimized for normal, safe and efficient operation. This C&CS will be in the highest control layer and will oversee the general installation, including every subsystem implied in the ELY4OFF design.

- **H2 load:** external demand of H2.

In the following sections, the tasks progress at the date of this report (end of April 2017), for each partner and the equipment associated, is evaluated.

II.1 FHA equipments: PV panels and peripheral systems

The ELY4OFF demonstration will be situated on FHA site at Walqa (Huesca, Spain). As described previously, FHA provides the following equipment (Table 3):

FHA equipment	
PV panels	
Peripheral systems	Hydrogen storage
	Fuel cell
	Batteries
	Converters
	Hydrogen dispenser

Table 3: Equipment provided by FHA

In the next section is reminded the Gantt project initial planning regarding peripheral systems.

II.1.1 Peripheral systems initial planning

Figure 4 below shows the initial planning regarding peripheral systems.

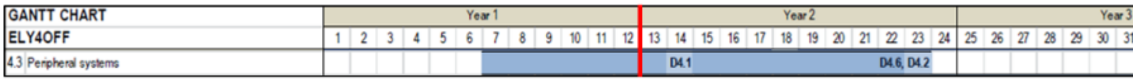


Figure 4: Initial planning regarding peripheral systems

<u>Note</u>: the red line represents report D2.7 writing date.

Task D4.3 was described as following by the Grant agreement [1]:

"Task 4.3 will focus on the design and development of the specific equipment that is going to be used in the facilities with the aim of increasing the overall efficiency of the system, such as use of a combination of FC/battery for shutdown periods, or the exploitation of residual or trace loads/flows in external systems (compression, storage). On the other hand, ELY4OFF will make use of the existing facilities on the FHA premises to demonstrate and study the potential uses of the hydrogen produced in an off-grid facility. Some of these systems will be updated to meet the testing requirements of the developed solution."

According to information above, task 4.3 should be advanced to approximately 31%. The progress is evaluated later in this report.

The current situation of each FHA equipment is presented in the following section.

<u>Note</u>: as there were not specific requirements expressed in report D2.3 about peripheral systems, the section dealing with FHA only evaluates the development progress for each peripheral system. Then, FHA tasks evaluation indicators are presented in the same way as for others partners.

II.1.2 Off-grid PV panels

PV power is a crucial element in the system, as it is the only source of electricity to the system.

FHA already operates a 100kW grid connected photovoltaic installation on its site of Walqa, ELY4OFF demonstration site. However, due to contractual power injections constraints related to the grid operator, the existing installation cannot be used for ELY4OFF project and addition PV plant has to be built. The construction place has already been defined: PV panels will be located next to the FHA building. The place of construction is illustrated on Figure 5 below.

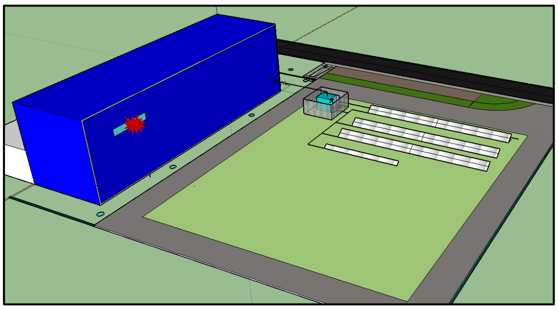



Figure 5: PV panels for ELY4OFF project will be built on a field next to FHA building (photo taken from FHA building ✸)

Currently, FHA is designing the PV field with panels from Eurener. The PV panels installation on the field should start at the around the end of 2017 / beginning of 2018.

PV indicators are presented in Table 4 below.

Equipment	Current situation	Action to be made	Risks analysis	
			Compliance with Gantt	Expected evolution
PV panels	**- Installation field available - PV power decided (60kWp) - Solar panels chosen**	**- Set the disposition of the panels on the fields - Build the PV facilities**		

Table 4: PV indicators

II.1.3 Hydrogen storage

Hydrogen storage is required to store hydrogen produced by the electrolyser. Hydrogen is then distributed to the final application or to the fuel cell for electrical power production.

Produced hydrogen can be stored as a gas in two different pressure tanks. These tanks are in series and as there are not operating at the same pressure, a compressor is required between them.

<u>Note</u>: a solid hydride storage system, also available at FHA site, will not be used for ELY4OFF project.

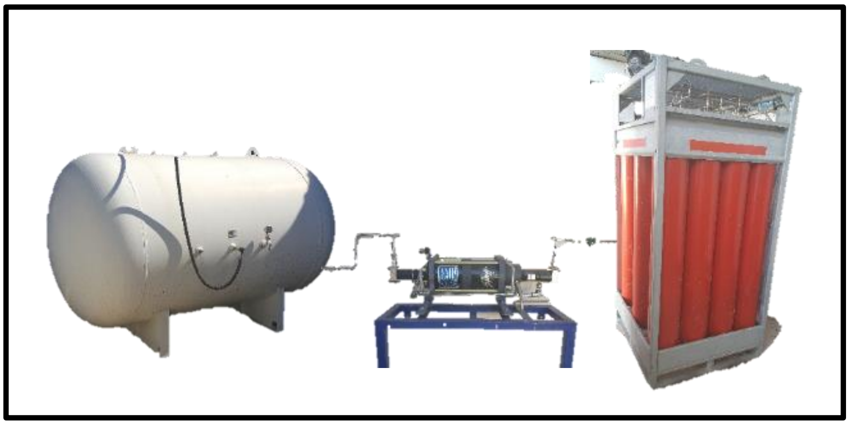


Figure 6: Hydrogen storage tanks and compressor

In the following sections technical characteristics of the tanks and the compressor are presented.

- **Medium pressure hydrogen storage tank**

The medium pressure hydrogen storage tank is the 1st step of the hydrogen storage. This tank is presented on Figure 7 below.

Figure 7: Medium pressure hydrogen storage tank

This tank is operating at 32 bars and has a storage capacity of 4 m^3 of hydrogen. Main characteristics of the tank are presented in the Table 5 below.

Characteristic	Value	Unit
Manufacturer	**Lapesa**	**/**
Pressure	**32**	**Bars**
Capacity (volume)	**4**	**m^3 of H2**

Table 5: Medium pressure hydrogen storage tank main characteristics

- **High pressure hydrogen storage tank**

The high pressure hydrogen storage tank is the 2nd step of the hydrogen storage. This tank is shown on Figure 8 below.

Figure 8: High pressure hydrogen storage tank

This tank is operating at 350 bars and has a storage capacity of 0.8 m^3 of hydrogen. Main characteristics of the tank are presented in the Table 6 below.

Characteristic	Value	Unit
Manufacturer	Wystrach	/
Pressure	350	Bars
Capacity (volume)	0.8	m3 of H2

Table 6: High pressure hydrogen storage tank main characteristics

- **Compressor**

As it was mentioned previously, the hydrogen tanks are in series and do not operate at the same pressure. A compressor is required to provide hydrogen from the medium pressure hydrogen storage tank (32 bars) to the high pressure hydrogen storage tank hydrogen tank n°2 (350 bars).

This compressor is shown on Figure 9 below.

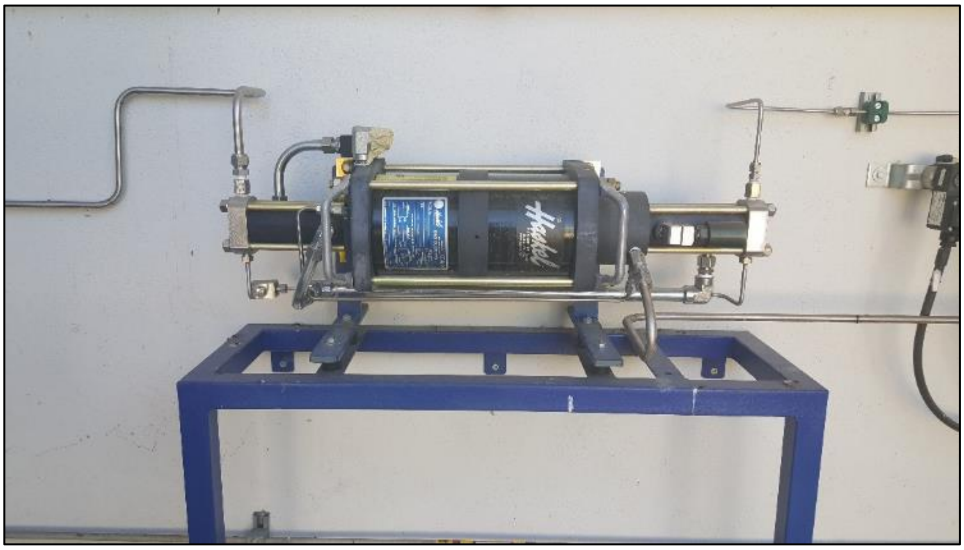


Figure 9: Compressor used between the 2 hydrogen storage tanks

Main characteristics of the compressor are presented in the Table 7 below.

Characteristic	Value	Unit
Brand	**Haskel**	**/**
Model	**8AGT 30-60**	**/**
Minimum inlet gas pressure	**1.7**	**Bars**
Maximum outlet pressure	**620**	**Bars**

Table 7: Compressor main characteristics

Compressor technical sheet is available on the following website: http://www.thomasnet.com/catalogs/item/235111-4460-1001-1054/haskel-international/model-agt-8-inch-in-series-two-stage-pneumatic-driven-gas-booster/

Hydrogen storage indicators are presented in Table 8 below.

Equipment	Current situation	Action to be made	Risks analysis	
			Compliance with Gantt	Expected evolution
Hydrogen storage	**- 2 tanks in series linked by a compressor** **- Equipment ready to be used**	**- The possibility to add more hydrogen storage capacity closer to the PV field is considered**		

Table 8: Hydrogen storage indicators

II.1.4 Batteries

Batteries will be used in ELY4OFF demonstration to supply electricity as backup to the system when required.

Lead-Acid batteries installed at FHA are shown on Figure 10 below.

Figure 10: Lead-Acid batteries which will be used for ELY4OFF project

Main characteristics of lead-acid batteries available for ELY4OFF project are presented in Table 9 below.

Characteristic	Value	Unit
Brand	**Exide Technologies**	/
Model	**OPzs Classic Solar**	/
Number of cycles	**Up to 2800 at 60% depth of discharge**	/
Total capacity	**30**	**kWh**

Table 9: Main characteristics of Lead-acid batteries available for ELY4OFF project [4]

Batteries technical specifications sheet is available on the following website: http://www.exide.fr/Media/files/Downloads/IndustEuro/Classic%20Solar.pdf

Batteries indicators are presented in Table 10 below.

Equipment	Current situation	Action to be made	Risks analysis	
			Compliance with Gantt	Expected evolution
Batteries	**- Lead-Acid batteries ready to be used**	/		

Table 10: Batteries indicators

II.1.5 Fuel cell

Fuel cell installed at FHA, as part of the demonstration system, can use part of the H_2 stored to supply electricity to the sub-systems when necessary.

The available fuel cell for ELY4OFF project is a 4.5kW fuel cell. The fuel cell is shown on Figure 11 below.

Figure 11: Available fuel cell for ELY4OFF project

Main characteristics of the available fuel cell for ELY4OFF project are presented in Table 11 below.

Characteristic	Value	Unit
Manufacturer	**Hydrogenics**	**/**
Model	**HyPM HD 4**	**/**
Technology	**PEM**	**/**
Electrical power	**4.5**	**kW**
Operating current	**0 - 120**	**A_{dc}**
Operating voltage	**40 - 80**	**V_{dc}**
Peak efficiency	**50**	**%**
Purity of hydrogen required	**≥ 99.99**	**%**
Supply pressure	**515 - 690**	**kPa**
Hydrogen consumption	**≤ 75**	**L/min**

Table 11: Main characteristics of the available fuel cell for ELY4OFF project [5]

Fuel cell indicators are presented in Table 12 below

Equipment	Current situation	Action to be made	Risks analysis	
			Compliance with Gantt	Expected evolution
Fuel cell	**- Fuel cell available for the project**	**- Confirm the good operation of the fuel cell**		

Table 12: Fuel cell indicators

II.1.6 Hydrogen dispenser

According to the proposal of the project, possible applications of the hydrogen for the ELY4OFF demonstration were:

- Mobility for FCEVs (Fuel Cell Electric Vehicles) and transport applications: 1,5 -2 kg/day ;
- Cogeneration system for heating and electricity supply to FHA building: 0,4 – 0,6 kg/day ;
- Backup system for computer server in FHA building: 0,2 kg/day.

Finally, it was defined in [3] that the final application for the demonstration would be *"hydrogen for mobility"* with customers accepting hydrogen production without any constraint (no minimal or maximal hydrogen load to provide).

Produced hydrogen within ELY4OFF project will be used for a mobility purpose specifically linked to the project H2Pyr, where 2 minibuses will operate in Huesca.

The hydrogen dispenser was not initially in the scope of ELY4OFF project. That is why the development progress for this equipment is not evaluated.

A hydrogen dispenser is already installed at FHA (Figure 12: and can be used for ELY4OFF project purpose.

Figure 12: a dispenser is available on FHA site

Main characteristics of the dispenser are available in the Table 13 below.

Characteristic	Value	Unit
Brand	**FHA and local companies**	**/**
Dispenser buses compatibility	**Nozzles TK25**	**/**
Dispenser cars compatibility	**Nozzles TK16**	**/**
Max working pressure	**447**	**Bar**
Temperature range	**-20 to 60**	**˚C**
Max flow	**20**	**kg/min**

Table 13: Main characteristics of the available dispenser on FHA site

<u>Note</u>: as the dispenser is not in the scope of ELYOFF, this section is only to inform partners on how hydrogen produced thanks to the project will be used.

II.1.7 FHA tasks progress indicators

All previous indicators about peripheral systems are summed up in the Table 14 below.

Equipment	Current situation	Action to be made	Risks analysis	
			Compliance with Gantt	Expected evolution
PV panels	**- Installation field available - PV power decided (60kWp) - Solar panels chosen**	**- Set the disposition of the panels on the fields**		
Hydrogen storage	**- 2 tanks in series linked by a compressor - Equipment ready to be used**	**- The possibility to add more hydrogen storage capacity closer to the PV field is considered**		
Batteries	**- Lead-Acid batteries ready to be used**	**/**		
Fuel cell	**- Fuel cell available for the project**	**- Confirm the good operation of the fuel cell**		

Table 14: FHA synthesis indicators

Regarding the overall task 4.3, Table 15 below gives progress overview.

Tasks	Initial planning	Estimated real progress	Risks analysis			Comments
			Compliance with Gantt	Expected evolution	Compliance with D2.3	
4.3	31%	**~60%**			**/[1]**	**- PV has to be built - Others peripherals systems are ready to be used**

Table 15: Task 4.3 indicators

[1]: Compliance with D2.3 is not evaluated as no technical requirements were expressed in D2.3 about peripheral equipment.

The initial planning expected a progress for task 4.3 is 31%. As all elements are available and ready to be used (excepted PV panels, construction date expected on 2018), it can be estimated a real progress of 60%.

II.2 Electrolysis system by ITM

The Electrolysis System (PEMWE, or Polymer Electrolyte Membrane Water Electrolyser) is manufactured by ITM. The main challenge consists in technical improvements to maximize average hydrogen yield and minimize the need for back-up power during off periods. It will be developed and manufactured at ITM facilities, then shipped and installed at demonstration site. The elements within the subsystem are: stack, control system, and auxiliary (pump, fans, chiller, dryer and electrical heater).

II.2.1 ITM initial planning

As shown by Figure 13 below from the Grant agreement [1], ITM is in charge of the development of the electrolyser and the associated Balance of Plant (BoP). Some tests and characterizations are also planned.

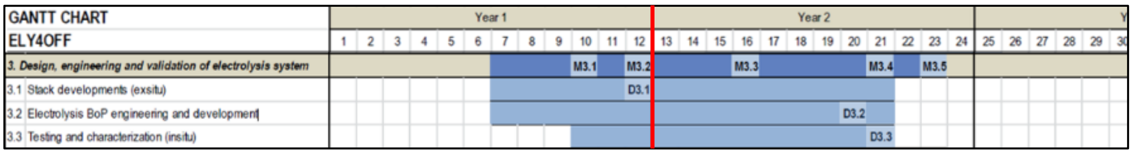


Figure 13: initial planning regarding electrolysis system

Note: the red line represents report D2.7 writing date

Please refer to the Grant agreement [1] for detailed WP3 description. Tasks included in WP3 and commented in this report are the following (Table 16).

<table>
<tr><th>Tasks</th><th>Starting month</th><th>Ending month</th></tr>
<tr><td>3.1: Stack developments</td><td rowspan="2">7 (November 2016)</td><td rowspan="3">21 (January 2018)</td></tr>
<tr><td>3.2: Electrolysis BOP engineering and development</td></tr>
<tr><td>3.3: Testing and characterization</td><td>10 (February 2017)</td></tr>
</table>

Table 16: WP3 commented tasks

According to Table 16, tasks 3.1 and 3.2 should be advanced to approximately 35%. Task 3.3 should be advanced to approximately 18%. These progress values are evaluated later in this report.

II.2.2 ITM compliance with D2.3

- Technical characteristics for electrolyser and BoP

D2.3 electrolyser and BoP characteristics	Planned value	Planned value confirmation	Comments
Number of Electrolyser Stacks	1	Ok	
Minimum Hydrogen Production	3 kg/24hrs	Ok	
Maximum Hydrogen Production	28 kg/24hrs	Ok	
Power at maximum load	56 kW	Ok	to be measured on demonstration
Water Consumption	15 liters/kg H_2	Ok	To be confirmed by demonstration
Operating Pressure	20 bar	Ok	
System Efficiency at Maximum Load	<50 kWh/kg	Ok	To be measured on demonstration
Hydrogen Purity	99.999% - ISO 14687-2:2012	Ok	
Electrolyser Packaging	13' ISO Container	Ok	
Temperature Range	-15 to + 40 °C	Ok	
Data Interface	Profinet / Modbus	Ok	
Water Quality	Drinking Water	Ok	
Certification	CE	Ok	
Designed to ensure safe operation at all times	/	Ok	
PSU is a separate system	/	Ok	
Cooling fan consumption to circulate air in the PSU room	0.55 kW	To be confirmed	To be measured on demonstration
Process fluids within the electrolyser temperature	55°C	Ok (water)	
Control system is designed for integration with others systems at the FHA demonstration site	/	Ok	
Data logging and export (via. Profinet or Modbus) provided	/	Ok	
Remote connection over the internet is possible allowing control of the equipment and maintenance/upgrades to the control software	/	Ok	
Ongoing leak detection and appropriate safety features incorporated	/	Ok	
Electrolyser hibernation power consumption (limited to frost protection and control systems)	0.9 -3.9 kW	OK	Will be measured in demonstration
Electrolyser standby mode power consumption	5-10 kW	OK	Will be measured onsite in demonstration
HMI included within the control room of the electrolyser	/	Ok	
Possibility to establish a remote data connection via a secure VPN tunnel	/	OK	
Electrolyser system life time if proper operation (during this process, it would be expected that certain parts would be replaced as part of a structured maintenance plan)	20 years	Ok	

Table 17: Compliance with D2.3 electrolyser and BoP characteristics

Any other topics: **None**

- Technical characteristics from the Grant Agreement

Grant Agreement main requirements	Planned value	Planned value confirmation	Comments
Number of cells	75	**Ok**	
Cells surface	$415cm^2$	**Ok**	
Nominal cell current density	$1 A/cm^2$	**Ok**	
Nominal cell voltage	1.6V	**Not OK**	**Measured 1.64V @60°C (Ambient Pressure)**
Current density range	0.05A/cm2 to 1.5A/cm2	**OK**	
Maximal temperature	60°C	**Ok**	**True for water only (hydrogen can get to 300°C in dryer)**
Pressure range	To atmospheric pressure to at least 20 bar hydrogen	**Ok**	
Sustain large pressure differences between the electrode compartment		**Ok**	

Table 18: Technical characteristics mentioned in Grant Agreement

Any other topics: **None**

- Regulations and standards to be respected for electrolyser and BoP designed

Regulation - Standard	Regulation – Standard Confirmation	Comments (implemented or not)
2006/42/EC Machinery Directive	**ok**	**COMPLIANCE with CE MARKING requirements**
2004/108/EXC Electromagnetic Compatibility Directive	**ok**	
97/23/EC Pressure Equipment Directive	**Ok**	
EN 60204-1:2006 + A1:2009 “Safety of machinery – Electrical equipment of machines Part 1: General requirements”.	**Ok**	
EN 1127-1:2007 “Explosion prevention and protection - Part 1 - Basic concepts and methodology”, clause 6.2.	**Ok**	
EN 60079-10-1:2009 “Explosive atmospheres - Part 10-1 - Classification of areas - Explosive gas atmospheres”	**Ok**	
EN 61000-6-2:2005 “Immunity for industrial environment”	**Ok**	
EN 61000-6-4:2007 “Emission standard for industrial environments”	**Ok**	
EN 13445-3:2009 “Unfired pressure vessels Part 3 – Design”, clauses 7.4.2, 10.4.4.1, 10.6.2.1 and 11.5.2.	**Ok**	
EN 13445-5:2009 “Unfired pressure vessels Part 5 – Inspection and Testing”, clause 10.2.3.	**Ok**	
EN ISO 4126-1: 2004 “Safety devices for protection against excessive pressure - Part 1 - Safety valves”	**Ok**	
EN 10272:2007 “Stainless steel bars for pressure purposes”	**Ok**	
EN 61000-6-2:2005 “Immunity for industrial environment”	**Ok**	

Table 19: Regulations and standards for electrolyser and BoP design

Any other topics: **None**

II.2.3 ITM tasks progress indicators

Table 20 below was filled by ITM in order to estimate their progress on the WP3 different commented tasks.

Tasks	Initial planning	Estimated real progress	Risks analysis			Comments
			Compliance with Gantt	Expected evolution	Compliance with D2.3	
3.1	35%	**65%**	**YES**		**YES**	**/**
3.2	35%	**30%**	**YES**		**YES**	**/**
3.3	18%	**20%**	**YES**		**YES**	**/**

Table 20: ITM progress in WP3 commented tasks

II.3 Power electronics by EPIC Power

Regarding EPIC Power tasks, the main challenge consists in the development of the necessary electrical architecture to couple the electrolyser to RE generation (PV), focusing on improvements of efficiency and enhanced flexibility over the state of art.

II.3.1 EPIC Power initial planning

As shown by Figure 14 below from the Grant agreement [1], EPIC Power is in charge of the development of power electronics required for ELY4OFF project though the task 4.1.

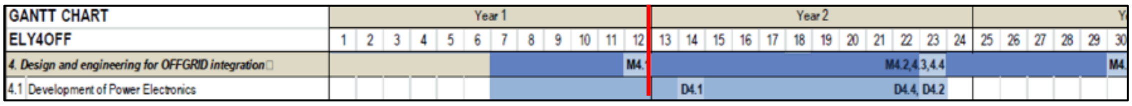


Figure 14: Initial planning regarding power electronics (task 4.1)

<u>Note</u>: the red line represents report D2.7 writing date

Tasks	Starting month	Ending month
4.1: Development of Power Electronics	*7 (November 2016)*	*23 (March 2018)*

Table 21: Task 4.1 starting and ending months

According to information above, task 4.1 should be advanced to approximately 31%. This progress value is evaluated later in this report.

II.3.2 EPIC Power compliance with D2.3

Listed requirements in tables below (from Table 22 to Table 27) were presented by Epic power in report D2.3. The objective of this part is to check, based on EPIC Power evaluation and comments, if proposed specifications are validated and, if relevant, already implemented.

- Input current-voltage characteristics:

Regarding input current-voltage characteristics, it was written in D2.3:

"The strategy of grouping of photovoltaic panels in order to get the Photovoltaic Arrays is still to be defined at WP4, and therefore this specification can be set. Considering that the PE system must be as close as possible to the Stack, the PE system will be far away from the photovoltaic arrays so a high input voltage would be desirable in order to minimize power losses. Therefore, a maximum practical DC voltage around 800V could be a good candidate, being the MPPT voltage around 600V. TO BE DEFINED".

As it was explained previously in this report (cf. section II.1.2), PV panels will be located next to FHA building. The distance between panels and electrolyser is now less important (about 10m) than previously expected (PV panels located on the parking at about 120m from the electrolysis system).

Table 22 below indicates if there is any change due to this modification of distance between PV panels and electrolysis system.

	Distance PV to ELY	PE input voltage
Previous case	~120m	800 V
Current case	~10m	***800 V***
Modification	Yes	***No***

Table 22: Impacts of the modification of PV panels place on PE input voltage

- Output current-voltage characteristics:

Output current-voltage characteristics	Planned value	Planned value confirmation	Comments
Voltage – low power, cold stack	110V to 138V	**Ok**	**/**
Voltage – full power, heated stack	125V	**Ok**	**/**
Current	40A to 450A	**Ok**	**DC/DC converters can be parallelized to achieve any current level**

Table 23: D2.3 output current-voltage characteristics confirmation

- Power electronic converter parameter

Power Electronic Converter Parameter	Planned value	Planned value confirmation	Comments
Conversion Efficiency	Above 90% along all the operating conditions	**Ok**	***Final efficiency will be measured after building first prototypes. Topology and technology have been selected to reach the highest efficiency.***
Volume	2.2m high, 1m width and 0.6m long	**Ok**	**Estimated 173x280x155 mm each 4.8 kW DC/DC converter. 13 converters fit well inside 2x1x0.6m cabinet**
Weight	No limit	**Ok**	**Probably lighter than ON grid system**
Operating ambient temperature (inside the container)	0°C to 50°C	**Ok**	**At higher temperatures the converter still working at derated power**
Storage temperature	-20°C to 50°C	**Ok**	**/**
Standby power consumption	Below 100W	**Ok**	**DC/DC converters only consume from PV panels**

Table 24: D2.3 power electronic converter parameter confirmation

Figures below present illustrations of the DC/DC converter design and DC/DC converters inside the electrical cabinet.

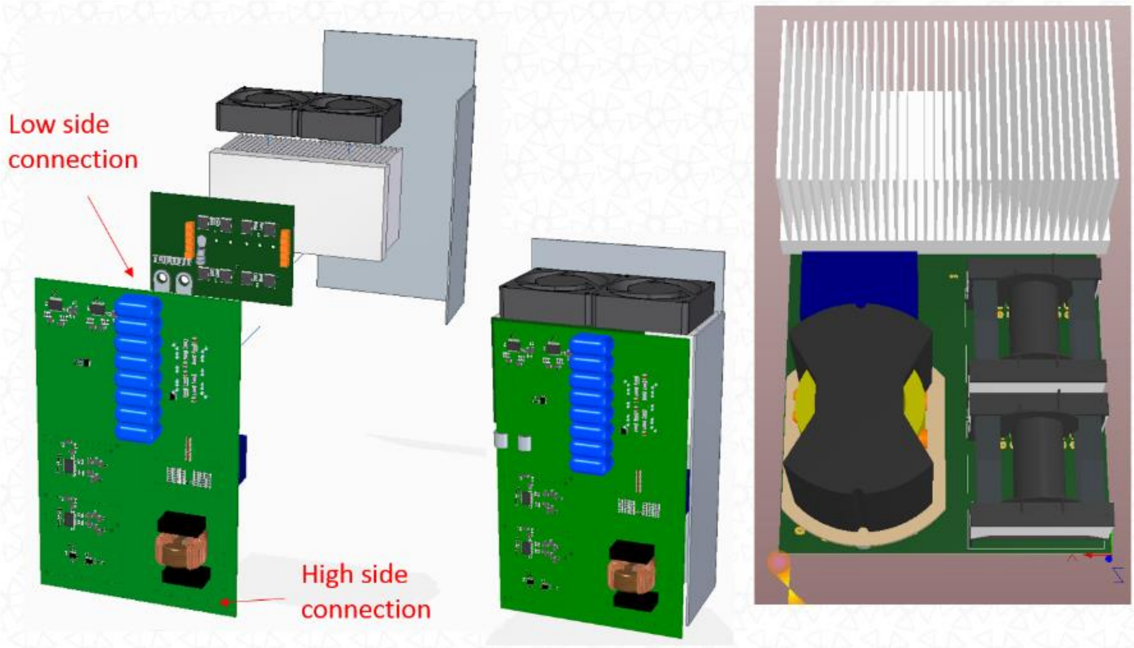


Figure 15: DC/DC converter design

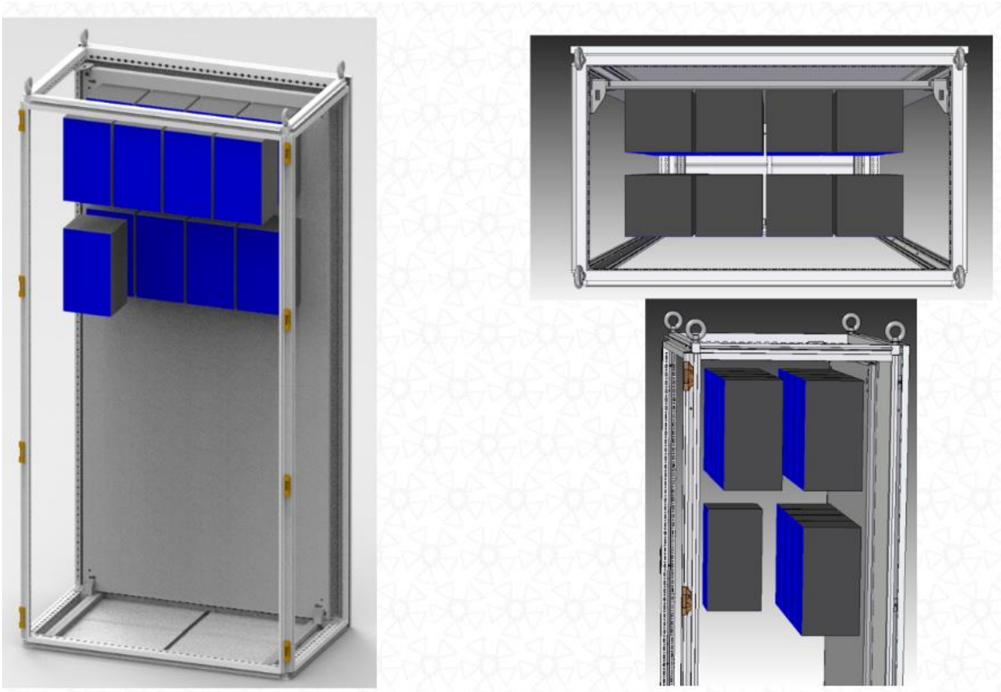


Figure 16: DC/DC converters inside electric cabinet

- Power electronic converter control capabilities

Operation phase	Planned Power Electronic Converter Control Capabilities	Planned capabilities confirmation	Comments
During Standby	Measure voltage at the input terminals	Ok	/
	Communicate the input voltage to the System Control	Ok	
	Receive start-of conversion command from the System Control and start the conversion	Ok	
During Conversion	Perform MPPT algorithm to achieve maximum power conversion from the Photovoltaic Array	Ok	
	When feeding exclusively the battery charger, regulate the output voltage keeping it inside the nominal output voltage range	Ok	
	Monitor input and output voltages and currents and operating temperature	Ok	
	Safely stop conversion and disconnect in case of an internal or external failure	Ok	
	Communicate to the System Control measured variables and operation status	Ok	
	Receive stop of conversion command from the System Control and stop to operate safely	Ok	

Table 25: D2.3 power electronic converter control capabilities confirmation

- Power electronic converter communication:

Communication direction	Power Electronic Converter Communications	Planned communications confirmation	Comments
Transmitted	Input voltage	Ok	/
	Input current	Ok	
	Output voltage	Ok	
	Output current	Ok	
	Temperature of the Power Electronic Unit	Ok	
	If failure, failure and type of failure	Ok	
Received	Start of conversion: stack feeding mode	Ok	
	Start of conversion: voltage regulation mode (when feeding only the battery charger)	Ok	
	Stop of conversion	Ok	

Table 26: D2.3 power electronic converter communication confirmation

- Power electronic converter desirable requirements

Type of requirements	Power Electronic Converter Desirable Requirements	Planned requirements confirmation	Comments
Redundancy	It should be desirable to design a conversion topology in such a way that operation is assured in the case: • One or several photovoltaic panels fails • One or several parts of the power electronic unit fails • One or several of the power or communication connections or conductors are broken	**Ok**	**Strings and DC/DC converters in parallel provides fully redundancy.**
Galvanic isolation	A careful study of the RCS at European level is required to state if the galvanic isolation is mandatory or not. Anyway, it should be almost mandatory, as it provides high level of safety in the case of hazardous failures, which is desirable considering that the system is dealing with hydrogen.	**Ok**	**DC/DC converters will be galvanic isolated. EN 62109-1 requires 2.5 kV of withstand voltage between PV and stack.**

Table 27: D2.3 power electronic converter desirable requirements confirmation

Any other topics: **None**

II.3.3 EPIC Power tasks progress indicators

Table 28 below was filled by EPIC Power in order to estimate their progress on the 4.1 task.

Tasks	Initial planning	Estimated real progress	Risks analysis			Comments
			Compliance with Gantt	Expected evolution	Compliance with D2.3	
4.1	31%	**40%**	**Yes**		**Yes**	**None**

Table 28: EPIC Power progress in task 4.1

II.4 Control and Communication System by Inycom

Regarding Inycom development tasks, the main challenge consists in the design of new control strategies able to operate in an off-grid system, optimized for normal, safe and efficient operation. This C&CS will be in the highest control layer and will oversee the general installation, including every subsystem implied in the ELY4OFF design.

II.4.1 Inycom initial planning

As shown by Table 29 below from the Grant agreement [1], Inycom is in charge of the development of C&CS required for ELY4OFF project though the task 4.2.

GANTT CHART	Year 1												Year 2												Ye					
ELY4OFF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
4. Design and engineering for OFFGRID integration												M4.1										M4.2,4.3,4.4								M4.5
4.2 Overarching C&CS system														D4.1								D4.5, D4.2								

Table 29: Initial planning regarding C&CS (task 4.2)

<u>Note</u>: the red line represents report D2.7 writing date

Tasks	Starting month	Ending month
4.2: Overarching C&CS system	*7 (November 2016)*	*23 (March 2018)*

Table 30: Task 4.2 starting and ending months

According to information above, tasks 4.2 should be advanced to approximately 31%. This value is checked later in this report.

II.4.2 Inycom compliance with D2.3

Requirements provided in Table 31 below were presented by Inycom in report D2.3, in order to design a robust, efficient and secure C&CS able to operate an integrated off-grid system with several technologies (PV, power electronics and auxiliary systems).

The objective of the following table is to evaluate if these requirements are confirmed and possibly already implemented.

C&CS capabilities	Planned capabilities confirmation	Comments
Communicate with the different subsystems of the general installation (PV, PEMWE, HSS, power electronics, etc.)	**In progress**	**Deliverable 4.1 is compiling the information and delivered on 31th May 2017.** **EPIC POWER: agreed on I/O signals, naming missing. Protocol: agreed. Finished: imminent (in conversations with Logan/Ruben).** **ITM: agreed on signals, naming and explanation of received signals**

		missing, details on standby mode missing. Protocol: agreed. Finished: 28th April 2017 (in conversations with Helio). FHA: agreement on signals I/O signals missing due to the lack of in field instrumentation. FHA is progressing in this field and will report advances to INYCOM by 25th April 2017 (in conversations with Pedro/Lorién). INYCOM: with the information above, elaboration of specifications including the hardware required to accompany the PLC to order components and developing the control logic for the overarching C&CS
Allow remote monitoring, data capture and analysis	Missing	Agreement needed first on the I/O signals for the PLC (see above)
Keep the system in safe mode above the minimum safe temperature, ensuring energy supply to the PLC and the pump and trace heating	Missing	Explanation on signals received from ITM needed (see above);
Consider PEMWE parameters of dynamic response, system efficiency and safety criteria	Missing	In conversations with ITM to modify the overarching control logic considering a standby mode for high voltage/current excursions at DC/DC output
Anticipate (via predictive algorithms, forecasting, and inputs from the different subsystems) all minor boundary conditions modifications considering weather forecasting, fault diagnosis, etc.	Missing	Agreement needed on the I/O signals for the PLC (see above)
Respond perfectly to any unexpected problem or failure that may arise, taking appropriate measures in each case, looking for maximizing hydrogen generation	Missing	To be implemented in the control programming after control logic agreed

and ensuring overall autonomy of the system		

Table 31: C&CS capabilities from D2.3 confirmation

Any other topics: **The development of the overarching C&CS is highly dependent on progress with the on-site equipment from FHA, ITM and EPIC power. Thus, considerable advances are expected in the following months.**

To ensure a proper functioning of the C&CS, some necessary additional elements were identified to be part of the demonstration system. These elements are shown on the Figure 17 below.

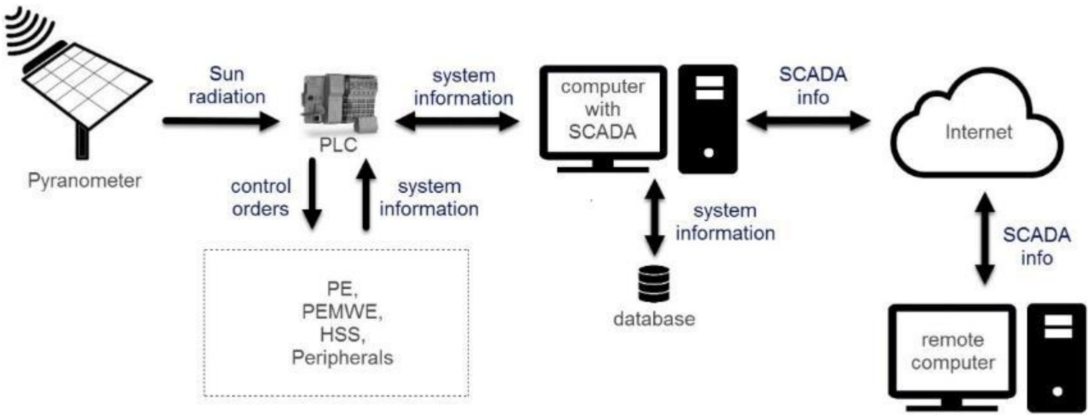


Figure 17: Additional elements for C&CS

The objective of the following table (Table 32) is to verify if these additional elements are confirmed and, if relevant, already available.

Information from D2.3			Precision in D2.7 (from Inycom)
Additional elements for C&CS	**Function**	**Model**	**Evolution**
Pyranometer	Measure solar panel radiation and send it to C&CS	Secondary Standard ISO Rating Pyranometer	**FHA is selecting a pyranometer and will report to INYCOM on the chosen one**
PLC (Programmable Logic Controller)	Monitor and interact with the rest of the system elements	Phoenix Contact ILC 191 ETH 2TX	**Already selected and definitive. The modules for I/O analogic and digital signals will be determined once it is agreed on the signals sent/received by each piece of equipment and once protocols are needed.**
CPU (Central Processing Unit)	Ensure PLC operation	ILC 191	

Computer with UPS	Monitor the system and avoid sudden loss of control, communicate with external weather station	/	**Easy to acquire, commercial equipment available.**
Supervisory Control and Data Acquisition (SCADA)	Monitor and control the system information and its components	Created by Visu2+ from Phoenix Contact or similar software	**Upcoming**

Table 32: Additional elements for C&CS presented in D2.3 confirmation

Any other topics: **The definitive selection of the instrumentation for the HSS by FHA is critical for INYCOM to know how to communicate with all the equipment. This step is to be concluded by 28th April 2017.**

II.4.3 Inycom tasks progress indicators

Table 33 below was filled by Inycom in order to estimate current progress of the 4.2 task.

Tasks	**Initial planning**	**Estimated real progress**	**Risks analysis**			**Comments**
			Compliance with Gantt	Expected evolution	Compliance with D2.3	
4.2	31%	**10%**	**Yes** Because progress on this task is not linear (cf. comments)		**Yes**	The real progress is clearly below the expected one because task 4.2 is not linear in terms of advances. As partners have to agree on signals and information sent/received by the overarching C&CS, the protocols and the logic of operation (objective of D4.1, 31st May 2017), the progress is right now in standby. The delivery of D4.1 will allow INYCOM to have clear: - The control logic - The PLC hardware. That will lead to: -Start programming the PLC - Start the design of the SCADA - Performing ex-situ testing ***COMPLIANCE WITH GANTT:*** No deliverables delayed, D4.1 expected to be in time (advanced draft version available, delivery on 31st March 2017) ***EXPECTED EVOLUTION:*** Satisfactory due to the feelings in Sheffield: partners committed to send information for D4.1.

Table 33: Inycom progress in task 4.2

III. System model development and validation

The second objective of this report is to present the computer model of the system that was developed during the first months of project. In the framework of the Hybrid Storage System (HSS) sizing (task 2.2), ELY4OFF system was modelled on the software Odyssey, an energy simulation software developed by CEA. This model is presented in the following paragraph.

The objectives of the present section are (i) to detail the system computer model, with its different components and parameters, and (ii) to run some simulations using this model in 2 different locations (not Huesca which was used for the HSS sizing as it is the demonstration location) and for 2 different hydrogen loads in order to confirm that a model of the system is available and operational.

Note 1: Please refer to report D2.3 to know how the HSS was sized.

Note 2: Simulations were realized using sizing parameters validated for the demonstration site in Huesca. Work presented here must be seen as an illustration of the capacities of the model and the simulation tool; no optimization of the system is proposed for the simulated scenarios.

III.1 Methodology to create the model

Model development and simulations were realized using the software ODYSSEY, developed by CEA. This software allows modelling the system as considered in the project, by assembling together the different required components of the system (electrolyser, fuel cell, auxiliaries, hydrogen storage, battery, PV panels …). The software is described in Appendix 2. Parameters used to represent each component of the system model are detailed in the next paragraphs.

Simulations are done over one year, beginning on June the 1st, with a 10 minutes time steps.

To allow simulations with ODYSSEY, the following methodology is applied to develop the ELY4OFF system model:

- Assembly of the different components ;
- Setting of the parameters of each technologies in order to be as close to reality as possible ;
- Setting of the operational strategy of the system ;
- Setting of time series required for input.

In the next sections these four main steps are described.

III.2 Modelling of ELY4OFF system on ODYSSEY

In this section, the model is detailed and required time series for simulation are described. Later, simulation are realized and results are analyzed, in order to verify that the model is operational, and illustrate the possibility to simulate different locations or hydrogen loads.

III.2.1 Components assembly

In order to create the ELY4OFF system on ODYSSEY, components or sub-sytems are assembled together as presented on Figure 18 below.

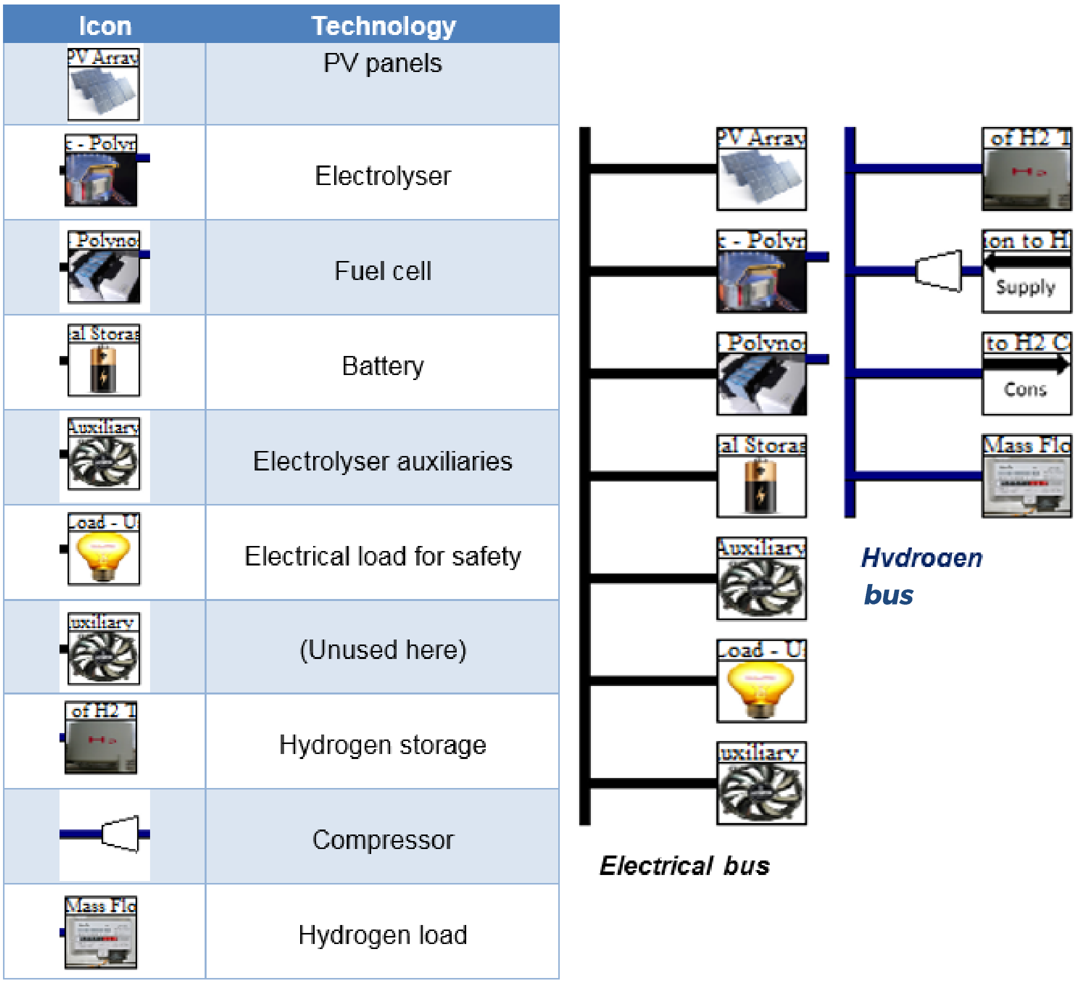


Figure 18: ELY4OFF project on ODYSSEY

<u>Notes</u>:

- the hydrogen supply component corresponds to the link between the electrolysis and the hydrogen bus ;
- the hydrogen consumption component corresponds to the link between the hydrogen bus and the fuel cell.

This is the architecture used for simulations. In the next part the main parameters to model each component are presented.

III.2.2 Components model and technical parameters

For each component, a model has to be defined and several parameters have to be set. In Table 34 below are exposed the selected model for each component.

Component	Model	Comment
PV panel	Time series obtained from http://pvwatts.nrel.gov/ with the technical parameter presented in next table	/
Electrolyser	Constant efficiency n = 0.53 (LHV)	Efficiency of the electrolyser in nominal operation, provided by ITM
Fuel cell	Constant efficiency n = 0.6	Generic fuel cell efficiency
Batteries	Constant efficiency in charge and discharge	/
Electrolyser BoP	Consumption = 0.3*stack consumption	ITM
Electrical load	Time series defined as equal to 400W+x*3000W, x depending on temperature and hours of the day	FHA
Hydrogen storage	Pressured tank	FHA
Hydrogen load	Time series defined by user	/

Table 34: Components models

Components main parameters, their values and their justifications are sum up in Table 35 below.

<table>
<tr><th>Component</th><th>Main Parameters</th><th>Value and Unit</th><th>Justification</th></tr>
<tr><td rowspan="3">PV</td><td>PV panels DC peak power</td><td>60 kWp</td><td>Maximum the project can afford</td></tr>
<tr><td>Azimuth</td><td>180° (= direction South)</td><td>FHA</td></tr>
<tr><td>Degree of inclination</td><td>20°</td><td></td></tr>
<tr><td rowspan="4">Electrolyser</td><td>Electrolyser efficiency</td><td>62 kWh/kg (constant)</td><td>ITM</td></tr>
<tr><td>Electrolyser max power</td><td>50 kW</td><td>ITM</td></tr>
<tr><td>Electrolyser min power</td><td>1 kW</td><td>ITM</td></tr>
<tr><td>Nominal operating pressure</td><td>20 bar</td><td>ITM</td></tr>
<tr><td>Electrolyser auxiliaries</td><td>Electrolyser BoP consumption</td><td>30% of the stack</td><td>ITM</td></tr>
<tr><td rowspan="4">Fuel cell</td><td>Fuel cell max power</td><td>4,5 kW</td><td>FHA[1]</td></tr>
<tr><td>Fuel cell efficiency</td><td>0,05 kgH2/kWh</td><td>Generic</td></tr>
<tr><td>Fuel cell starting operation[2]</td><td>0,3 battery State of Charge (SOC)</td><td>CEA TECH hypothesis</td></tr>
<tr><td>Fuel cell stopping operation[2]</td><td>0,4 battery SOC</td><td>CEA TECH hypothesis</td></tr>
<tr><td rowspan="3">Battery</td><td>Capacity of the batteries</td><td>30 kWh</td><td>FHA[3]</td></tr>
<tr><td>Cycle efficiency</td><td>0.75</td><td>Literature</td></tr>
<tr><td>Minimal SOC</td><td>0.2</td><td>Literature</td></tr>
<tr><td rowspan="4">Hydrogen storage</td><td>H2 Storage Volume</td><td>10 kg</td><td>FHA from D2.3 (minimal value required for safety purpose)</td></tr>
<tr><td>Maximum mass flow rate of H2 storage</td><td>10 kg/h</td><td>Generic</td></tr>
<tr><td>Initial Pressure</td><td>10 bar</td><td>FHA rack</td></tr>
<tr><td>Maximal Pressure</td><td>350 bar</td><td>FHA rack</td></tr>
<tr><td>Compressor</td><td>Efficiency</td><td>0.72</td><td>Generic</td></tr>
</table>

[1] *After an evaluation of different values of FC power and his influence on the consumption, 4.5 kW have*

been chosen as parameter for further studies because of a better behaviour than smaller Fuel Cells and because FHA has it already in the demo site.

[2] The fuel cell starts and stops depending on the SOC of the battery. When the battery SOC reach 0.3 and if electricity is required, the FC starts. Once the battery loaded to a SOC equal to 0.4, the FC stops.

[3] A value of 30 kWh will be used as initial value (it covers the backup of the system for 2 days in summer, and half day in winter)

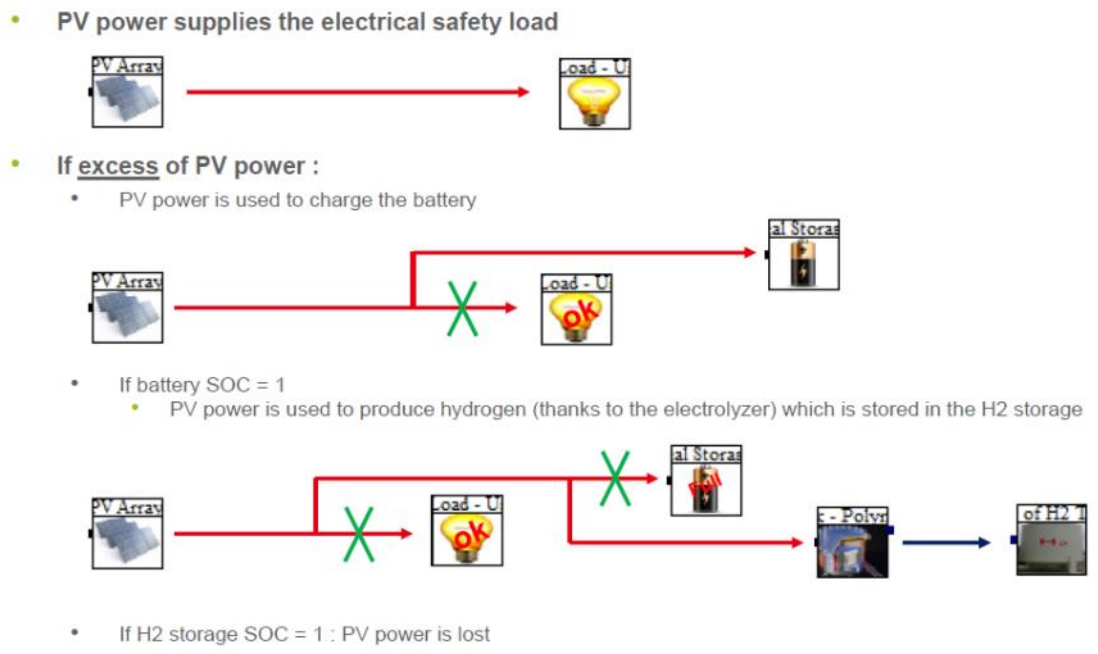
Table 35. Technologies main parameters

The efficiency of converter is not taken into account (it is very high as informed by EPIC).

III.2.3 Operating strategy defined in ODYSSEY

For each simulation time-step, the basic rule for ODYSSEY is to ensure the balance between available and consumed electricity power and the balance between available and required hydrogen load. The operating strategy of the represented energy system is defined through priorities of use for available electricity and hydrogen. As an example, for each time step, "excess" of "deficit" of electricity is determined by comparing the available power and the electrical load to provide. If there is electricity excess, this excess can be stored. In case of electricity deficit, priorities must also be set in: the user can define which storage resource will be used first in order to provide the load. When empty (or at a defined minimum State of Charge (SOC)), the second storage component can provide power to the electrical load.

In the case of ELY4OFF simulations handled in this document, the specified strategy and the associated rules of operation in case of excess or deficit of energy are illustrated on Figure 19.



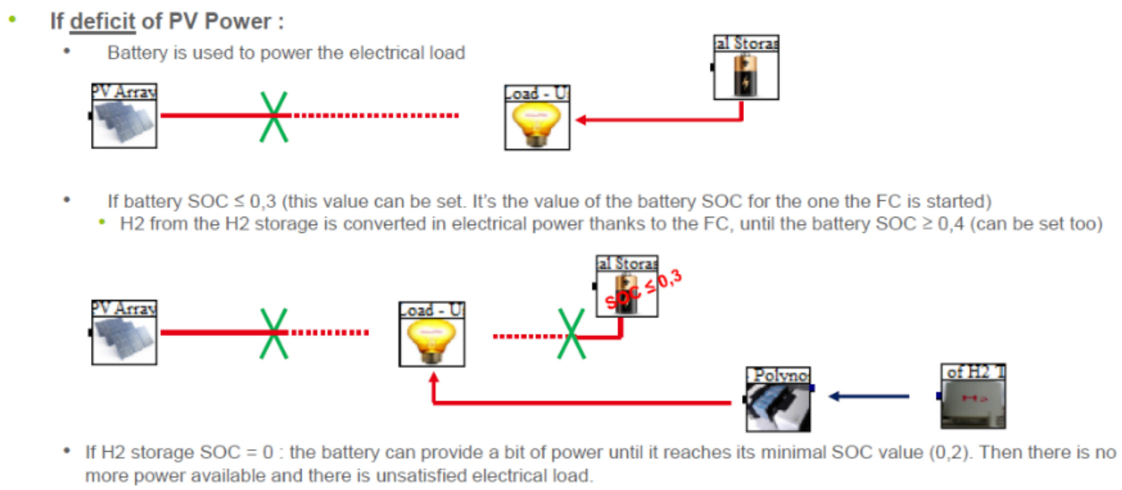


Figure 19: Strategy used in ODYSSEY for simulations

The different time series required for both loads (electrical and hydrogen) and the PV production are described in the next section.

III.2.4Time series

Some components require time series to set values of consumption or production over the year for each time step. In ELY4OFF project, components set with a time series are presented in Table 36.

Simulations are done over one year, with a 10 minutes time step.

Technology	Time series function	Time series unit
PV panels	PV panels production all year long	[W]
Electrical load for safety	Electrical consumption over the year for safety issues	[W]
Hydrogen load	Hydrogen to deliver for a specific use	[kg/h]

Table 36: Time series used for ELY4OFF simulations

Each of these time series are described in the following sections.

III.2.4.1 PV panels – Electricity production time series

PV panels are the only source of power generation considered for the system in this study. It converts solar radiations into electricity. Obviously, power generation based on PV panels, for a given maximal peak power, depends on the location. For these simulations, two different places which could be relevant for an ELY4OFF system were selected: the Spanish city of Santa Cruz de Tenerife in Canaries Islands (Figure

20), and the Italian mountain station city of Paganella in the Alps (Figure 21). Indeed, these places benefit from an interesting solar resource potential (especially in Tenerife) and may present some isolated sites with difficult access to electrical grid.

Figure 20: Santa Cruz de Tenerife

Figure 21: Paganella

Once validated where the system would be tested through simulations, it is now possible to define electrical production time series. Time series were obtained from the website http://pvwatts.nrel.gov/.

Hypothesis for PV panels production determination for each site were the following:

- Prediction of system's average monthly and annual output over a 25-year system life
- PV panels DC peak power: 60kW
- Azimuth: 180° (= direction South)
- Degree of inclination: 20°

Generated PV productions profiles for both cities, over 1 year and beginning on June the 1st, are presented on Figure 22.

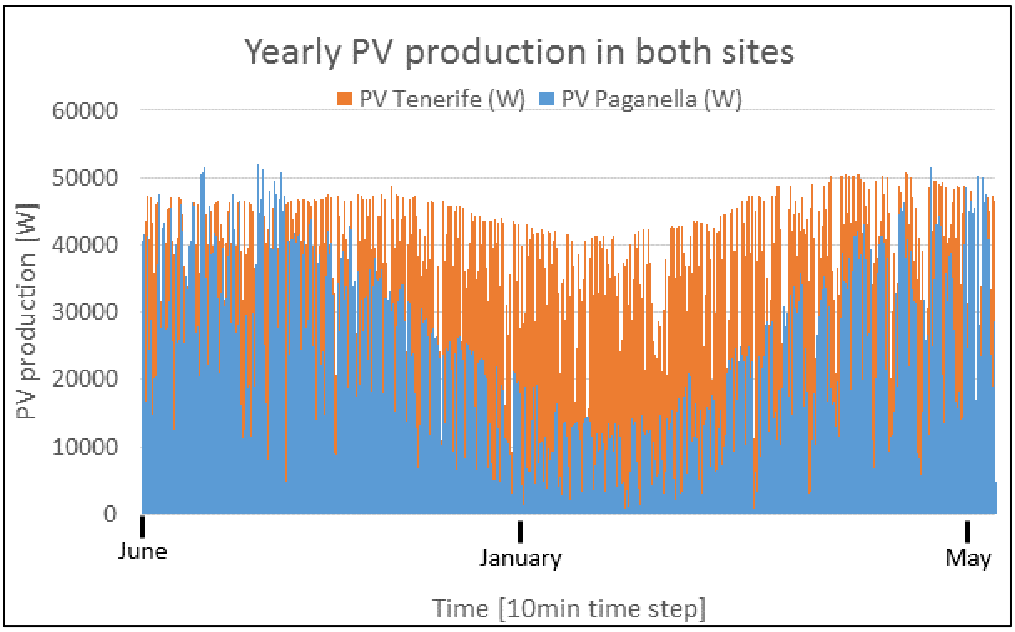


Figure 22: Yearly PV production in both sites

As shown on the graphic, the maximal value of PV production is quite similar on both sites (in Paganella and in Tenerife). However, Tenerife profile is much more constant over the year. Table 37 below gives main recap values of these 2 PV productions over a year.

	Tenerife	Paganella
Total energy production [MWh] per year	105.28	63.17
Power average [kW]	12.02	7.21
Peak value [kW]	50.69	51.97

Table 37: Recap values of PV production in both sites

III.2.4.2 Electrical load to ensure system safety

The system is considered in an off-grid situation and connected to an intermittent renewable energy source (PV panels), which means that it does not have an access to a continuous energy source. The electrical load to ensure safety corresponds to the electrical load required by the system at any time in order to ensure the installations safe operation. Electrical load is required by auxiliaries ensuring the following functions:

- Control of the system: associated load is necessary to ensure the correct management of the system. The consumption is 400 W at any time.
- Heating of the system: associated load is necessary for the electrolyser to be maintained at an acceptable temperature, in order to avoid freezing problems. Depending on the ambient temperature, heaters will have to operate or not. The peak consumption is 2650 W at freezing temperatures, and this value will decrease as the temperature increases.

The time series of the electrical load for safety are built according to hypothesis presented above. As in Tenerife, temperatures are high all year long (average always >15°C, Figure 23), it is considered that heating is not necessary. The electrical load is then equal to 400W constant all year long. Regarding Paganella, temperature can be very low, as shown on Figure 23 below.

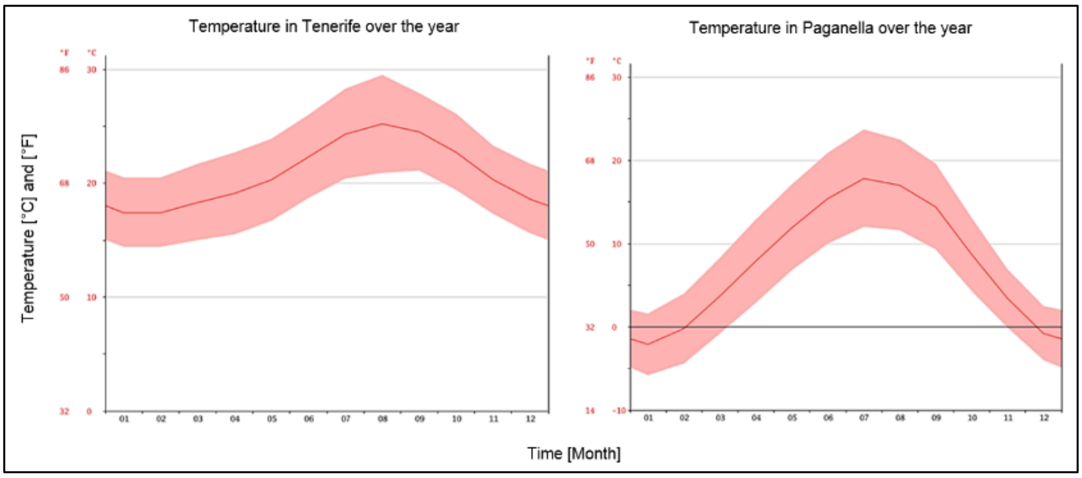


Figure 23: Yearly average temperature in both sites

The electrical load for system safety is built based on hourly temperature obtained on http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#. However, only 1 day is available by month. That is the reason why the same day is applied for a given month.

Figure 24 below shows the evolution of the electrical load in Paganella all year long. Please remind that Tenerife's electrical load is equal to 400W constant all year long.

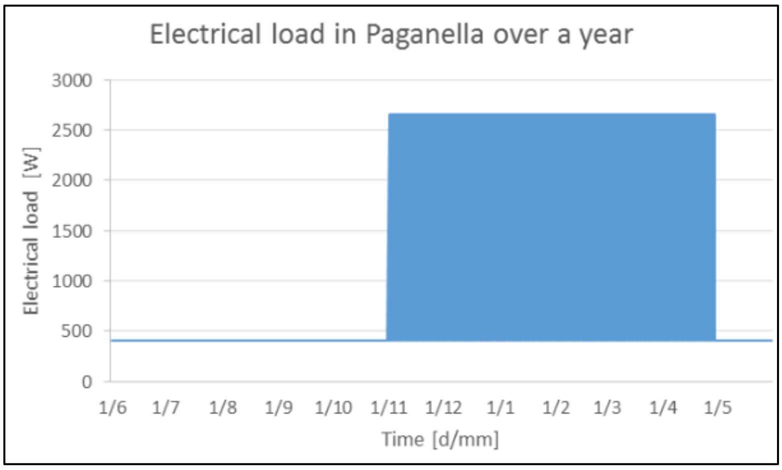


Figure 24: Electrical load all year long in Paganella

Table 38 below gives main recap values of these 2 electrical loads over a year.

	Tenerife	Paganella
Total energy consumed [MWh]	3.50	8.93
Power average [kW]	400	1019.86
Peak value [kW]	400	2650

Table 38: Recap values of electrical loads in both sites

III.2.4.3 Hydrogen load

According to the proposal of the ELY4OFF project, possible applications of the hydrogen for the demonstration site could be the following ones:

- Mobility for FCEVs and transport applications: 1,5 -2 kg/day
- Cogeneration system for heating and electricity supply to FHA building: 0,4 – 0,6 kg/day
- Backup system for computer server in FHA building: 0,2 kg/day

In the framework of this report, in order to validate the utilization of the model, two types of hydrogen loads, inspired from the proposal of the project, are studied:

1. <u>Mobility for FCEVs and transport application</u> with peak consumption from April to October included defined as following:

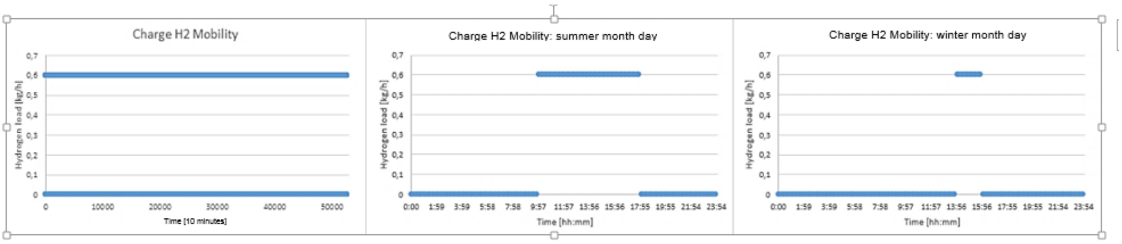
Period	Hydrogen load
From November to March included	1.2 kg/day (0.6kg/h during 2h from 2 to 4pm)
From April to October included	4.8 kg/day (0.6kg/h during 8h from 10am to 6pm)

Table 39: Mobility hydrogen load

Loads are defined arbitrarily, only based on hydrogen amount exposed in the proposal of the project. The hydrogen load to supply is set as more important in summer months as more PV power production is expected.

<u>Note</u>: Mobility hydrogen load is higher than ones from proposal of the project as the system is simulated on quite sunny places (especially Tenerife), and because the objective of this report is to illustrate that the model can contribute to the identification of unmet hydrogen load occurrence.

Figure 25 below illustrates the hydrogen load (i) over one year, (ii) during a summer month day and (iii) during a winter month day.



Time [10

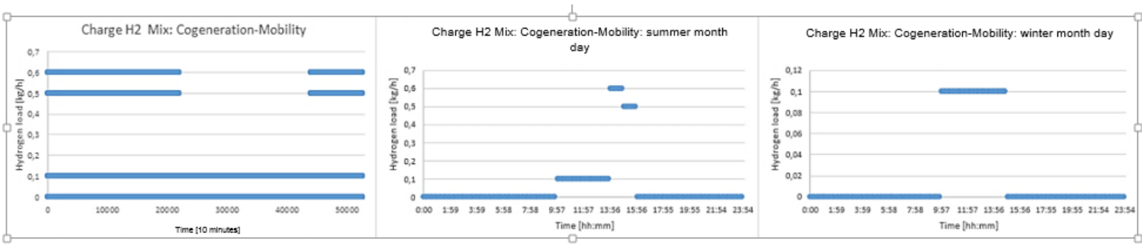
Figure 25: Mobility hydrogen load

2. Cogeneration system for heating and electricity supply to a building as the one of FHA (could be a tourist office for example) all year long **with an additional mobility load summer months** (as more PV production is expected during these months), defined as following (and based on the proposal of the project):

Period	Hydrogen load
From November to March included	0.5 kg/day (0.1kg/h during 5h from 10am to 3pm for cogeneration)
From April to October included	1.7 kg/day (0.1kg/h during 5h from 10am to 3pm for cogeneration + 0.5kg/h during 2h from 2pm to 4pm for mobility)

Table 40: Hydrogen load mixing cogeneration and mobility

Figure 26 below gives a view on the year, of a summer month day and a winter month day.



Time [10

Figure 26: Mix hydrogen load: mobility and cogeneration

Note: The cogeneration load is only represented by the associated demand. In the next section, when "*electrical load*" is mentioned, it refers to the load required by the ELY4OFF system to ensure safe operation

These two hydrogen loads were used for simulations. Simulation results are presented in next sections of this report.

III.3 Use of the model through 4 simulations scenarios

In this section simulation results and analysis are presented. The four following scenarios results are detailed:

i. Tenerife: mobility hydrogen load
ii. Tenerife: mix hydrogen load: mobility and cogeneration
iii. Paganella: mobility hydrogen load
iv. Paganella: mix hydrogen load: mobility and cogeneration

III.3.1 Tenerife: mobility hydrogen load

Main calculated indicators for this simulation case are given in Table 41 below.

Main indicators		Value	Unit
PV	Maximal possible production	105.28	MWh
	Used production	84.21	MWh
	Percentage of use	80	%
Electrical load	Total	3.504	MWh
	Percentage of satisfaction	100	%
Hydrogen load	Total	1208.4	kg
	Percentage of satisfaction	80.6	%
Electrolyser	Hydrogen production	974.069	kg
Fuel cell	Electricity production	0	MWh

Table 41: Main indicators for the case of Tenerife - Hydrogen load for mobility

As shown in the previous table, 80% of the electricity that could be produced with the PV panels is used. The electrical load is totally satisfied in this case, and without using the fuel cell: indeed, as no heating of the system is required in Tenerife (as explained in the previous section), the electrical load to ensure is quite low (400W constant) and batteries of the defined capacity (30kWh) are sufficient. The 2 graphics below show the repartition of the PV production uses and the how the electrical load is supplied.

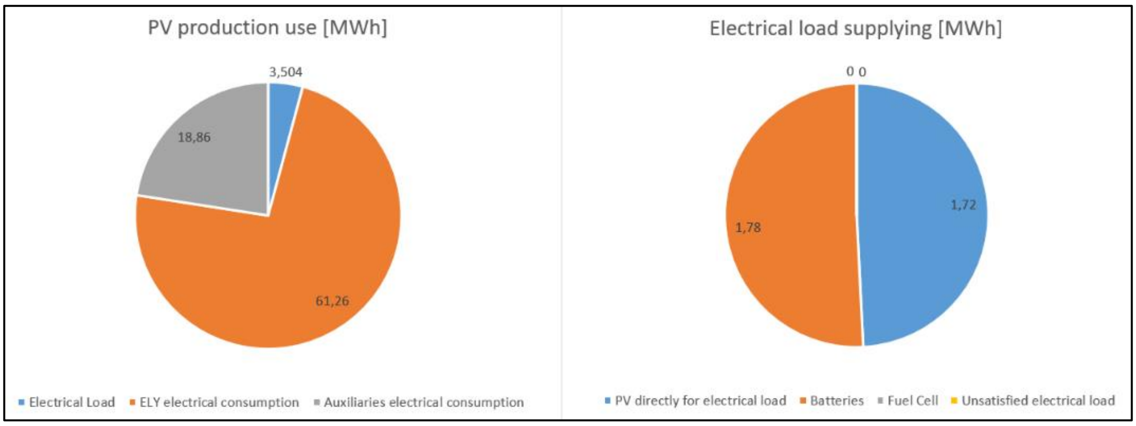


Figure 27: On left side, the repartition of the PV production. On right side, the repartition of the electrical load supply

On the left side figure, it is shown that the electrolyser and the auxiliaries (electrolyser auxiliaries and compressor) represent a major part of the PV power consumption. This is a good indicator to say that Tenerife is obviously a relevant place to run this system, as the part of electrical consumption for safety is low (especially for heating). It allows using an important quantity of PV production to produce hydrogen, which is of course the purpose of the installation.

Regarding the hydrogen load, it is satisfied at 80.6%. The 2 graphics below allow to understand the periods when hydrogen load is not satisfied. It illustrates on the left side the unsatisfied hydrogen mass all year long in [kg]. On the right side is displayed the hydrogen storage SOC (State Of Charge).

Note: please remind the simulation starts in June. Furthermore, the load is different between November to March than between April to October. Please refer to previous Table 39 to check the corresponding hydrogen load.

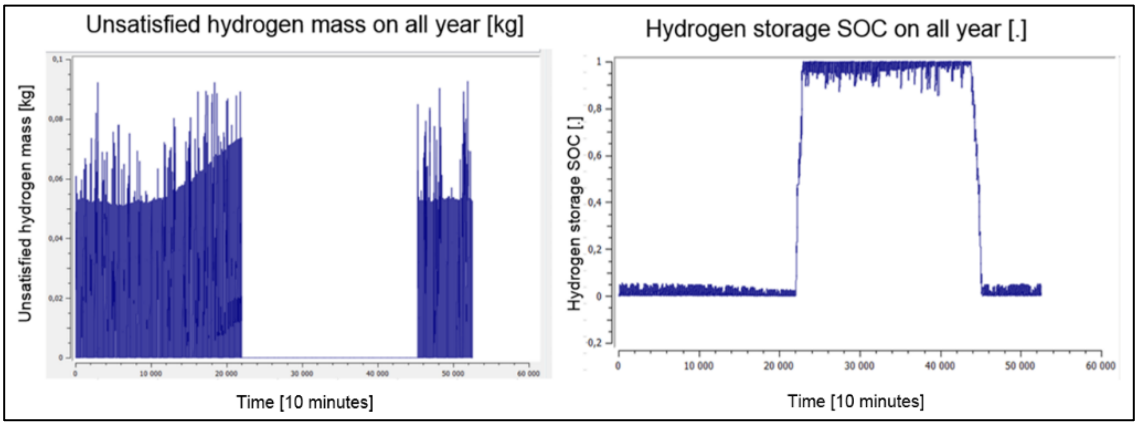


Figure 28: On left side, the unsatisfied hydrogen mass on all year. On right side, the hydrogen storage SOC evolution on all year.

These graphics show that the hydrogen load during winter months (from November to March included) is satisfied. The hydrogen storage is often full (SOC = 1) which means that the electrolyser production is almost sufficient to provide the load without using the hydrogen storage. However, this is not the case in summer (from April to October included): the hydrogen load is more important than in winter (multiplied by 4) which leads to unsatisfied hydrogen mass. The hydrogen storage cannot fill and its SOC is often close to 0.

Several indicators evolutions during a day of a summer month are presented on Figure 29 below to understand why the hydrogen load is not satisfied.

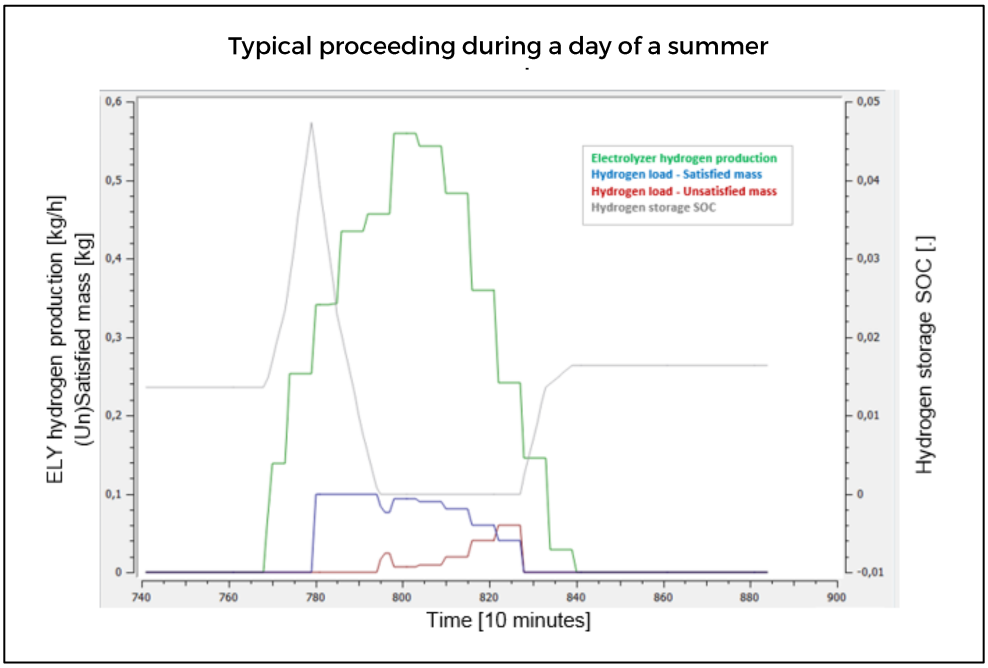


Figure 29: Typical proceeding during a day of a summer month

According to the graphic, the proceeding during a day of a summer month is the following:

- When the electrolyser starts producing hydrogen, this one is stored in the tank as the hydrogen load is equal to zero.
- When the hydrogen load begins, the electrolyser doesn't produce enough hydrogen to supply the load. That explains why the hydrogen stored previously is used in order to supply the load (the SOC is lowing).
- When the hydrogen storage is empty (SOC = 0), even if the electrolyser hydrogen production has raised (thanks to a better solar radiation as the day is progressing and the load begins at 10am), it is not producing enough to satisfy the load.

From November to March, the hydrogen load is less important as it was defined taking into account that less PV production is expected due to less sunlight. However, in Tenerife, this load is very easy to provide by the system, as it is shown by the fact that the hydrogen storage SOC keeps close to 1 in winter (SOC > 0.8, Figure 28 right side).

III.3.2 Tenerife: mix hydrogen load: mobility and cogeneration

Main calculated indicators for this simulation case are given in Table 42 below.

Main indicators		Value	Unit
PV	Maximal possible production	105.28	MWh
	Used production	38.12	MWh
	Percentage of use	36.2	%
Electrical load	Total	3.504	MWh
	Percentage of satisfaction	100	%
Hydrogen load	Total	396.5	kg
	Percentage of satisfaction	100	%
Electrolyser	Hydrogen production	405.35	kg
Fuel cell	Electricity production	0	MWh

Table 42: Main indicators for the case of Tenerife - Mix hydrogen load

As shown in the table, only 36.2% of the electricity that is possible to produce with the PV panels is used. As with the previous case in Tenerife, the electrical load is totally satisfied and without using the fuel cell: indeed, as no heating of the system is required in Tenerife (as explained in the previous section), the electrical load to ensure is quite low (400W constant) and batteries are sufficient. The 2 graphics below show the repartition of the PV production uses and the how the electrical load is supplied.

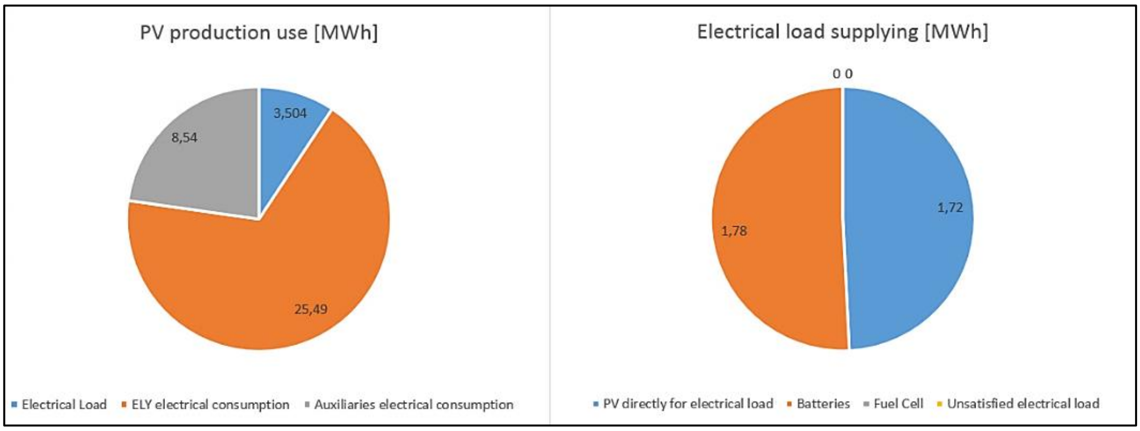


Figure 30: On left side, the repartition of the PV production. On right side, the repartition of the electrical load supply

The same remarks as the ones for the previous Tenerife scenario can be made. The electrolyser and the auxiliaries (electrolyser auxiliaries and compressor) represent a huge proportion of the PV consumption.

Regarding the hydrogen load, it is satisfied at 100%. The graphic below shows the hydrogen storage SOC during all year long.

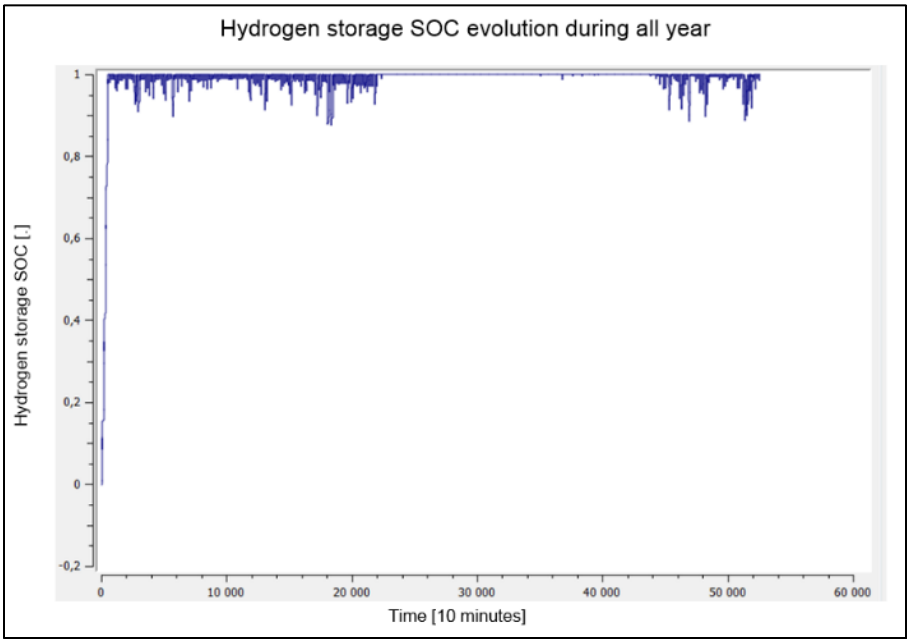


Figure 31: Hydrogen storage SOC evolution during all year long

As it is shown on figure above, the hydrogen storage SOC remains very high all year long (SOC > 0.9). It indicates that the system is probably oversized for this hydrogen load in this location, and it would require optimization of its components to better fit with the hydrogen load. This work could be done with Odyssey as the system model is now operational. It was not realized in this work as the purpose is only to illustrate the capability of the model.

III.3.3 Paganella: Mobility hydrogen load

Main calculated indicators for this simulation scenario are given in Table 43 below.

Main indicators		Value	Unit
PV	Maximal possible production	63.16	MWh
	Used production	63.05	MWh
	Percentage of use	99.8	%
Electrical load	Total	8.93	MWh
	Percentage of satisfaction	79.5	%
Hydrogen load	Total	1208.4	kg
	Percentage of satisfaction	53.9	%
Electrolyser	Hydrogen production	670.9	kg
Fuel cell	Electricity production	0.38	MWh

Table 43: Main indicators for the case of Paganella - Hydrogen load for mobility

As shown in the table, almost all the PV power that could be produced with PV panels is used (99.8%). However, the electrical load is not totally satisfied in this case despite the use of hydrogen to produce electricity thanks to the fuel cell. The 2 graphics below show the repartition of the PV production uses and how the electrical load is supplied.

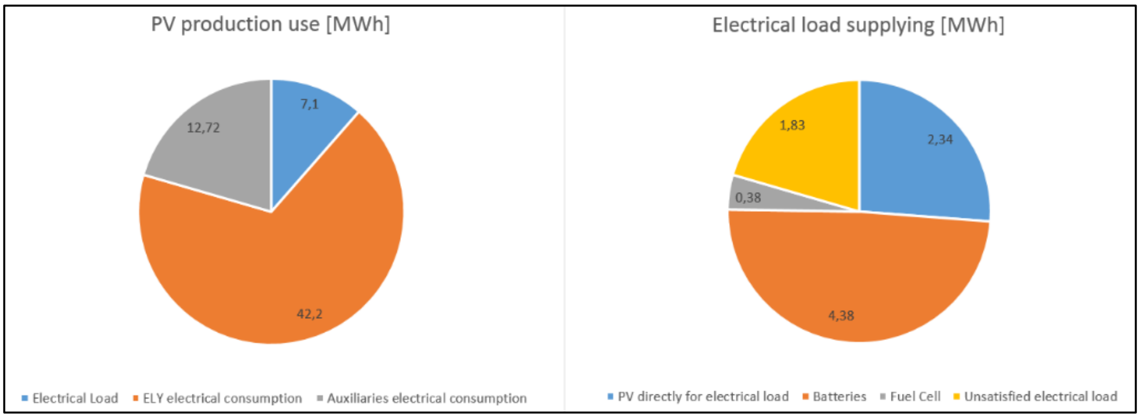


Figure 32: On left side, the repartition of the PV production. On right side, the repartition of the electrical load supply

As shown by the left side graph, most part of the electrical consumption is used to produce hydrogen. However, the system cannot satisfy the system electrical load in winter (Figure 33). This is due to the low PV production occurring in this season and also because the defined hydrogen load is too important for the defined system with the set parameters in this location. The hydrogen load doesn't allow to fill the hydrogen tank in summer in order to use it in winter to satisfy the electrical load. A good indicator of that is that the PV production percentage of use, almost equal to 100%, which indicates that the system is already operating using all the PV resource available.

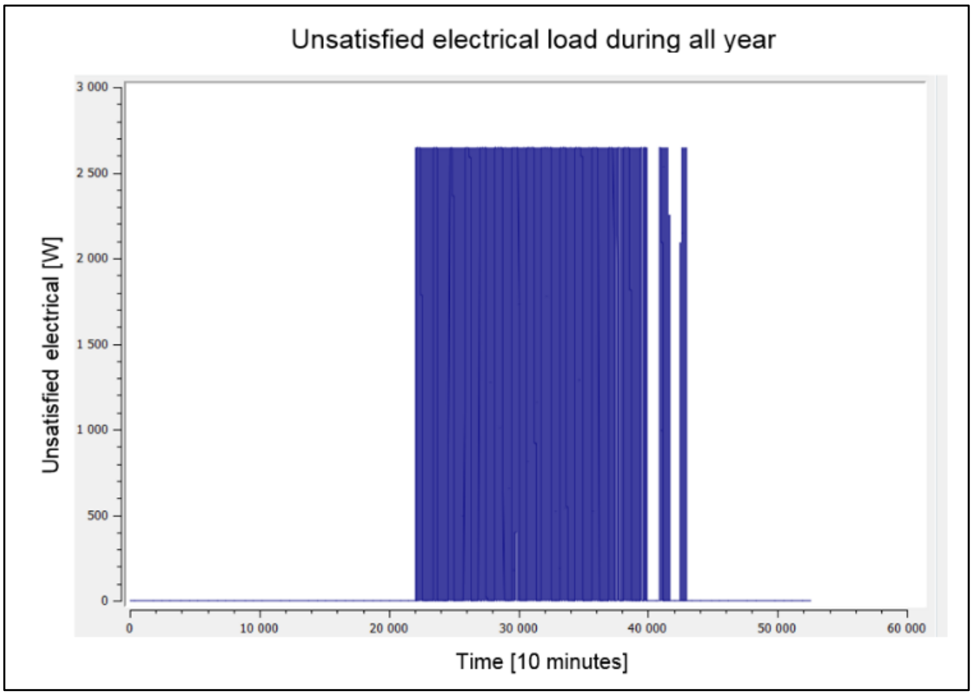


Figure 33: The system cannot supply the electrical load during winter months

A typical day of winter is detailed below thanks to 2 figures. Figure 34 shows when occurs the unsatisfied and satisfied electrical load, and the PV power production. Figure 35 shows how component try to supply the electrical load.

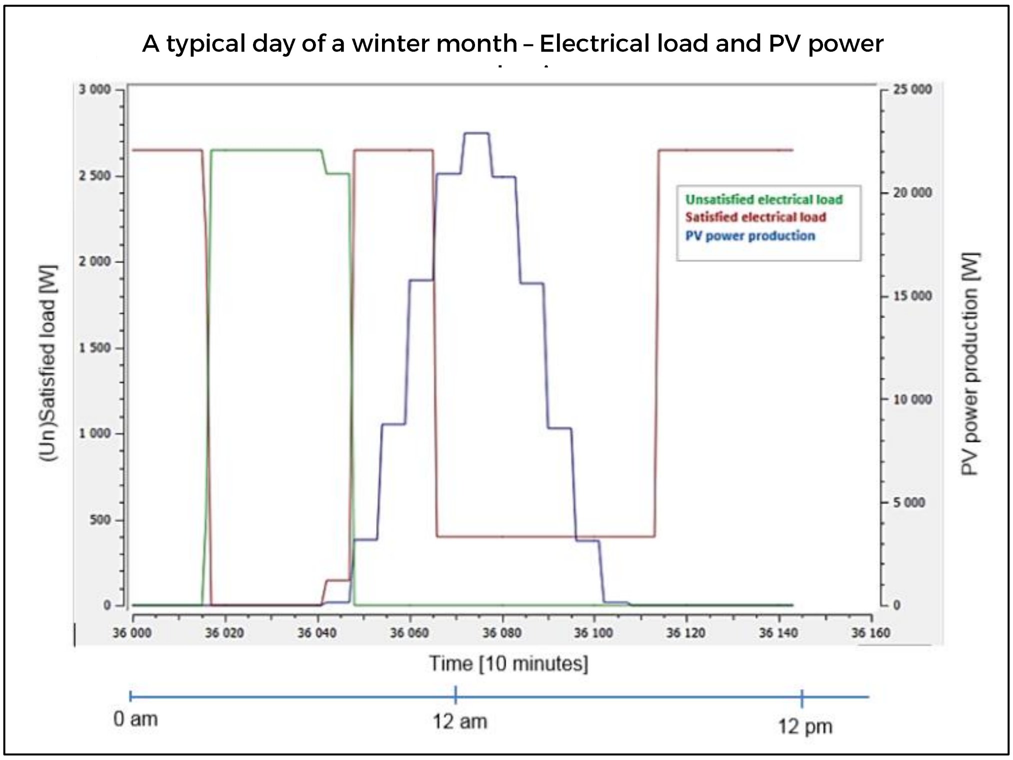


Figure 34: The unsatisfied load occurs at the end of the night, just before the PV starts producing

Figure 34 shows that the unmet electrical load occurs at the end of the night. Next figure helps to understand how components are used to provide the electrical load.

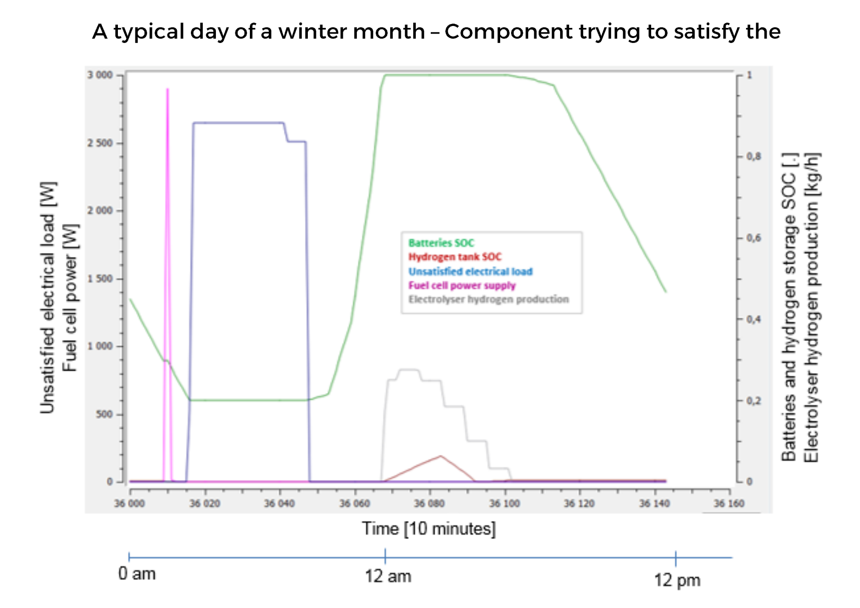


Figure 35: Behaviour of the system components during a day of a winter month

Note: before reading the next paragraph, please remember that the batteries are 1[st] used when it happens a deficit of PV power. When batteries SOC reaches 0.3, the fuel cell is used until hydrogen storage SOC = 0. Then batteries are used until their minimal SOC (0.2). For more informations, please refer to the section on strategy III.2.3.

As displayed by Figure 35, the electrical load of the night (until about 1.30am) is carried on by batteries, as the batteries SOC decreases (green curve). When batteries SOC < 0.3, the fuel cell is used to produce electricity (pink curve) until the hydrogen tank SOC reaches 0 (SOC not visible on the graphic as at this moment the hydrogen storage SOC is very low). When the hydrogen storage is empty, batteries run again until they are considered empty (SOC = 0.2). At this moment (2.40am) the unsatisfied electrical load (blue curve) occurs, as it is still the night (PV production = 0) and both storages are empty. It lasts until 8am. Then PV power allows to load batteries and once its SOC equal 1, to produce hydrogen (grey curve) to satisfy the hydrogen load (not detailed here) and to store extra hydrogen in the hydrogen tank (the SOC increases, red curve).

These 2 figures show that, due to the fact that the system is not able to store enough energy in its 2 means of storage (batteries and hydrogen storage) despite the use of 99.8% of the PV production, unsatisfied electrical load occurs during nights of winter months. An installation in Paganella would probably require more PV panels in order to survive to a winter in mountains characterized by low temperature and low PV production.

Regarding the hydrogen production, it is only satisfied at 53.9% and unmet load occurs all year long. Below shows both satisfied and unsatisfied loads during a day of both a summer and a winter month.

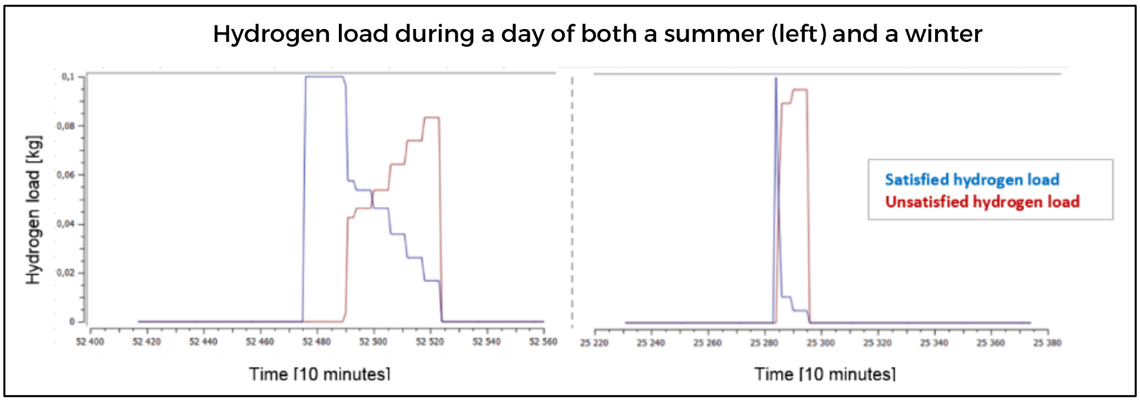


Figure 36: Hydrogen load satisfaction during a day of both a summer and a winter month

Note: please be aware that the behavior shown on Figure 36 is not exactly the same for each day of a same month kind. However, these 2 chosen days are representative of what generally happens in this simulation case.

In both cases, when the hydrogen load occurs, the hydrogen storage can provide hydrogen in order to help the electrolyser to satisfy the load. However, when the hydrogen storage becomes empty, the electrolyser doesn't get enough power from PV panels to produce enough hydrogen to supply the load. This is even more true for a day during winter.

III.3.4 Paganella: mix hydrogen load: mobility and cogeneration

Main calculated indicators for this simulation scenario are given in Table 44 below.

Main indicators		Value	Unit
PV	Maximal possible production	63.17	MWh
	Used production	44.46	MWh
	Percentage of use	70.4	%
Electrical load	Total	8.93	MWh
	Percentage of satisfaction	85.8	%
Hydrogen load	Total	396.5	kg
	Percentage of satisfaction	92.4	%
Electrolyser	Hydrogen production	438.5	kg
Fuel cell	Electricity production	63.5	MWh

Table 44: Main indicators for the case of Paganella - Hydrogen load for mobility

As shown in the table, not all the electrical power that is possible to produce with the PV panels is used (70.4% is used). Furthermore, both electrical and hydrogen loads are not satisfied in this scenario despite the use of hydrogen to produce electricity thanks to the fuel cell. The 2 graphics below show the repartition of the PV production uses and how the electrical load is supplied.

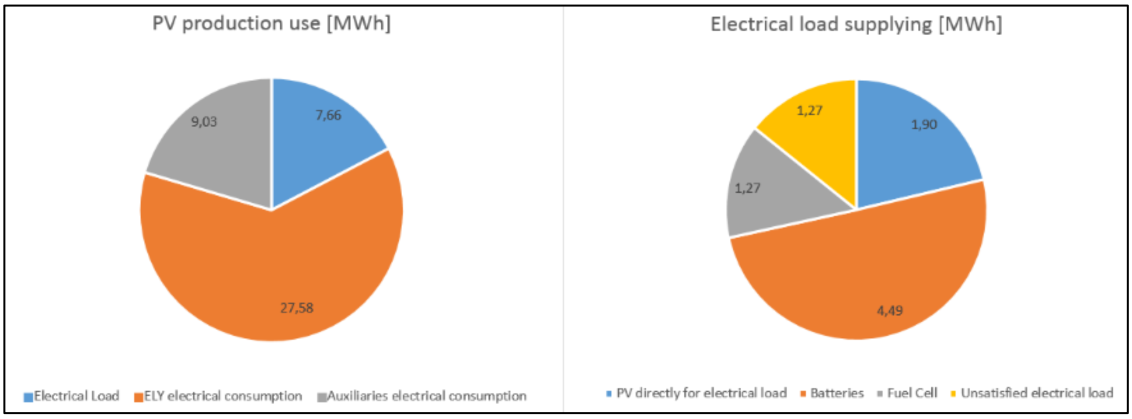


Figure 37: On left side, the repartition of the PV production. On right side, the repartition of the electrical load supply

In this case, a problem for the loads satisfaction is that the storage capacities are not sufficient. Indeed, there are excesses of PV power during summer months, which are wasted because both storages (batteries and hydrogen storage) are full (SOC = 1, Figure 38). On another hand, there are unmet loads only during winter months (Figure 39). It means that with more storage capacity, it could be possible to reduce and maybe totally avoid these unmet loads in winter months by storing PV production excesses of summer months. These explanations are illustrated below.

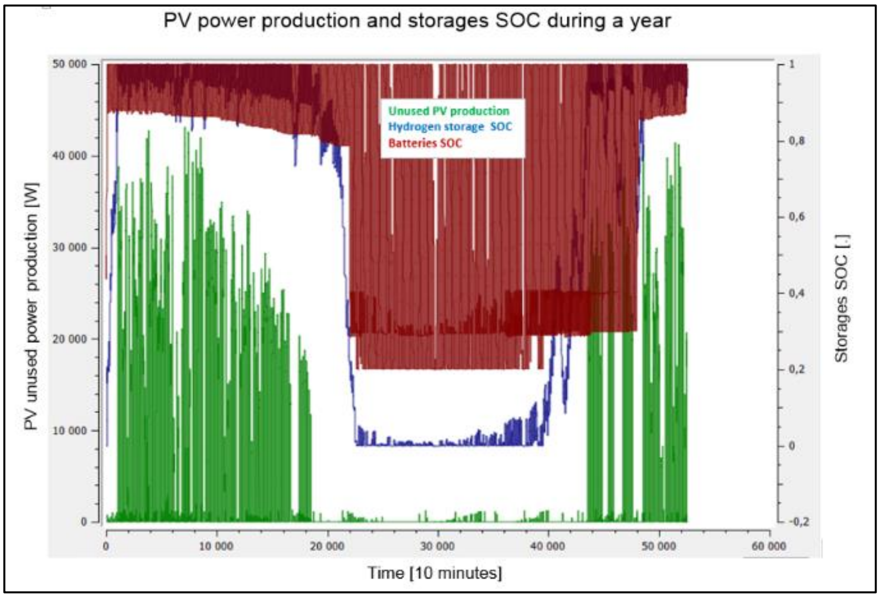


Figure 38: There are PV production excesses not exploited during summer months due to the low capacity storages size

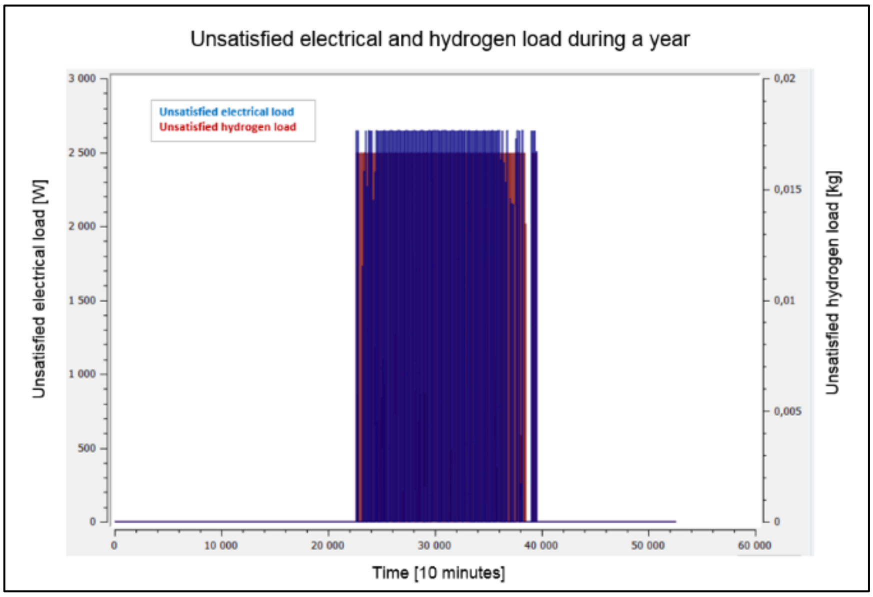


Figure 39: Both unsatisfied electrical and hydrogen loads occurs during winter months

In this case, it is not a problem of PV surface to produce energy as in the previous Paganella case. But as there is unused PV and both loads are unsatisfied, it could be relevant to enlarge storage capacities to ensure loads during winter months.

III.3.5 Conclusion

These 4 simulation cases show the dependence of results to the location and the hydrogen load to supply. Results and conclusion are different for each case (Table 45).

Location	Hydrogen load	Satisfied electrical load [%]	Satisfied hydrogen load [%]	PV production used [%]	Comments
Tenerife	Mobility	100	80.6	80	Hydrogen load too important during summer months, as unmet load occurs. However the system survives (electrical load 100% satisfied) without using the fuel cell as batteries are sufficient. PV unused is due to winter months. In these months, hydrogen load is defined as less important but the good sun radiations in Tenerife during winter could allow to provide more hydrogen.
	Mix	100	100	36.2	Both loads (hydrogen and electrical) are 100% satisfied. A lot of PV is unused. This case would require optimization to adapt the system size to the hydrogen load. Odyssey allows to do that. It is not treated in this document as the purpose is only to illustrate the use of the defined model.
Paganella	Mobility	79.5	53.9	99.8	Both loads are far to be totally satisfied. The system doesn't survive as the electrical load is not ensure. However, the PV production is almost totally used. It means that defined hydrogen load is too demanding for Paganella location.
	Mix	85.8	92.4	70.4	Both loads are unsatisfied, and unmet loads occur in winter months. Furthermore, about 30% of PV power is unused, mainly due to summer months. In this case, it could be improved by enlarging storages capacity in order to store PV excesses of summer months and use it during winter months.

Table 45: Results for each simulation case

Table 45 shows that for a same hydrogen load, results and behavior of the system are totally different depending on the locations. Also, for a given location, results and behavior of the system are different depending on the hydrogen load to satisfy.

When considering the location where the system is simulated, there is a strong impact on the available solar radiations and consequently on the PV power production profile. In Tenerife this profile is much more constant than in Paganella. It could allow to define more demanding hydrogen load in winter months, and it explains why fuel cell is unused. Furthermore, the location impacts the ambient temperature and the associated electrical load to ensure the safe operation of the system, as heaters are required at freezing temperatures. The electrical load is in this study much more important in Paganella than in Tenerife.

III.4 Conclusion

One of the objective of this report was to present the computer model of the ELY4OFF system that was developed in the first months of the project using Odyssey, a simulation software developed by CEA. This model represents the whole system including its main components: the electrolyser and its auxiliaries, the hybrid storage system composed of batteries, hydrogen storage system and fuel cell. The consumption of the compressor is also taken into account. Parameters and strategy were set in order to be as close as possible from the real system, and were defined thanks to known data (FHA data, report D2.3, ...).

Once the model is built, inputs data must be set to allow simulation, calculation of performances indicators and observation of components behavior. First required time serie is the available PV power which depends on the location and the available surface for PV installation. Second required time serie is the hydrogen load to supply which must be set based on the anticipated application for the produced hydrogen. Finally, location has also an impact on the ambient temperature and so the electrical load to supply to avoid freezing of the system. This represents the third required input time serie for the model.

The impacts of these inputs data were illustrated through scenarios at two locations (Tenerife and Paganella) for which 2 different hydrogen loads were applied. It was observed that the constant PV production profile of Tenerife during a year could allow to set constant hydrogen load, and also that with the batteries size defined, the fuel cell was not used. Regarding Paganella, the higher electrical load combined with lower PV power production lead to more difficulties to ensure the safety of the system. However, it could be improved by optimizing the different storage capacities.

The model developed with ODYSSEY proved to be very useful to evaluate impacts of various hypothesis such as PV profile, load profiles, hydrogen application and components sizing. By analyzing the comportment of the system, the model can help identifying room for improvement and optimization and will be used for this matter for the rest of the project.

In the next steps of the project, this model will be used to analyze the influence of the sizing of the different components through several techno-economic scenarios evaluation (T6.6).

IV. Conclusions and Perspectives

Purposes of this report were (i) to give an overview of demonstration tasks progress and their compliance with previous work done within the project, and (ii) to present the developed computer model of ELY4OFF system.

In the first part of the present report, the progress on the different project tasks was checked. It was done thanks to tables, filled by each partners, aiming to estimate a progress estimation and to confirm information from the previous report D2.3. Additional information were presented when necessary. Progress indicators were estimated in order to evaluate the compliance with design specifications and demonstrations tasks planning. A synthesis of this section is presented in the table below.

Partner	Task	Initial planning	Estimated real progress	Risks analysis			Comments
				Compliance with Gantt	Expected evolution	Compliance with D2.3	
FHA	4.3	31%	60%			Not Evaluated	- PV has to be built - Others peripherals systems are ready to be used
ITM	3.1	35%	65%				
	3.2	35%	30%				
	3.3	18%	20%				
Epic Power	4.1	31%	40%				None
Inycom	4..2	31%	10%				- Real progress not representative as task 4.2 is not linear in terms of progress. - Good expected evolution

Table 46: Tasks progress synthesis

In the second part of this report, the developed computer model of ELY4OFF system was presented and its utilization was illustrated through four scenarios. The system model was developed on Odyssey software.

After a presentation of the necessary input data (components models, parameters, input time series), simulated scenarios validates the interest of the model. The model developed with ODYSSEY proved to be very useful to evaluate impacts of various hypothesis such as available PV profile, electrical load profiles, hydrogen application and components sizing. By analyzing the comportment of the system, the model can help identifying room for improvement and optimization in the sizing of peripheral components such as hydrogen storage, fuel cell and batteries.

During the next two years of project, by adding economic parameters (investment cost, operation cost) for each component, this model will be used to realize accurate techno-economic studies for specific business cases (Task 6.6).

References

[1] ELY4OFF Grant Agreement (Grant Agreement number: 700359)

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[5] Hydrogenics Advanced Hydrogen Solutions. August 9. 2010. HyPM HD 4, (P/N 1037915) Specification Sheet

Appendices

Appendix 1: RCS update regarding demo site

This chapter describes the specific regulations and codes of application for the construction of the new PV field that will used instead of the initially proposed solution, the existing 60 kW located in a parking lot of FHA (described in D2.1 report).

In addition, some concepts not yet presented in any report, like water supply and other inputs are described in this section.

In the proposal it was mentioned that FHA would use the 60 kW photovoltaic field installed in a nearby parking lot, but due to administrative hurdles for using it in an off-grid scenario, it was finally decided to implement a new photovoltaic system to be dedicated exclusively to ELY4OFF in an off-grid configuration. The following image shows the most probably location of the PV field and the stack, in an area belonging to FHA and currently with no specific use.

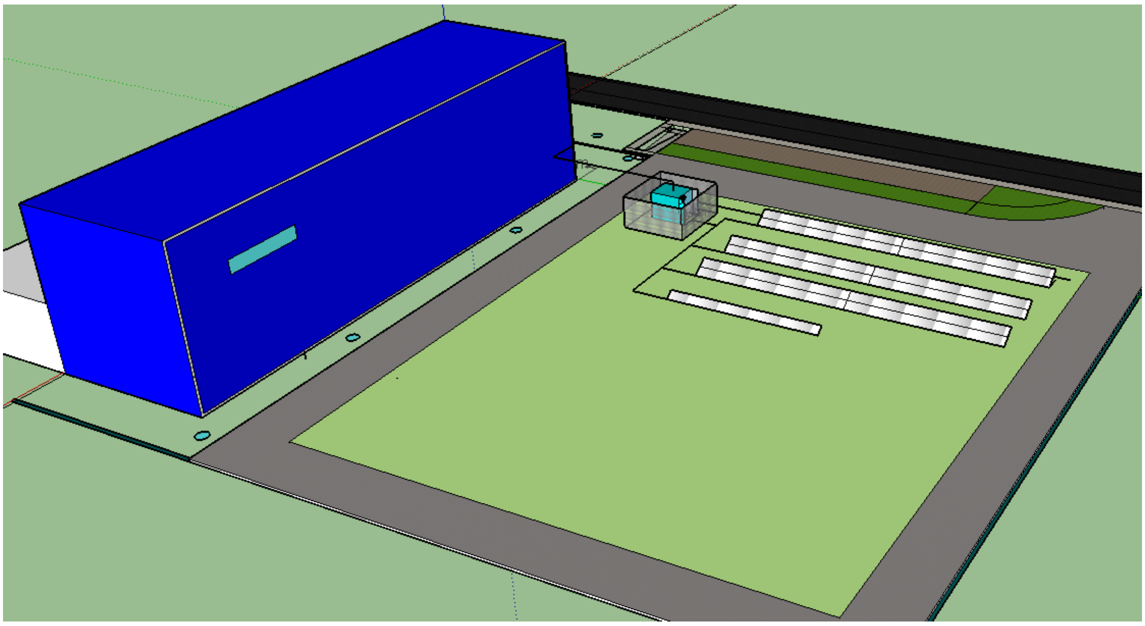

Figure 40: FHA building and possible location of the new PV field

This situation implies the necessity of asking for permits to install the new solar panels. We have reviewed the procedure for achieving them, and the specific regulations and codes of application are:

- Royal Decree 842/2002 of 2 August, on the Electrotechnical Regulation for Low Voltage (B.O.E., 18-09-2002)
- Technical Building Code (CTE)
- European directives of safety and electromagnetic compatibility

The steps to be taken to authorize and build the isolated photovoltaic field in Aragón are as follow:

1. Civil engineering: is required to obtain a municipal works permit
2. Electrical Low Voltage Regulation, obliges to develop a Project if the installed peak power is higher than 10 kW.

3. Legalization procedure for an isolated installation
   - ✓ License of municipal works and authorizations
   - ✓ Certificate of commissioning
   - ✓ Registration with Provincial Service of Industry. Commissioning communication
   - ✓ Review from the distribution company

Another aspect that has not been treated in detail is the availability of water and requirements of the drainage system. Following there is a brief discussion on these topics:

- **Water for the electrolyser**: it is directly dependant on the production of hydrogen, being the consumption of around 15 litres per kg of hydrogen. Based on simulations with Odyssey, the profile of production of H2 has been obtained, and therefore an estimation on the amount of water required per month is available (see figure 2). Total amount of water needed during the demo period is expected to be around 19 m^3. Considering that current consumption of water in FHA facilities is of 590 m^3/year, this matter does not suppose any trouble.

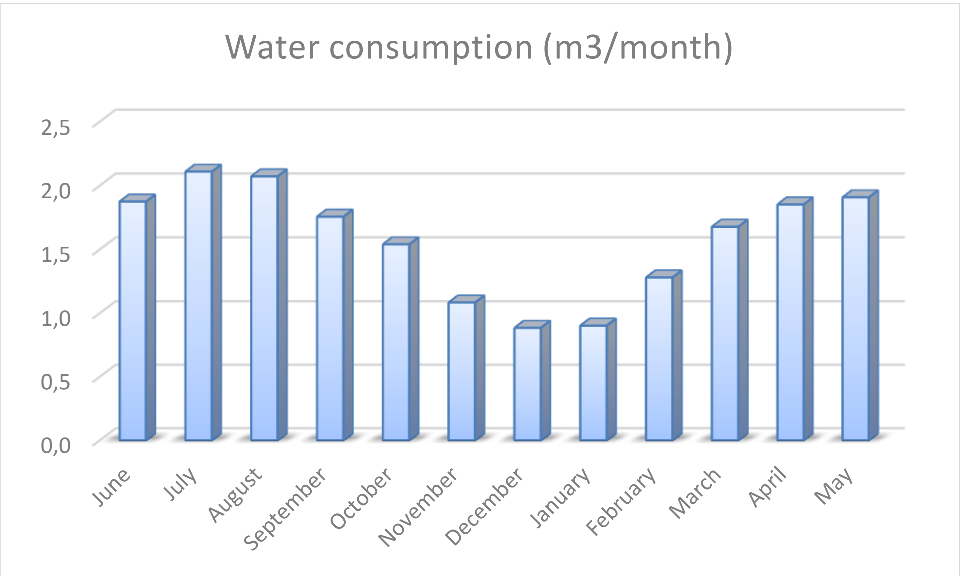

Figure 41: Water needed for the electrolyser during the expected demo period.

- **Drainage system**: It is composed by two streams, the larger one comes from purification of the water introduced to the process; the rest comes from the drying of the H2 stream produced in the electrolyser. It is not hazardous to environment, so it does not pose any problem on site (the existing raining drainage systems can be used safely)

Appendix 2: Technical characteristics and features of Odyssey

This appendix describes the objectives of the software Odyssey, its organization and the different steps for the realization of simulations. However, please notice that this document is not a user instructions.

Context and objectives

Odyssey is a modelling and simulation device for electric or electric-hydrogen systems. It allows to the user to model the energetic system to study and then to simulate its behavior, thanks to predefined operating strategies. The simulations can be done with two different objectives:

- Sensitivity analysis: study the impact of the variations of one or several components model parameters (performance/ageing) or of the strategies on the technical-economical performances of the system.
- Optimization: optimize parameter(s) or strategy(ies) in order to improve the chosen technical-economic performance(s).

Odyssey allows to create a system with different components and with the wanted design. For each component, the user has to choose between several models (performances/ageing).

Presentation of the Odyssey platform organization

The organization of the simulation platform is described in the Figure 42 below. The platform is constituted of a principal block, called Virtual Power Plant. This Virtual Power Plant is constituted of one or several RE-storage Plant(s). These RE-storage Plants are defined from different libraries. What’s more, several modules can interact with the Virtual Power Plant, the RE-storage Plant(s) or the components of one RE-storage Plant.

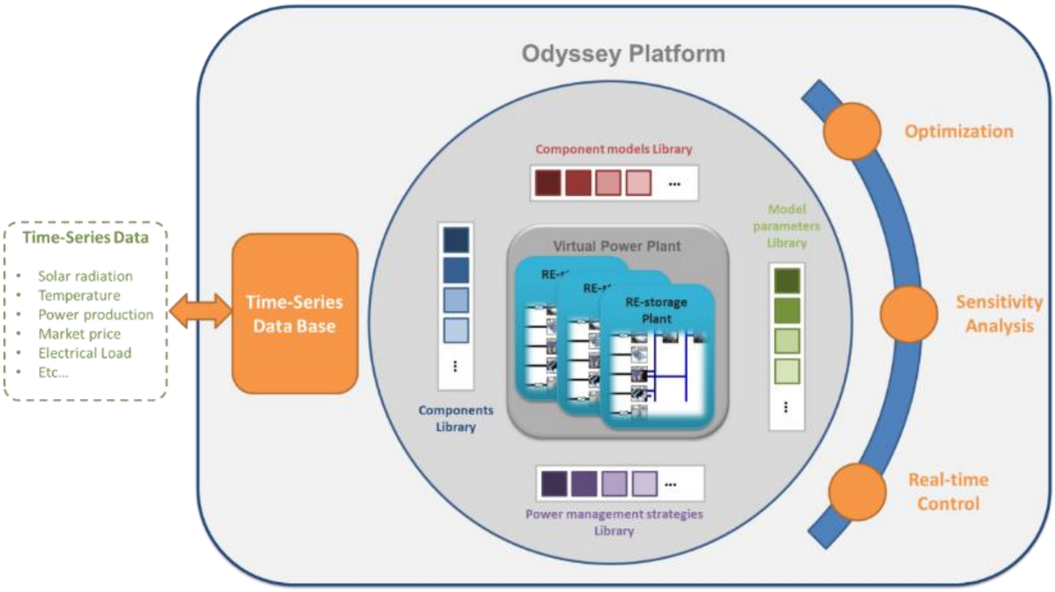

Figure 42 : General organization of the Odyssey platform

Presentation of the inputs and outputs of Odyssey

The Figure 43 shows the inputs needed for the realization of simulations, and the outputs which can be evaluated by the platform.

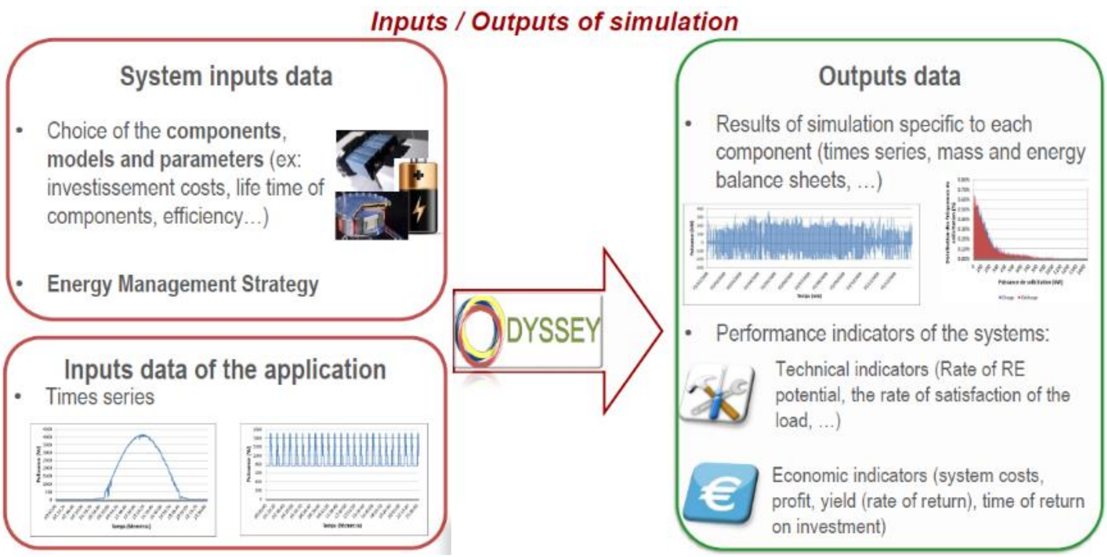

Figure 43 : Presentation of the inputs and outputs of Odyssey

The following data are considered as inputs by the platform:

- Components' choices;
- Electrical and fluidic architecture;
- Components models choices (performances/ageing);
- Models' parameters (performances/ageing);
- Temporal data which can be needed by components (temperature, electricity price, etc.);
- Management strategies;

- Management strategies' parameters.

After a simulation, Odyssey provides two kinds of results:

- Indicators of the Virtual Power Plant' technical-economical performances, indicators of the RE-storage Plant' technical-economical performances;
- Specific information of each components which constituted the difference plants;
    - Temporal series showing state variables of the component (pressure, temperature, power, etc.);
    - "Assessment" information of components' state variables;
    - Statistical information on components' state variables.

Presentation of the simulated energetic system

The simulated energetic system is composed of several components of different natures.

These elements are listed below:

Kind of technology	Component
Electrical production	PV panels
	Diesel generator
	Fuel Cell
Hydrogen production	Water electrolysis
Electrical storage	Generic
	Batteries
Hydrogen storage	Pressured gas
Oxygen storage	Pressured gas
Power adaptation	Transformer
	Power electronics

Table 47: List of components currently available in Odyssey

In addition of the components, it is possible to add electric charge, connection to an electric grid and connection to a hydrogen grid.

Management strategies in Odyssey

There are 3 levels of management strategies, depending on which object they are applied: strategies for the Virtual Power Plant, strategies for the RE-storage plant, and strategies for the controller of the RE-storage plant. The figure below shows the organization of the management strategies in Odyssey.

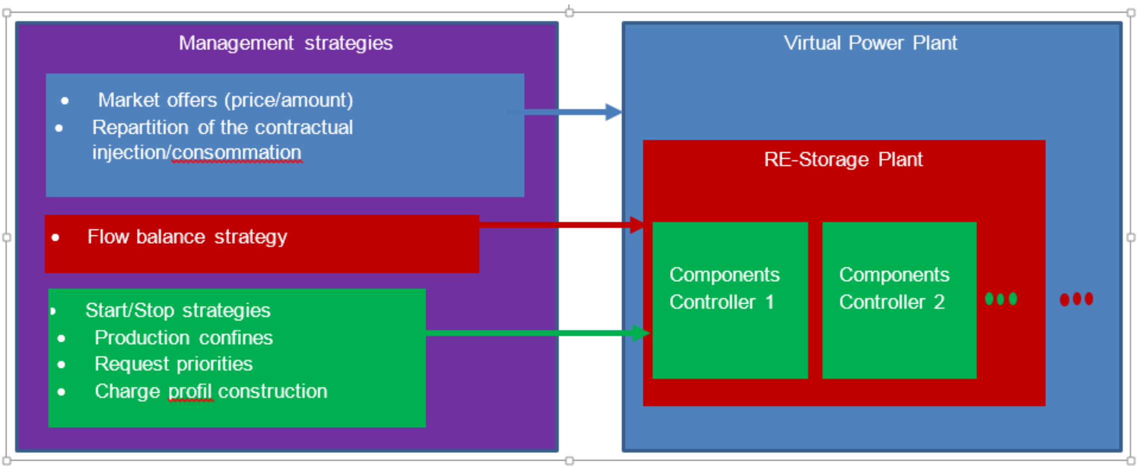

Figure 44: Organization of the management strategies in Odyssey

A controller has to manage several components of a same kind. For example, a controller can be in charge of managing several batteries and another controller can be in charge of managing several stacks of an electrolyser. There are as many controllers as there are components of a different kind.

All the strategies described before are available in the library of management strategies. For each level and depending on the nature of the controller, one or several strategies are available and can be chosen by the user. The optimization of the management strategies is done thanks to the optimization of their parameters.

Functioning of the software – Steps of a simulation

Previous steps of the realization of a simulation

The previous steps of the realization of a simulation can be sum up in 4 points:

- Opening of a .TIM file, containing the input time series;
- Creation of the different RE-Storage Plant and definition of the electric and fluidic architecture of each plant;
- Selection of the components' model and selection of the parameter of these models;
- Selection and configuration of the management strategies.

Phases of a simulation

Once the previous steps of the simulation (listed just before) achieved, the user can launch the simulation. A simulation with Odyssey is composed of 3 phases: the initialization, the calculation and the post-treatment. The Figure 45 below shows the different phases of the proceeding of a simulation.

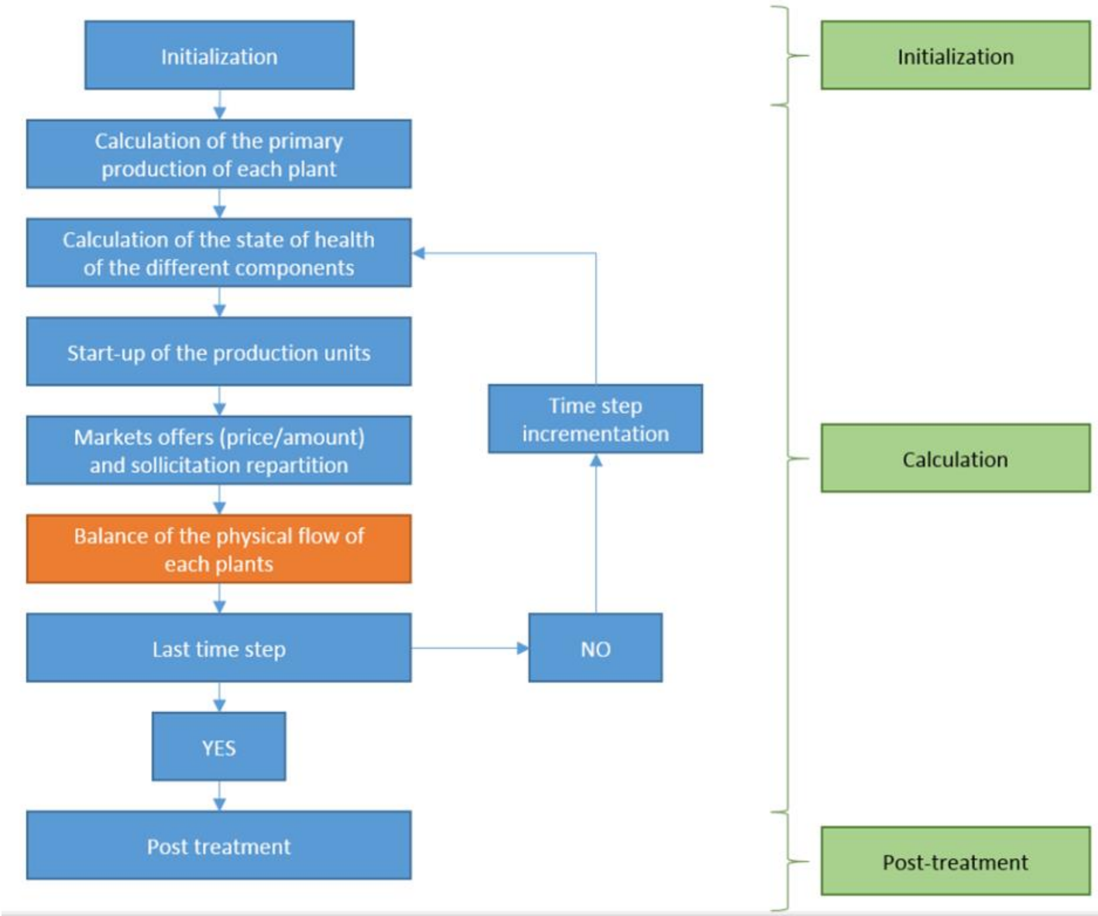

Figure 45 : Logic diagram showing the steps followed by Odyssey during a simulation

Initialization phase

During this phase, Odyssey makes sure that the inputs needed for the simulation have been given by the user. Otherwise, the simulation is stopped and the user is informed of what he has to do to run the simulation. The second objective of the initialization phase is to initialize the temporal series of each components in order to correspond with the simulation's step time. Finally, this phase is used to realize some pre-calculation.

Calculation phase

Once the initialization phase over, Odyssey begins the calculation phase. An important step of this phase is the balance of the physical flow of each plants. These balances are realized depending on the strategies defined by the user.

Post-Treatment phase

During this phase are done the calculation of the technical and economic indicators chosen by the user.

Software functionalities: proceeding of a sensitivity analysis and an optimization

Sensitivity analysis

In Odyssey, every kinds of parameters can be study thanks to a sensitivity analysis. The user can choose the parameters he wants to see their influences on the virtual power plant, the different RE-storage plant or the different components of the plants (Figure 46).

	Property	Dependent	Value	Unit	Optimization	Analysis
1	Footprint	☐	0	m2	☐	☐
2	Min SOC	☐	0	-	☐	☑
3	Max SOC	☐	1	-	☐	☐
4	Initial SOC	☐	0.8	-	☐	☐
5	Number of Batteries in Series	☐	1700	-	☐	☑
6	Number of Batteries in Parallel	☐	1	-	☐	☐

Figure 46 : Screenshot showing an example of selection of user parameters as variables for a sensitivity analysis

In the module Sensitivity Analysis, the user defines the maximal value, the minimal value and the variation step for each chosen parameters. He also chooses the technical and/or economic indicators he wants to observe (Figure 47, Figure 48).

Parameters

	VPP/Project	Parameter	Min	Max	Step	Points
1	Virtual Power Plant/AO-CRE-PV_1.0.0.0	Virtual Power Plant/AO-CRE-PV_1.0.0.0/Main Electrical Bus/Battery Bank / Number of Batteries in Series	2000	3000	20	51
2	Virtual Power Plant/AO-CRE-PV_1.0.0.0	Virtual Power Plant/AO-CRE-PV_1.0.0.0/Main Electrical Bus/Battery Bank / Min SOC	0	0.5	0.1	6
3	Virtual Power Plant/AO-CRE-PV_1.0.0.0	Virtual Power Plant/AO-CRE-PV_...rical Bus/Grid Contractual Injection - CRE PV 2011 / Energy_Sell_Price	300	600	10	31

Figure 47 : Screenshot showing how to complete the maximal value, the minimal value and the variation step of user parameters

Technical Indicators

		Indicator	Unit
1	☑	Unused Primary Production - energy ba...	-
2	☑	Unused Primary Production - time based	-
3	☑	Unmet Electrical Load - energy based	-
4	☑	Unmet Electrical Load - time based	-
5	☐	Unmet H2 Load - mass based	-
6	☐	Unmet H2 Load - time based	-
7	☐	Footprint	-

Figure 48 : Screenshot showing how to choose the indicators that the user wants to observe

Once these different information completed, the user can launch the sensitivity analysis. This one is constituted of a succession of simulations. The algorithm used is a determinist and exhaustive algorithm. It consists in searching all the possible combinations of values of the parameters, depending on the minimal, maximal and step value chosen by the user. For each combination, Odyssey realizes a simulation and evaluates the chosen indicators. Then, these information are stored and Odyssey do the calculation for the next combination of parameters. Results of the sensitivity analysis are presented in a table in which one each line is constituted of a combination of parameters and of the associated indicators' values.

Optimization

The optimization is done depending on the chosen optimization criteria among all the different technical and economic indicators available in the platform. Depending on the nature of the criteria, the optimization has to minimize it (total costs, …), or maximize it (profit, …). In a similar way to the sensitivity analysis, the same steps (Figure 46, Figure 47) must be done before launching the optimization. Then the user chooses the parameters to consider as optimization parameters in the *Optimization module*.

An optimization is then constituted of a succession of simulation. For each simulation, Odyssey evaluates the chosen criteria. The results are presented in a table in which one each line is constituted of the optimal values for the optimization variables and the values of the optimization criteria.

IT files provided

- Odyssey application (.exe) and needed librairies (.dll) for a 32 bit Windows operating system
- Odyssey application (.exe) and needed librairies (.dll) for a 64 bit Windows operating system

To run Odyssey, the following configuration are needed:

Kind of computer: PC
Processor: 2.4 GHz, at least 2 hearts
Memory size: 2 GB
Hard drive size: about 500 Mo (51 needed for odyssey), for the storage of the temporal series
Operating system: 32 bit Windows or 64 bit Windows