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GreenDataNet

Renewable Energy Map and Guidelines

CEA / EATON
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Rev 2.0

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4 REVISION SHEET

Revision Number	Date	Brief summary of changes
Rev 0.1	27/07/2014	Baseline document
Rev 1.0	29/09/2014	Integration of the CEA simulation and conclusion.
Rev 1.1	24/10/2014	Completion of the QGIS useful procedure for GreenDataNet : • Georeferencer • Raster calculator Correction of previous revision and adding about simulation results.
Rev 2.0	15/01/2014	Integration of GDN partners and Project Officer remarks

1. INTRODUCTION

1.1. DOCUMENT PURPOSE

The choice of the Data Centre location could have important impact in term of cooling system and also for the renewable energy usage. The purpose of this document is to present a free software tool that will be used for GreenDataNet project to identify the best locations of the Demonstrator. It allows other users to identify within Europe what could be the best locations of Data Centre depending of free cooling potential, solar irradiation and wind speed but also the method to generate a decision map taking into account all their relevant data and parameters.
Hence other renewable resources (as biomass or hydropower) data, economic data as electricity prices, and environmental data as greenhouse gases emissions could be considered by a data center developer to select the best locations and could be integrated through maps within the used software tool. As the framework of the Task 1.2 is not to gather data and to build a wide variety of maps, it has been decided to focus on the most relevant ones for urban data center in Europe as defined for the GreenDataNet project: temperature for free cooling, solar irradiation and wind speed for electricity production.

The following document corresponds to the part of the Work Package 1 (WP1) Task 1.2 (Investigation of renewable energy potential) purpose and the associated delivery D1.3.

1.2. DEFINITION, ACRONYMS AND ABBREVIATIONS

1.2.1. KEY DEFINITIONS

Not applicable.

1.2.2. KEY ACRONYMS AND ABBREVATIONS

DC	Data Centre
ESS	Energy Storage System
GEC	Green Energy Coefficient
GUI	Graphical User Interface
KPI	Key Performance Indicator
NASA	National Aeronautics and Space Administration
PV	Photovoltaic
QGIS	Quantum Geographic Information System
REF	Renewable Energy Factor
S2D	Solar simulation data producer
SOE	State Of Energy

1.3. KEY REFERENCES AND SUPPORTING DOCUMENTATION

The references and supporting documentation are defined in the footnote of the pages.

1.4. DOCUMENT OVERVIEW

The document is organized in several parts consisting:

1) To introduce the QGIS tool and describe the use of QGIS linked with GreenDataNet project
2) To identify and propose some locations for the demonstrator of a urban Data Centre
3) To present results of simulations on the environmental impact of such Data Centre by using Photovoltaic Renewable Energy for various potential locations

2. QGIS TOOL DESCRIPTION

2.1. INTRODUCTION

QGIS is a free and Open Source Geographic Information System (GIS). QGIS is multi-platform tool and supports numerous vector and database formats and functionalities. By using QGIS it can be visualized, managed, edited and analyzed maps. The QGIS is used in this project in order to present the variation of the temperature, wind speed and irradiation in order to determine the good location for the integration of the renewable energy to Data Centre. However it could be used to integrate other parameters as electricity prices, greenhouse gases emissions, and hydropower potential as soon as data and maps are available.

2.2. DOWNLOAD AND INSTALLATION OF QGIS

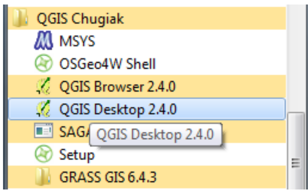
The first step is to download and install QGIS tool from the next link:

http://www.qgis.org/fr/site/forusers/download.html

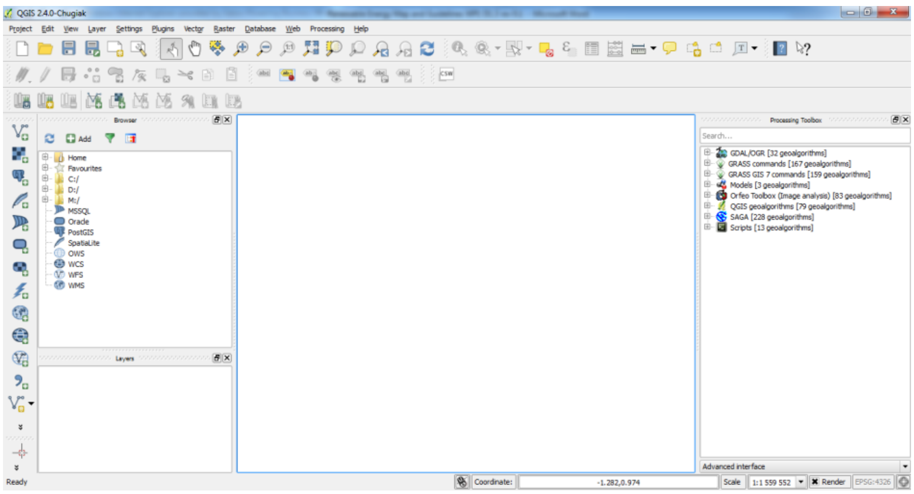
The current version is QGIS 2.4 and was released in June 2014. QGIS is available on Windows, MacOS X, Linux and Android.

After downloading the application for the associated Operating System, the installation procedure has to be followed and QGIS could be launched.

Launch the QGIS desktop from the start menu:



The QGIS tool environment should appear:



2.3. LOADING DATA IN THE QGIS ENVIRONMENT

To achieve the objective of the GreenDataNet project, the following three sets of data need to be loaded in the QGIS environment:

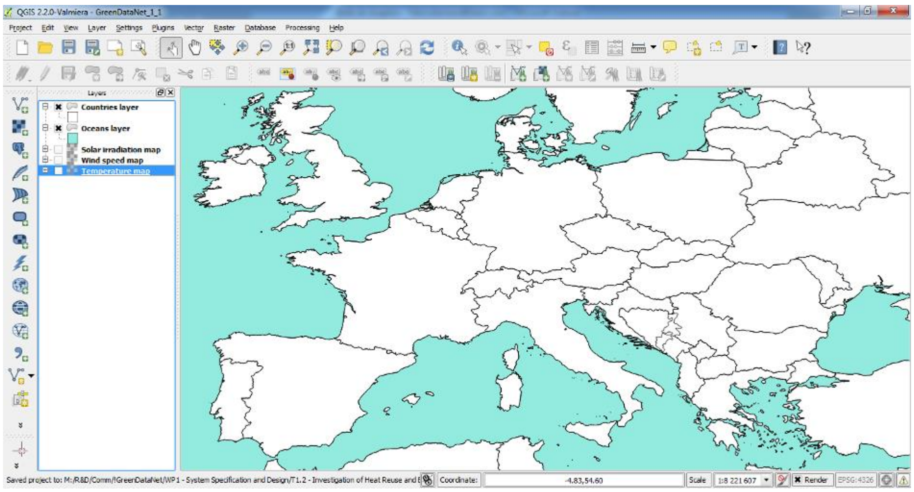
1) The temperature, air side and water side economizer mapping allowing to identify the best location in term of cooling efficiency
2) The solar irradiation mapping allowing to locate the best location of photovoltaic usage
3) The wind mapping allowing identifying location that could host wind generator.

The limitation of the performed work within GreenDataNet is the scale of available maps because they only have 100km square accuracy.

This is not enough to analyze the annual renewable energy potential and the associated temperature for a given location in order to design with accuracy the renewable energy plant and cooling components for a data centre. But in all the case, it should be sufficient to identify some specific locations or areas and proceed to the PV simulation accordingly. Moreover similar method, as the one presented here, could be later applied if maps with better accuracy are available.

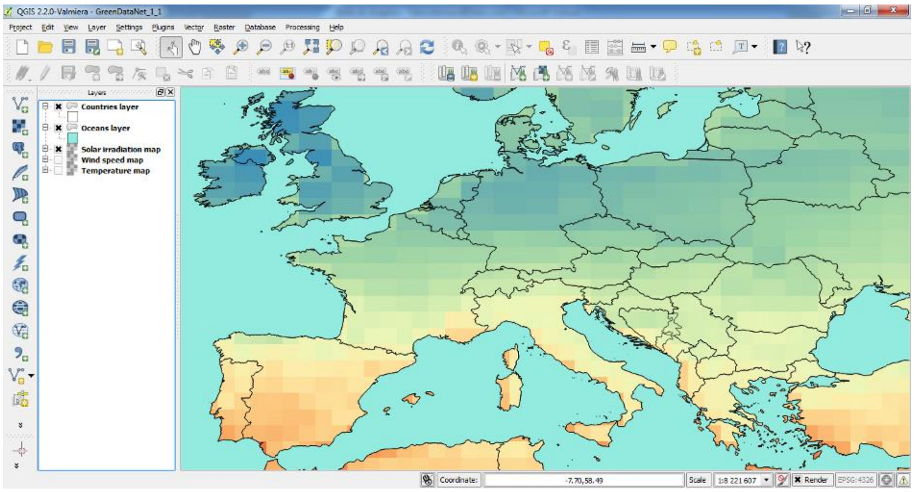
The next procedure should be followed up to load Data in the QGIS environment:

- Download the QGIS GreenDataNet zip file from here.
- Unzip the content and open the GreenDataNet qgs project file
  The next interface should appear:

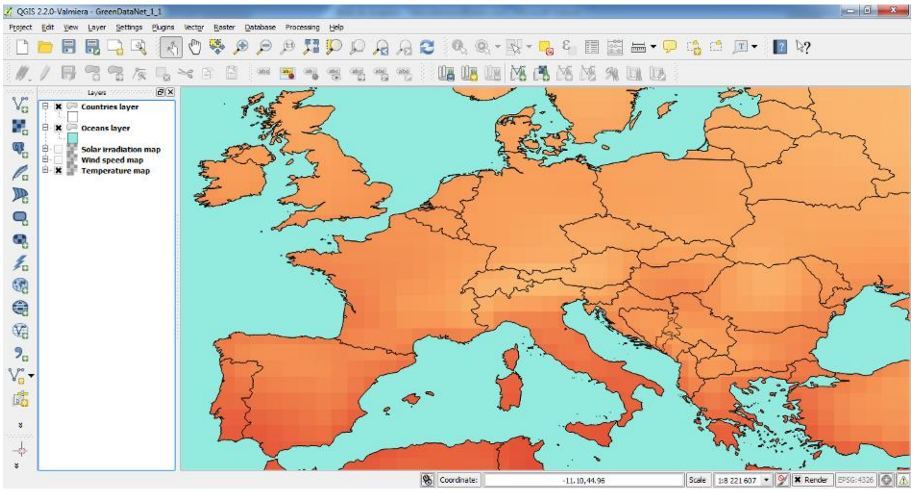


Only countries and ocean layer are enabled. The solar, wind and temperature layer are disabled.

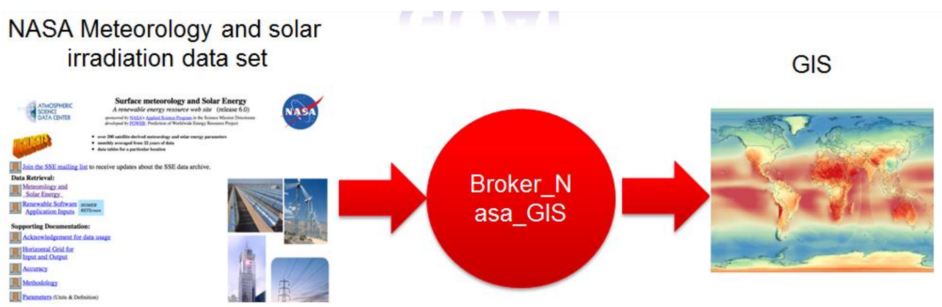
- Enable the solar irradiation map. The QGIS environment appears as the following screenshot with lower solar resources in blue and higher in red. The irradiation data are average of annual irradiation from NASA database and the format of data is directly applicable within QGIS project.



- Enable the temperature layer with the countries and ocean layers and disable the other layers (here solar irradiation map) in order to visualize the temperature variation on the map. The present data is yearly average temperature of the globe. The temperature data comes from NASA website.



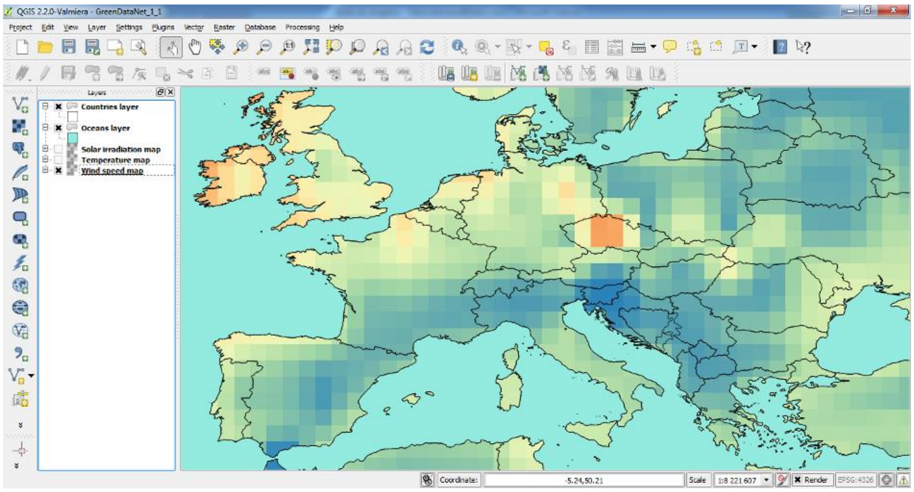
- More details or data can be added to the map by drag and drop of files with the extension .asc.
- However not all the data is available in the required format. It is the case for some data coming from the NASA website as the wind speed and temperature data used in GreenDataNet. Then a "Broker_Nasa_GIS" has been developed in order to produce a GIS format file with .asc extension for the wind speed map and from the wind speed data with NASA format.



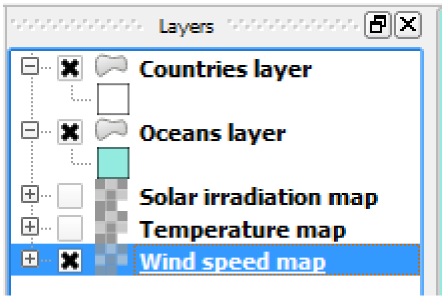
The .asc files contain information organized like in the following figure. Each value in this file represents the data for a point of the map:

```
NCOLS 360
NROWS 180
XLLCORNER -180
YLLCORNER -90
cellsize 1.0
NODATA_value -9999.000
7.03 7.03 7.04 7.03 7.03 7.03 7.03 7.03 7.04 7.04 7.04 7.04
7.09 7.09 7.09 7.09 7.09 7.09 7.09 7.09 7.09 7.09 7.09 7.09
7.05 7.06 7.06 7.05 7.05 7.05 7.05 7.06 7.06 7.07 7.07 7.07
7.23 7.23 7.23 7.23 7.23 7.23 7.23 7.23 7.23 7.23 7.23 7.23
7.10 7.10 7.10 7.10 7.10 7.10 7.11 7.11 7.12 7.13 7.13 7.14
7.43 7.43 7.43 7.42 7.42 7.42 7.41 7.41 7.41 7.40 7.40 7.40
7.16 7.16 7.17 7.17 7.18 7.18 7.19 7.20 7.21 7.22 7.22 7.23
7.67 7.66 7.66 7.66 7.65 7.65 7.64 7.63 7.62 7.62 7.61 7.60
7.08 7.09 7.09 7.10 7.10 7.11 7.12 7.12 7.13 7.14 7.15 7.16
7.90 7.90 7.90 7.89 7.88 7.88 7.86 7.85 7.85 7.84 7.83 7.82
6.87 6.87 6.87 6.87 6.87 6.88 6.88 6.89 6.89 6.90 6.91 6.92
8.13 8.13 8.13 8.12 8.12 8.11 8.10 8.08 8.07 8.06 8.05 8.04
6.78 6.78 6.77 6.78 6.78 6.78 6.78 6.79 6.79 6.79 6.80 6.81
8.28 8.27 8.27 8.25 8.24 8.23 8.23 8.22 8.22 8.21 8.20 8.19
6.82 6.82 6.82 6.82 6.82 6.82 6.82 6.82 6.82 6.82 6.82 6.83
```

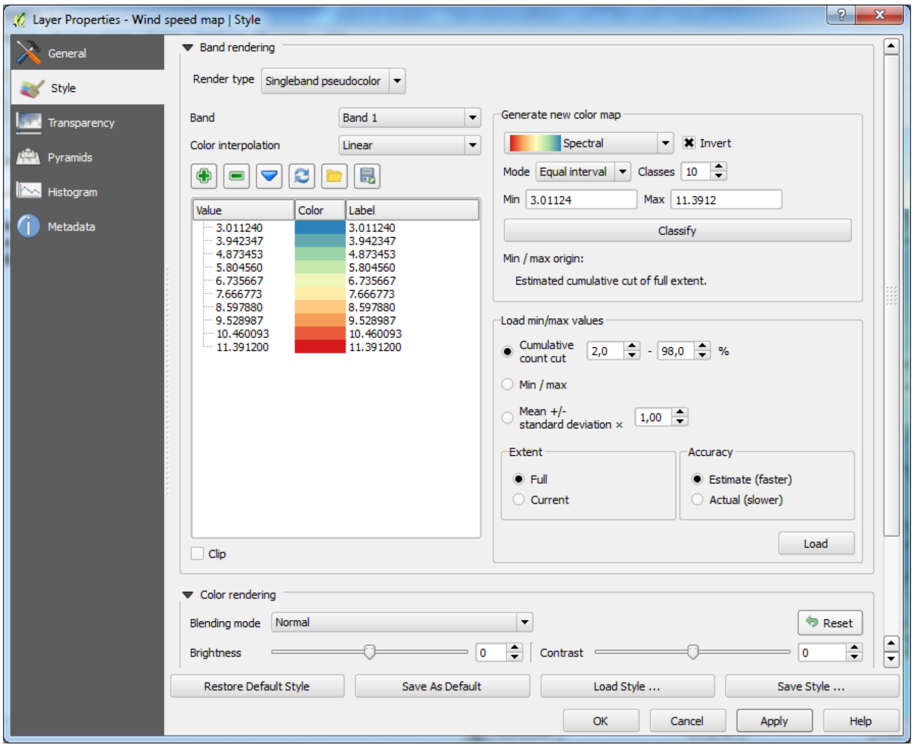
- Enable the wind speed layer with the countries and ocean layers and disable the other layers (temperature and solar irradiation maps) in order to visualize the wind speed layer variation on the map.



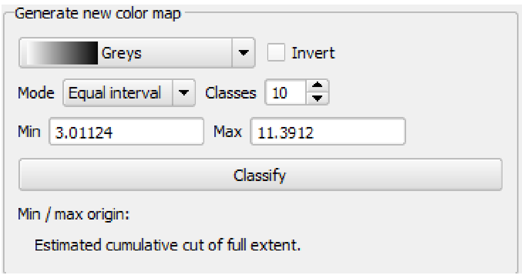
- The color representation of each layer could be setup through the next step:
  .1. Double click on the desired layer :



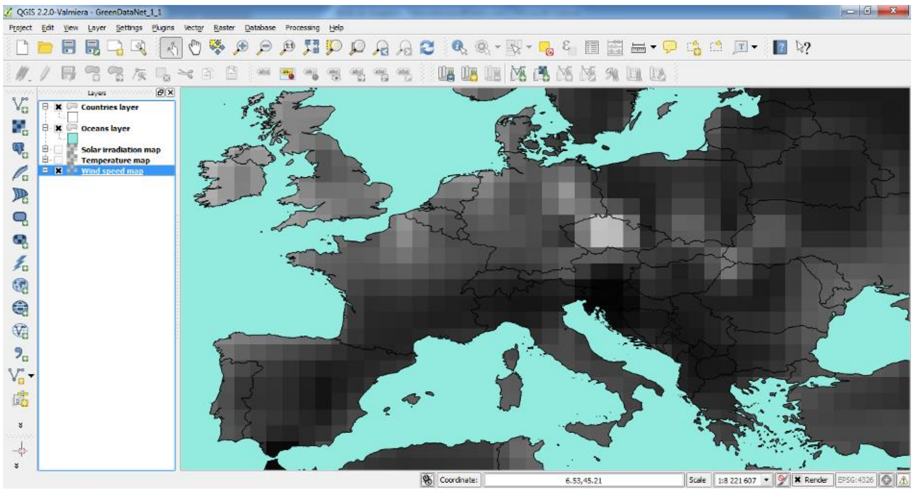
.2. Next figure appears:



.3. Choose the following parameters and click on the button 'Classify':



After applying these parameters, the following representation is get:



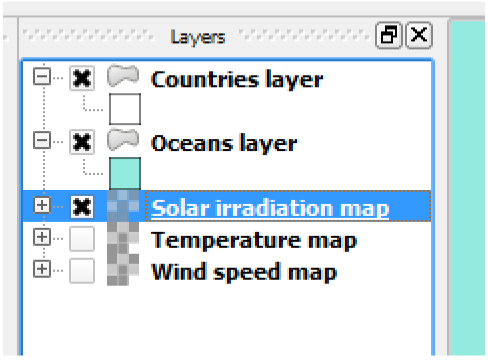
- Same procedure could be repeated for the other layers of data.

2.4. USEFUL PROCEDURE FOR GREENDATANET

2.4.1. INFORMATION TOOL

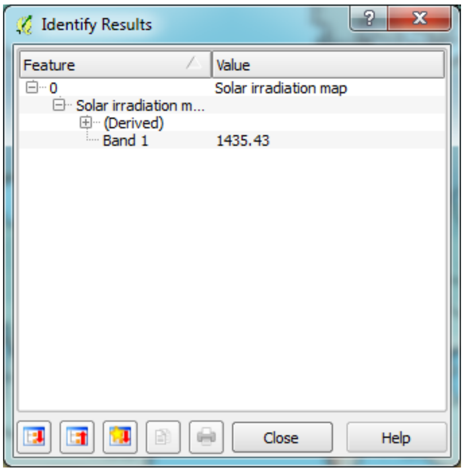
In order to obtain information about a specific point of the map, the information tool ( ) is used.

First, select from the layers window the information needed by a click:



In this case, the solar irradiation map is selected.

Then by clicking on the location on the map through the information tool, the data appears as shown in the following window:



This procedure will be used in the next part of the document to identify for each map the minimum and maximum values corresponding to European countries. Through this, it will help to determine the location of DC depending of the weight of each parameter (wind, solar or temperatures).

2.4.2. GEOREFERENCER PLUGIN

Raster data in GIS are matrices of discrete cells that represent features on, above or below the earth's surface. Each cell in the raster grid has the same size, and cells are usually rectangular. The Georeferencer Plugin is a tool for generating world files for rasters. It allows to reference rasters to geographic or projected coordinate systems by creating a new GeoTiff or by adding a world file to the existing image. The basic approach to georeferencing a raster is to locate points on the raster for which you can accurately determine coordinates.

To illustrate the use of this plugin, the next map published by European Environment Agency[1] (see **Figure 1**) could be referenced rasters to the geographic system used in the previous paragraph 2.3. This Part should help to import data, which is not a table but a map, to the GreenDataNet QGIS interface. For that a method (plugin) and specific information are needed in order superimpose accurately the different layers.

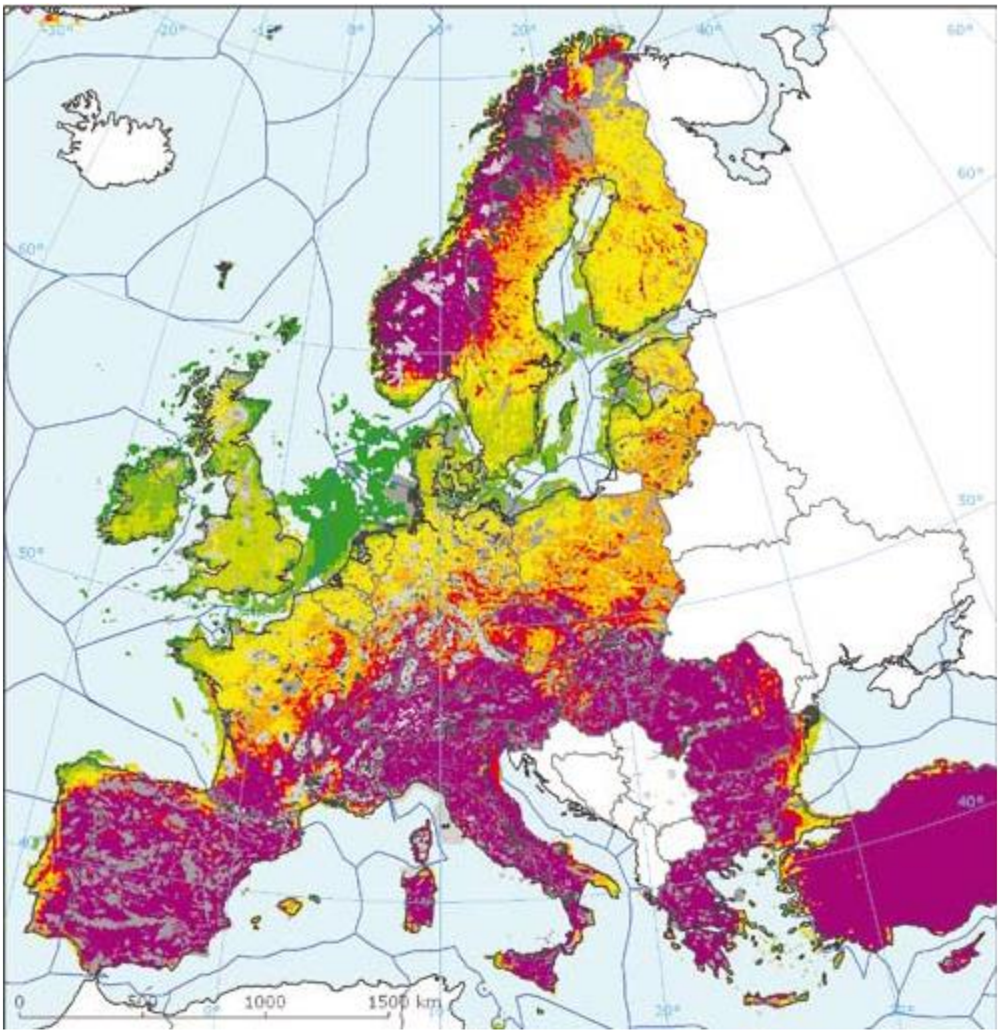


Figure 1 - Distribution of full load hours in Europe map

[1] www.energy.eu/publications/a07.pdf

2.4.2.1. ENTERING GROUND CONTROL POINTS (GCPS)

To start georeferencing an unreferenced raster, it has to be loaded using the button. The raster will be shown up in the main working area of the dialog. Once the raster is loaded, it can be started to enter reference points.

Using the Add Point button, add points to the main working area and enter their coordinates. For this procedure you have to click on a point in the raster image and enter the X and Y coordinates manually.

It can also be clicked a point in the raster image and chosen the From map canvas button to add the X and Y coordinates with the help of a georeferenced map already loaded in the QGIS map canvas.

With the button, the GCPS in both windows can be moved, if they are at the wrong place.
Continue entering points. You should have at least four points, and the more coordinates you can provide the better the result will be. There are additional tools on the plugin dialog to zoom and to mark out the working area in order to locate a relevant set of GCPS points.

After this step, the result appears like as the following screenshot (see **Figure 2**):

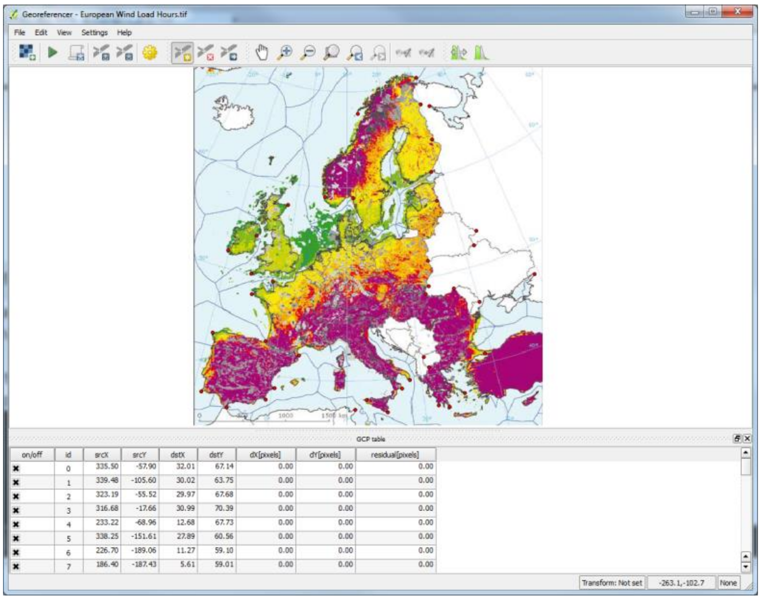
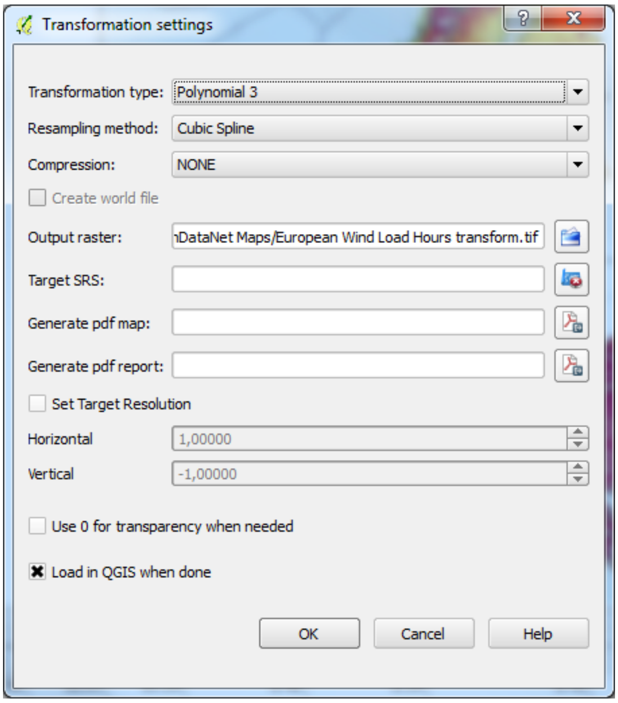


Figure 2 – Georeferencer setting points

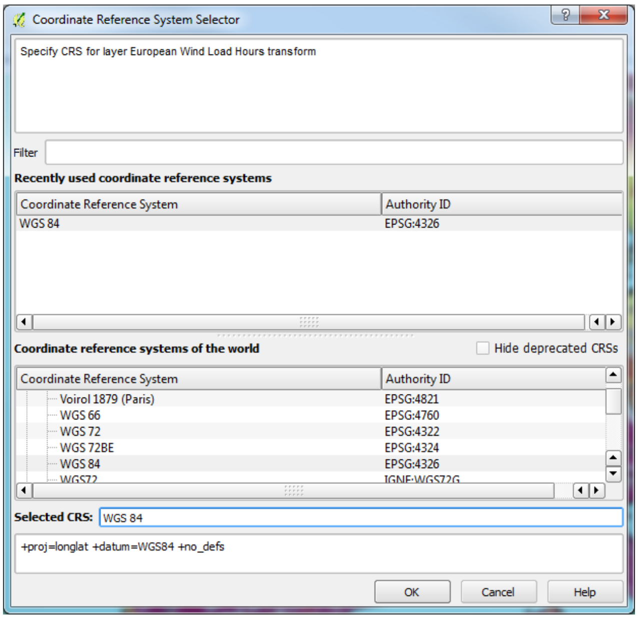
The GCPS points that are added to the map are stored in a separate text file usually together with the raster image. This allows us to reopen the Georeferencer plugin at a later date and add new points or delete existing ones to optimize the result.

2.4.2.2. DEFINING THE TRANSFORMATION SETTINGS

By selecting “Settings” => “Transformation settings”, the next windows should appear and it has to be applied the next parameters to get the best transformation from the original map to the QGIS map:



After clicking on the “File” => “Start Georeferencering” the next window appears, and the default coordinator reference system of the imported picture (here WGS84) to the QGIS environment has to be validated.



The QGIS tool performs the projection into its coordinator reference system and the result appears on the QGIS desktop as illustrated by **Figure 3**.

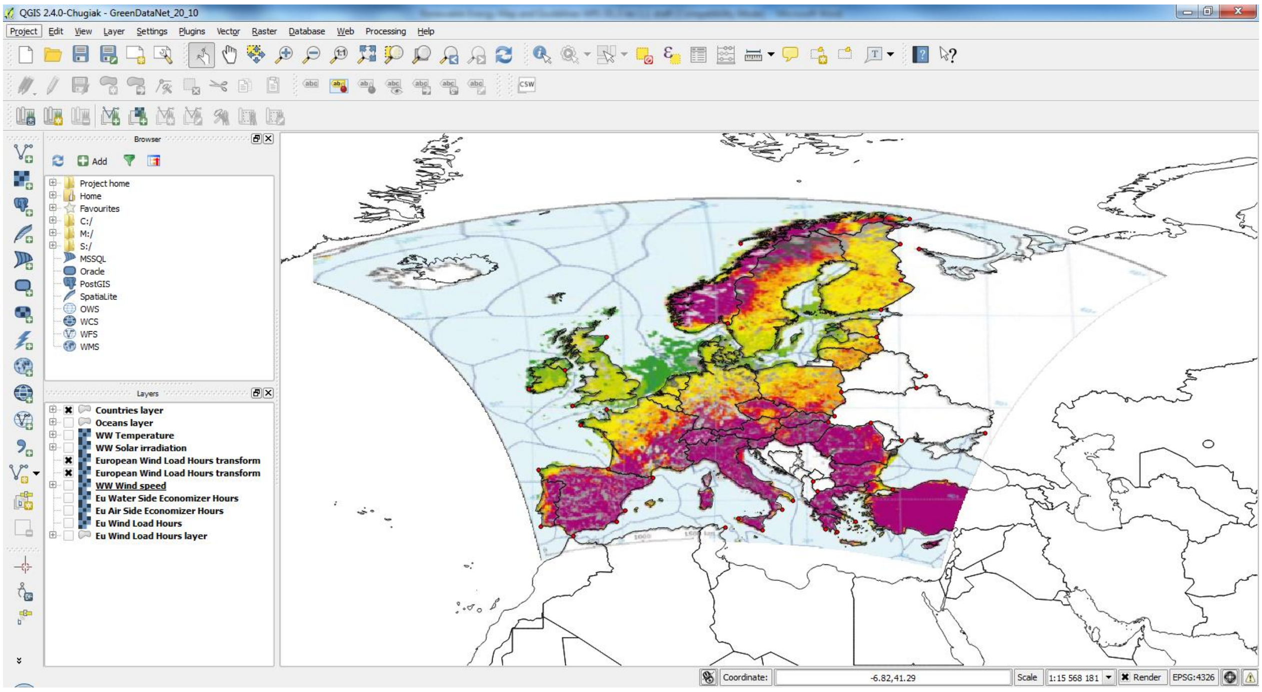


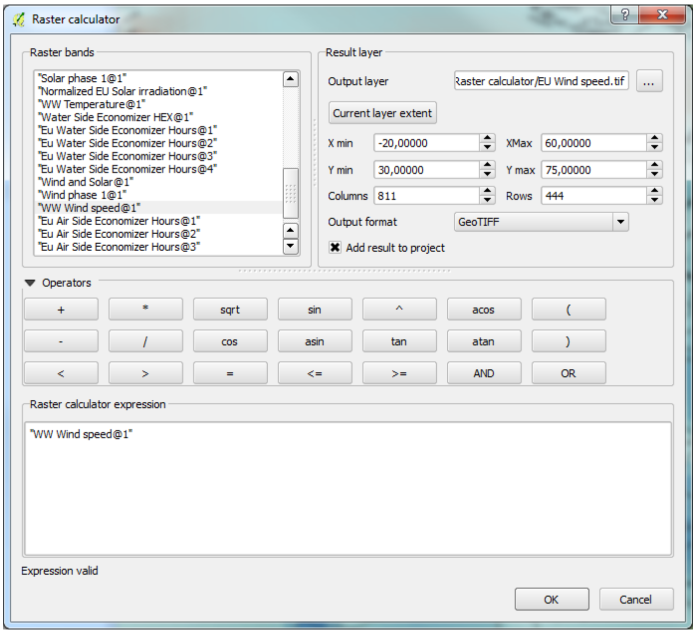
Figure 3 – Georeferencer results

2.4.3. RASTER CALCULATOR

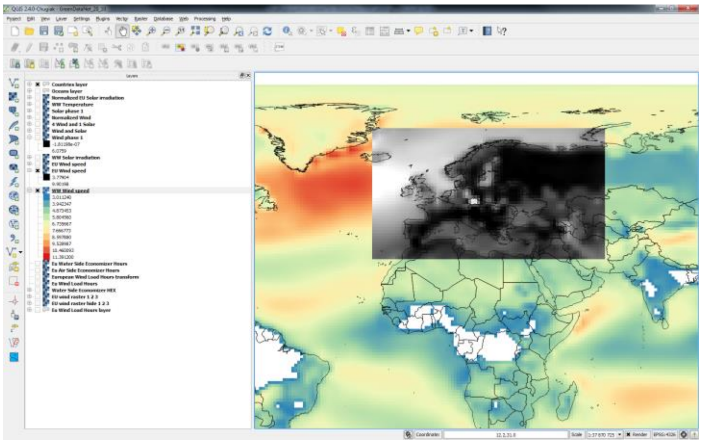
The Raster calculator allows performing calculation on the basis of existing raster pixel values. The results are written to a new raster layer. This tool is useful in the GreenDataNet prospective to identify best location based on specific criteria.

For example by considering the irradiation map or wind map, each map has their own pixel value scale. The first step consists to normalize the pixel value.

By clicking on the "Raster" => "Raster calculator", the next windows appear:



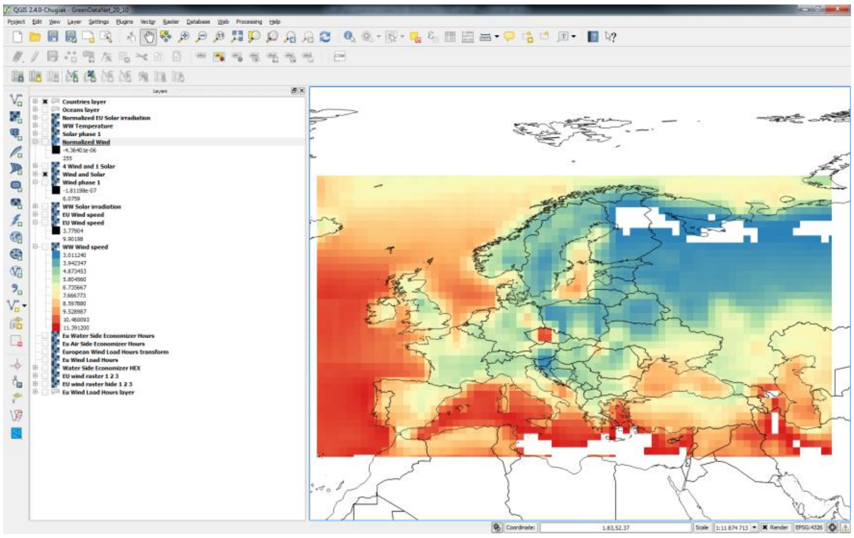
By modifying XMin, XMax, Ymin and YMax, the calculation area could be limited to specific geographic area (Europe for example). The output layer name has to be filled. In this example, the Wind speed is selected without any transformation. The next result appears after the click OK.



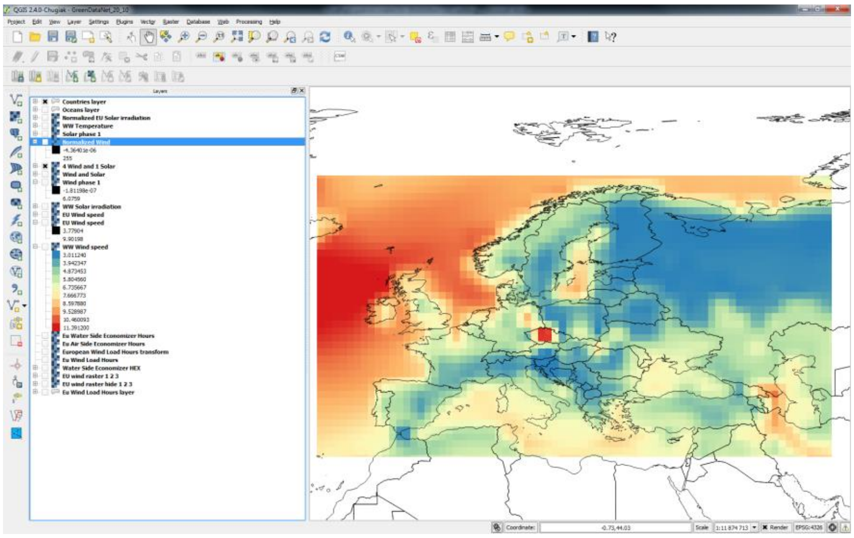
A new layer has appeared with the selected named "EU Wind speed".

The raster calculator allows obtaining these normalized maps by identifying the min and max value for the concern area (in our case Europe).

By applying the raster calculator on the Europe area for Wind and Solar irradiation (normalized both on [0..255] scale), the sum of the map with the same weight for wind and solar irradiation give the following result :



Now by applying 4 times more importance to the wind than to the solar irradiation, the next result appears :



Through this useful tools, it allows to define physical criteria weight and obtain the conjunction of them and identify the potential interesting location.

In the same time, it is possible to define a location and check the corresponding physical parameter allowing to identify the environmental constraint for the data centre.

Hence this tool (and the associated method) developped within the GreenDataNet project and based on the QGIS open-source platform help to integrate various data and map for a given area and to weight them in order to be used as a powerful decision support tool for Data Centre developpers depending on the available data they are interested on.

3. LOCATION IDENTIFICATION

3.1. INTRODUCTION

The goal of this paragraph is to use the decision support tool presented previously and to identify the best locations in Europe for an energy-efficient data centre. By searching for an energy-efficient data centre, a part of this paragraph will detail a potential KPI that could be used to quantify and benchmark this objective.

The other parts introduce several maps allowing identifying for each parameter the best locations for urban data centres as described in GreenDataNet Deliverable 1.1 by taking into account:

1) Temperature in conjunction with air side economizer or water side economizer cooling system,
2) Wind,
3) Solar irradiation.

As explained in the previous part of this deliverable it is possible to consider other parameters (environmental impact, economic calculations, and other renewable resources). But in view of the GreenDataNet framework it has been decided to focus only on the most relevant data to answer to 'Where is the best location for an energy-efficient urban data centre?'.

3.2. LOCATION, RENEWABLE ENERGY AND KPI

The location of data centre depending on the potential of renewable energy must be linked with dedicated KPI that could be used to classify this potential and benchmark the data centre between each other.

The GreenGrid[2] has defined the Green Energy Coefficient (GEC) that could be also finding in the literature as Renewable Energy Factor (REF). It is a KPI to quantify the use of renewable energy managed by owner/operator for its data centre. Renewable energy here is in the form of electricity and not thermal energy. The GEC is defined as the ratio of renewable energy use to all the energy use of the data centre (cooling, IT load, etc…).

The GEC seems to be very simple but the "Green Energy" definition depends on the origin of the Energy. This one could be produce locally (Photovoltaic panel on the roof, Wind turbine generator, etc...) but the energy could also be considered green if the network electricity provider is able to certify the 'green' origin of the electricity (Green Energy Certificate).

This point induces more complexity in the GEC calculation because the Green Energy Certificate depends also of the regional and local authorities.

The GreenDataNet project has to take this point into account in the coming recommendations and not only considering the capability for a data centre to be powered by local renewable energy. It has to be considered in the software architecture specification in sort that information could be exchanged between electricity network provider and data centre owner.

[2] http://www.thegreengrid.org/~/media/WhitePapers/Harmonizing%20Global%20Metrics%20for%20Data%20Center%20Energy%20Efficiency%202012-10-02.pdf?lang=en

3.3. TEMPERATURE AND COOLING SYSTEM MAP CONSIDERATION

In the Deliverable 1.4 "Heat Reuse Feasibility Use Case and Recommendation", the conclusion of the 3.2 paragraph is that air or water side economizer has to be put in place to improve the Data Centre efficiency.

According to that, the next two maps from the Green Grid® present the available hours for both economizer types:

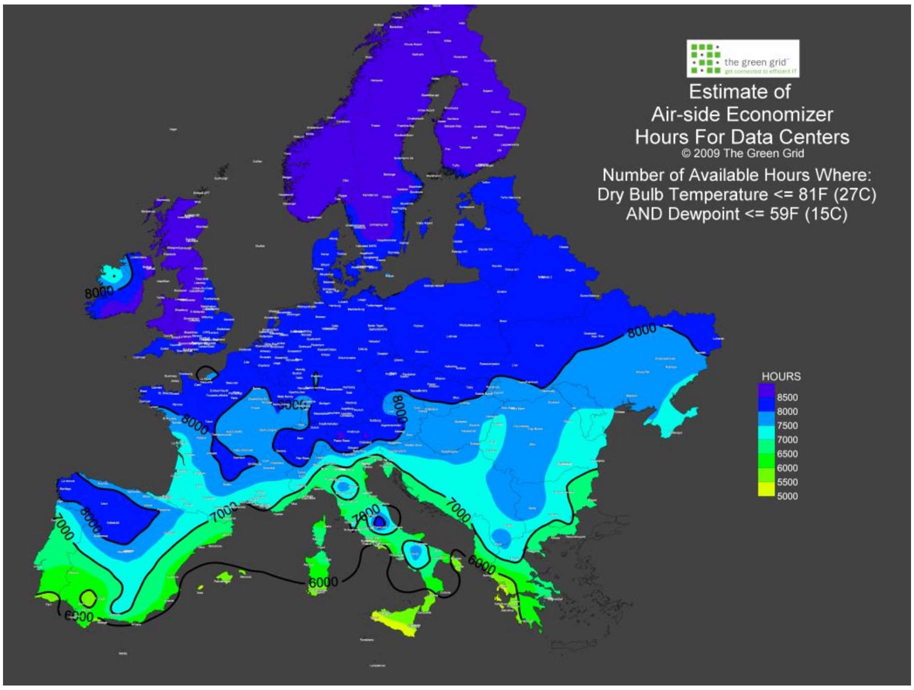


Figure 4 - Air Side Economizer map

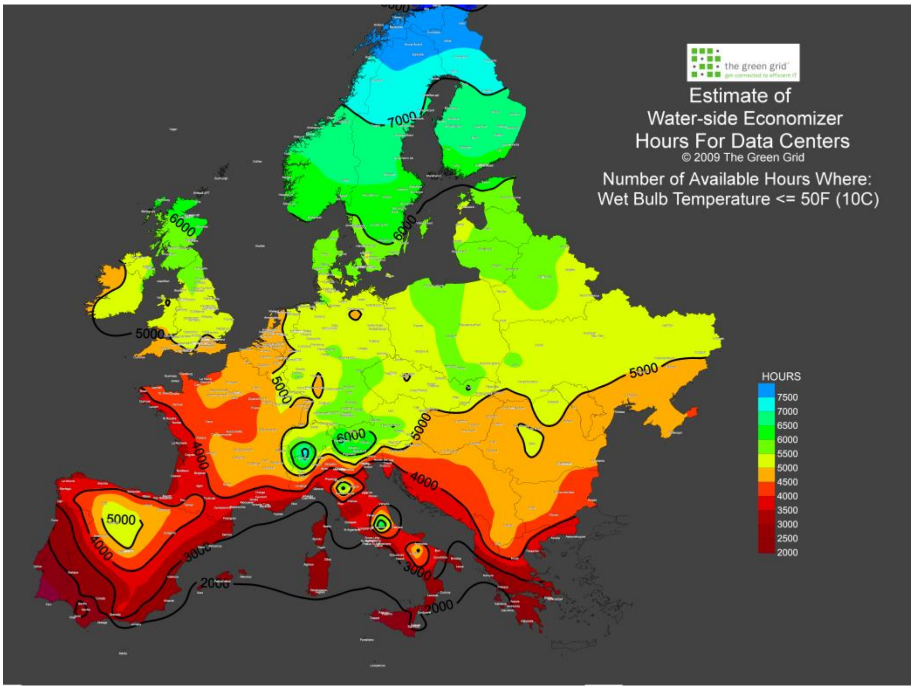


Figure 5 – Water Side Economizer map

By using the QGIS Georeferencer tool and the procedure detailed in the paragraph 2.4.2.2, the previous maps (in.jpg format) could be loaded in the QGIS environment as shown by the **Figure 6** and **Figure 7**.

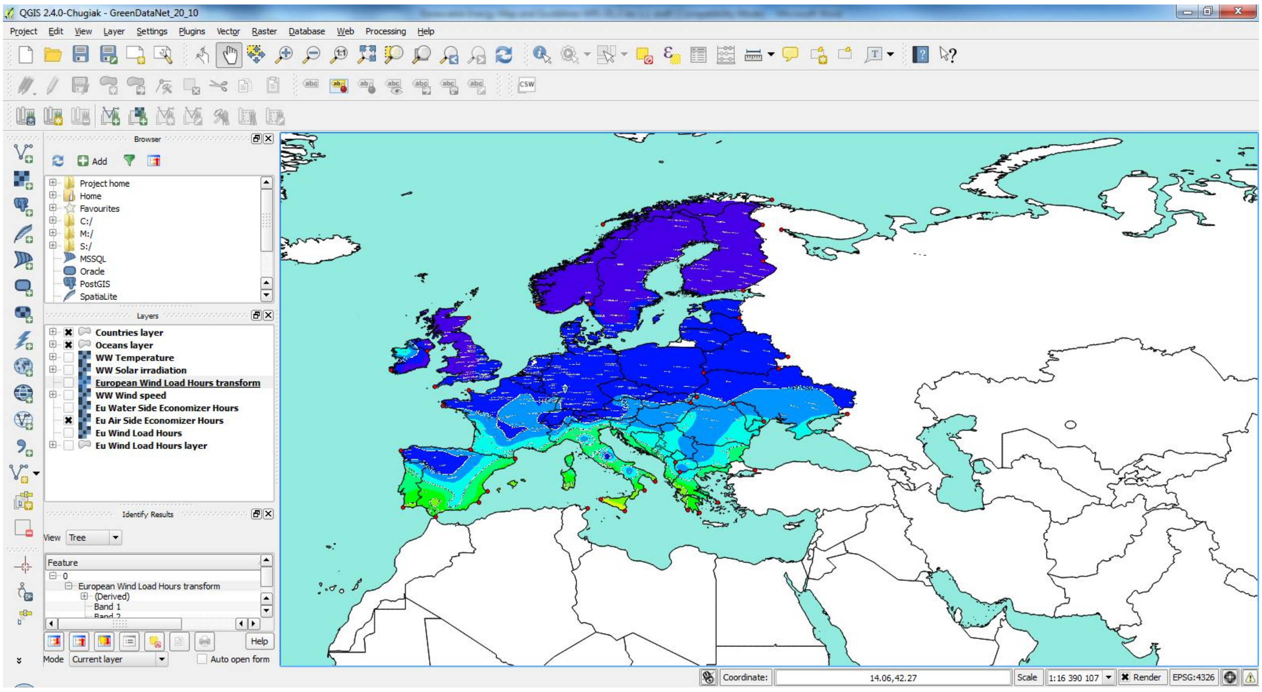


Figure 6 – QGIS integration of the Air Side Economizer map

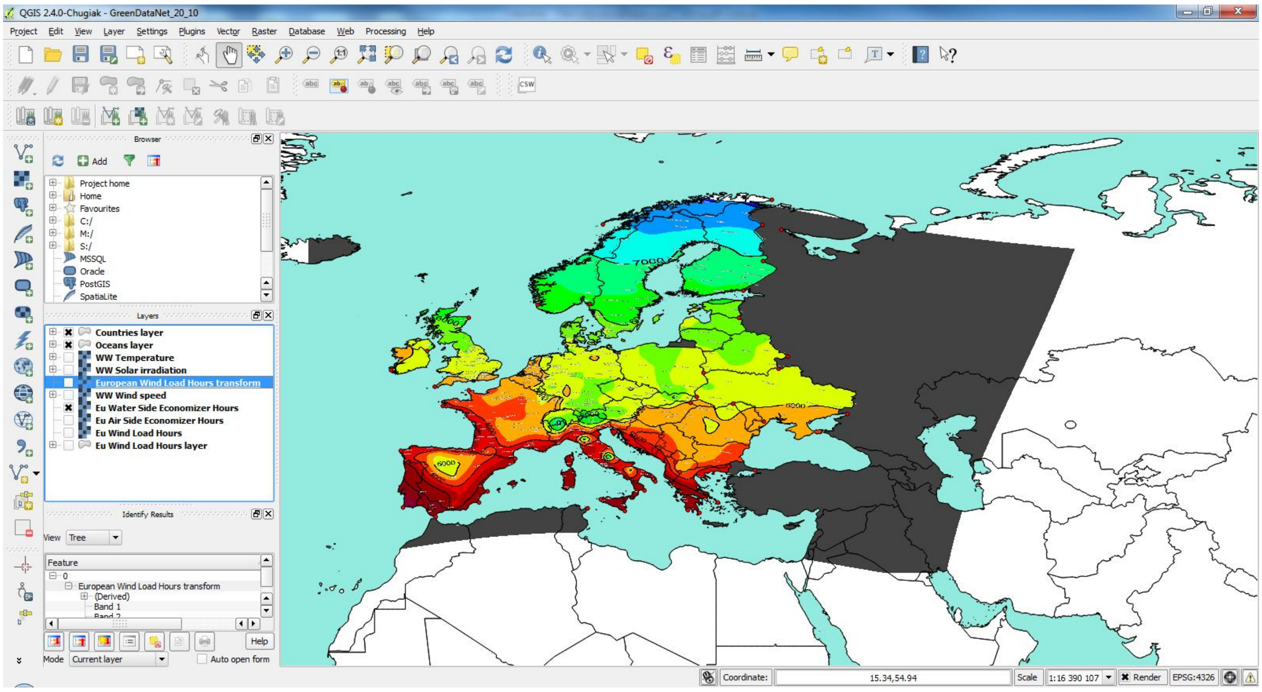


Figure 7 - QGIS integration of the Water Side Economizer map

The threshold of temperature for using water or air economizer could be discussed and changed (for example ASHARE standards allow higher room temperature and therefore also higher water temperature, see Deliverable 1.1), but whatever this threshold the trends for the most appropriate locations will stay similar and only the final PUE of the Data Centre will be modified (increase or decrease).

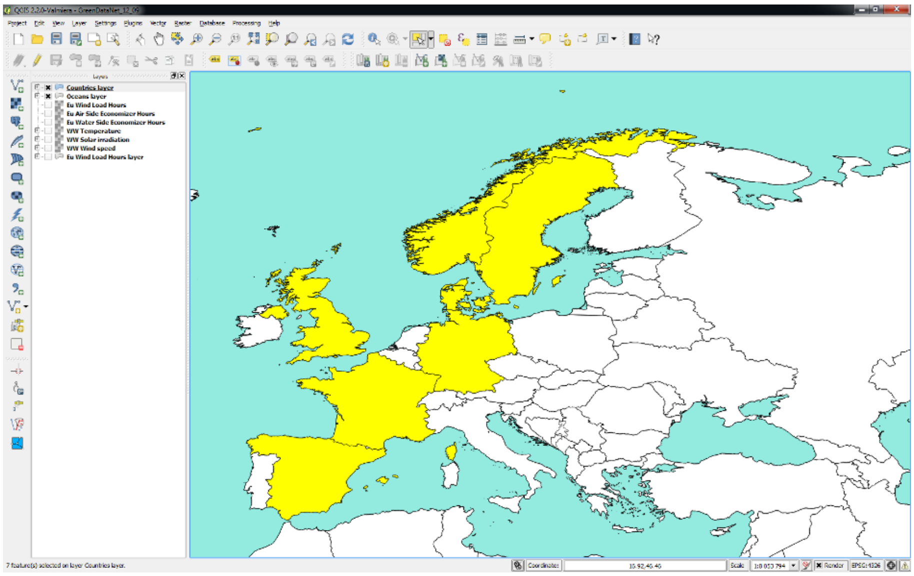
These two previous maps could be aggregated / compared to the temperature map already loaded in the GreenDataNet QGIS project. The point to underline is that lower is the temperature average better is the air or water side economizer usage.
The integration of this data within the developed tool allows in the next part of the document to merge / to compare / to cross-reference the whole data for a deeper analysis of the location choice.

By considering the two previous maps and the associated data, the continental Nordic and French/Switzerland areas seems to be appropriates to install DC using the technologies described in the deliverable 1.4.

The Nordic countries (Norway, Sweden, and Denmark) allow using air side economizer cooling system upper more than 8000 hours per year.

In the same time, the hereafter listed countries are interesting locations to use the water side economizer cooling system:

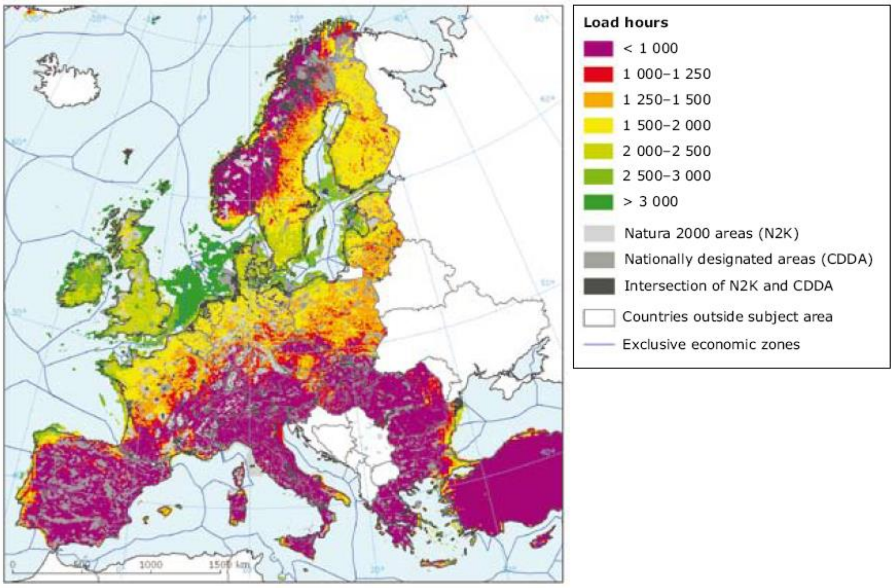
1) Spain
2) Germany
3) South East of France
4) United Kingdom



3.4. WIND ENERGY

The European Environment Agency has published a report "Europe's onshore and offshore wind energy potential[3]. This one provides useful indications (figures and maps) about the best locations of the wind energy capacity, and also lists some associated environmental (on birds, bat and marine species) and social (landscape, noise, area occupied...) constraints to make use of the expected wind power potential. Nevertheless, some local legal and technical constraints are not taken into account to decrease the wind energy potential of the affected areas; for instance the distance to the first home, the distance to weather forecast or aviation radar, and the power limitation of injection to electrical grid could reduce the wind energy potential of a given site.

For example, the **Figure 8** presents the distribution of the full load-hour about wind energy taking into account roughness and some orographic effects, and associates the environmental protected areas.



Source: EEA, 2008.

Figure 8 – Distribution of full load hours in Europe for the wind energy

Thanks to this map and EEA figures, it appears that the main potential wind energy areas are located in the north-west of the Europe and are at 60% onshore (45000TWh of 70000TWh in 2030) and 40% offshore (less than 50m of sea depth) if no environmental, technical or legal restrictions are considered. Moreover it is reported that the most promising European countries for onshore wind energy in absolute values up to 2030 are France, Sweden, United-Kingdom, Finland, Germany, Poland and Spain. The most promising European countries up to 2030 for the development of offshore wind energy, which has a much higher energy density in GWh/km² than onshore wind energy, are the United-Kingdom, Norway, Sweden, Denmark and the Netherlands. According to that, the use of the wind in the scope of the GreenDataNet is complicate to evaluate for a given location and it is suggested to consider wind energy potential mainly through the Green Energy Certificate system that has been explained in the part 3.2.

The wind energy has not to be critical criteria to select the location of the GreenDataNet demonstrator. However, the use of green energy certificates is linked to the country where the current European wind power

[3] http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential

market is mature and important. The yearly report[4] from the EurObserv'ER organism gives important facts and figures about the current wind power market in Europe, and the first fifth European countries with the higher installed windpower capacity in terms of MW are listed as follow and reported within QGIS environment (see **Figure 9**):

1) Germany
2) Spain
3) United Kingdom
4) France
5) Italy

As it is previously suggested to consider wind energy potential through GEC (provided by the country where is installed the data centre) and not local production, the **Figure 9** is more representative than the distribution of full load hours in Europe (see **Figure 8**) that was also integrated within QGIS tool (see **Figure 3**).

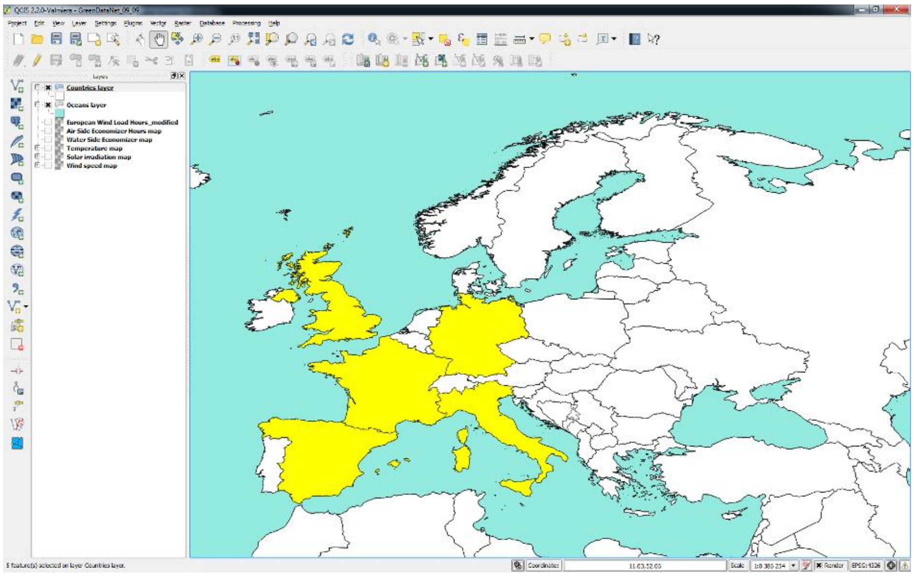


Figure 9 - First five countries in Europe for the electricity production from wind power

Even if these countries have an important potential in term of wind power production, an attention has to be paid to the development of the green energy certificate in each one of this country.

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[4] http://www.energies-renouvelables.org/barometre.asp

3.5. SOLAR IRRADIATION

The next solar irradiation map shows the number of hours available to produce photovoltaic (PV) electricity.

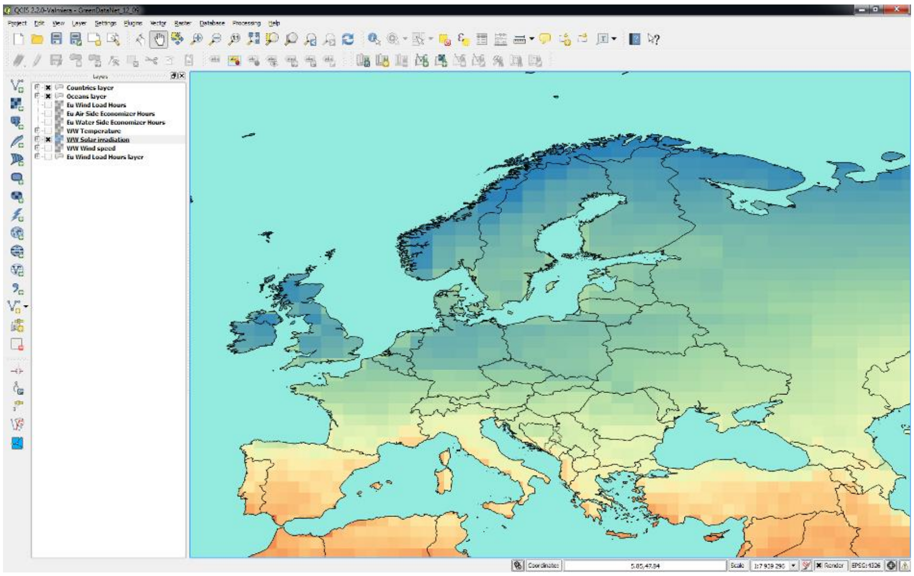

Figure 10 - Solar irradiation map in Europe

The potential PV production is between 900 and 2200 hours per year within Europe. It should be favorable for the GreenDataNet project to select a European south location in the next 3 countries:

1) Spain
2) France
3) Italy

This study of solar irradiation gives a good overview of the solar irradiation over Europe. However due to lots of local specificities that can impact PV production, further investigations with more accurate data and maps (than the data used here with 100km square resolution) are needed to determine the best location within a restricted area and regarding the PV potential.

For instance the following **Figure 11** illustrates local variations of yearly solar irradiation for the restricted area of south-east of France. Beyond the variations at a regional scale there are also more local variations of solar irradiation due to horizon (far shadings) and the near shadings effects. Unfortunately, such high resolution maps or data are not open-source available at Europe scale and then were not used in this task of GreenDataNet project.

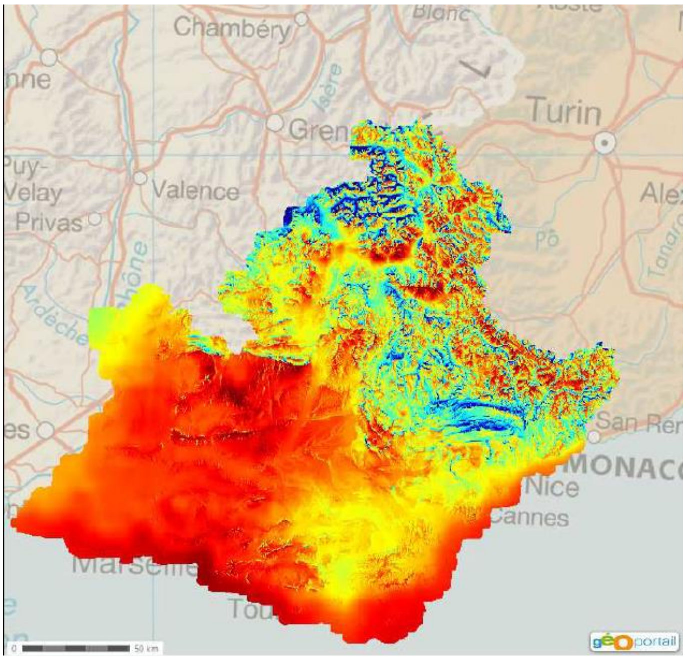

Figure 11 – Yearly solar irradiation map for south-east of France (sources: IGN, Mines ParisTech)

3.6. LOCATION RECOMMANDATIONS

The previous parts (and especially part 3.4) show that the location of the data centre is not only a question of renewable proximity but also the availability of energy network operator to produce renewable energy certificate.

GreenDataNet project aims to address urban DC and this imposes constraints to implement renewable energy locally. So the use of local wind power should not be easy to implement in urban area instead of photovoltaic panel that could be put on the roof of urban buildings.
So the wind energy in the mix of renewable energy use has to be considered through the integration of renewable energy certificates (GEC) and could be de-correlated from the location selection.

By aggregating / rastering / merging the temperature data, the cooling system use, the wind energy certificate map and the solar irradiation data, it appears that four countries are adapted to install an energy-efficient Data Centre for the GreenDataNet project:

1) France
2) Spain
3) Netherlands
4) Switzerland

This list of four countries is not restricted; it gives appropriate areas to develop energy-efficient Data Centre regarding the data and hypothesis chosen (for instance weight for each parameter) for GreenDataNet project. Depending on the aim (economic, environmental, specific renewable energy, urban/not urban location, customers …) of a Data Centre developer and the data he knows, the same method presented here above could be applied to create other maps (for instance for environmental impact a weighted map per country regarding the greenhouse gas emissions of the electricity production mix); then the most adapted locations regarding its criteria of interest to establish its Data Centre could be identified.

For France, the city of Chambéry (SE of France) has been chosen as it is located in area with a good compromise between cold temperature to use air side economizer system and quite high solar irradiation. Moreover the CEA team involved in GreenDataNet project works there and real irradiation data are available for further GreenDataNet steps.
In Spain, the city of Barcelona (NE of Spain) has been selected as there is a high solar irradiation and water side economizer could be deployed. Moreover a high amount of wind power is installed in Spain.
The Netherlands case will allow integrating the impact of the Water or Air Side economizer technology that could improve the Data Centre efficiency. The solar irradiation in Netherlands is quite low but it is very close to countries with high amount of windpower installed (Germany, United Kingdom and France). The city of Amsterdam has been chosen as ICTroom, member of GreenDataNet consortium, has its offices there.
For Switzerland, the city of Zürich (N of Switzerland) was selected as it is a good compromise between cold temperature and solar irradiation. There is slightly less solar irradiation than in Chambéry but the weather is also a little bit colder. Zürich is also the city where is headquartered Crédit Suisse.

Finally it can be underlined that the presented approach in this report uses average data with a relatively low spatial resolution that **do not take into account local effects especially on renewable energy production**. This approach fits well with the requirements to look for a location for big Data Centres that aggregate several customers distributed all over a country, a continent or the world and that aim to optimize the energy consumption. This point is slightly in contradiction with the GreenDataNet project that is focused on small and medium-size urban Data Centre, for which the choice of the location to install it is mainly directed by local demand and existing support structure.
However **the approach presented in this part and the previous one can be duplicated for a more restricted area** (country, land, district, city…) with dedicated data and information in order to find the most appropriate places to install the Data Centre in this studied restricted area.

Once appropriate locations in Europe have been selected to build an energy-efficient Data Centre, it is interesting to have a first overview of the local energy behaviour of this Data Centre. It permits to give through

energy simulations a good overview, especially of the potential green performance, for the next Work Packages.
The Green Energy Certificate system for wind energy that is suggested for GreenDataNet is out of the framework of the local energy management of the Data Centre. Then it does not have any impact and will not be consider for the simulations.
The solar irradiation data will be considered for the local energy management of the Data Centre in order to produce electricity from renewable resources as it is possible to easily install PV panels on the roof or on the surroundings of the building where the Data Centre is hosted.
The location of the Data Centre has a great impact on the choice of the cooling technology and on its rate of use. A higher need of cooling and a less efficient cooling technology increase the energy consumption for other loads than IT and so the PUE, and create seasonal variations. As the choice of the cooling technology and the calculation of resultant energy consumption are wide and very specific topics, it has been decided for the first energy simulations to stay focus on the IT electricity consumption and to have cooling and auxiliary powers that are not location-dependant (so to not make a lot of calculations to define the adapted cooling for each location). Nevertheless it has to be kept in mind that cooling loads could be more or less important depending on the Data Centre location, and so the locations with the more PV resources would have the higher cooling requirements (and so the lower P.U.E) whereas the locations with the poorest PV resources would have the lower cooling requirements.
Finally, the size of Data Centre could have an important impact for the size of the photovoltaic area install for the Data Centre. According to that and to the Deliverable 1.1 definition of GreenDataNet Data Centre, four different power sizes of urban Data Centre will be considered. A size of 20kW will be considered for the urban Data Centre Type I (small size), and three power sizes (80kW, 160kW and 220kW) will be taken into account to cover the wide range of Data Centre Type II (medium size).

Hence in the next part of this deliverable, results of simulations of local energy management with local PV production, IT electricity consumption and local electricity storage will be performed. It aims to give a first overview on how much renewable energy is needed to cover the IT loads, cooling loads, and auxiliary loads (UPS, transformers, lighting …) of different sizes of urban Data Centres as defined in GreenDataNet project.

4. SIMULATIONS AND SIZING SOFTWARE TOOL FOR ENERGY STORAGE AND PV INSTALLATION

4.1. INTRODUCTION

The aim of this subtask is to develop a software tool for optimally sizing the energy storage and the PV installation to be connected to a DC system. The subtask is divided into two components:

- The solar data generation for the sites to be simulated according to an orientation and a tilt angle
- The simulation and sizing of energy storage and PV installation regarding IT loads of a DC

In order to meet these requirements, the work is based on two software tools developed in CEA:

- S2D which is a software tool for solar data generation. The S2D tool transposes solar irradiation data on a specific site according to an orientation and a tilt angle and generates the solar production data.
- M2C which is a simulation platform for the development of advanced energy management strategies for combined systems including photovoltaic generation. M2C is used for sizing and simulating the different components of the system.

According to QGIS results (see 3.6), the sizing of energy storage and PV plant is performed on 4 sites:

- Chambéry, France
- Zürich, Switzerland
- Barcelona, Spain
- Amsterdam, Holland

Each set of simulation is directed by a goal. Four kinds of simulation are done according to four goals:

- Goal 1: optimal sizing of energy storage and PV installation in order to attempt 20% of self-production and to maximize the self-consumption.
- Goal 2: optimal sizing of energy storage and PV installation in order to attempt 40% of self- production and to maximize the self-consumption.
- Goal 3: optimal sizing of energy storage and PV installation in order to attempt 60% of self- production and to maximize the self-consumption.
- Goal 4: optimal sizing of energy storage and PV installation in order to attempt 80% of self-production and to maximize the self-consumption.

For each simulation, the performed steps are:

1. Selecting the buildings that constitute the simulated site on the graphical user interface of S2D
2. Generating the solar data for the selected site and obtaining the configuration for M2C simulation
3. Choosing the parameters of M2C simulation. In this step, the system is defined, i.e. the components, as well as the simulation and control time frames, the storage system, and the peak power of the PV installation
4. Running the simulations and examining results
5. Calibrating the parameters according to the simulation results and rerunning the simulation with the new parameters as long as the simulation goal is not reached.
6. Saving the values of annual consumption, self-production, self-consumption … The results are presented using a Graphical User Interface (GUI).

The document is organized as follows: in the next section the solar data generation tool (S2D) is presented. Then, the generation process of the solar data irradiation in the selected sites is shown using S2D. The third subsection presents the M2C simulation platform. The energy management strategy and the PV and battery models used in the simulations are introduced. Finally, the results of simulations are presented in subsection 4.

4.2. SOLAR DATA GENERATION

The S2D platform (Solar PV Simulation Data Producer) is a web application, developed in CEA, based on Html5, PHP and JS technologies. S2D transposes the solar data irradiation on a specific site according to an orientation and a tilt angle and generates the solar production data series (kWh/kWp and kWh). The aims of this platform are:

- Proposing a graphical interface based on web technologies allowing the user to select easily the location of the PV installation named « PV installation map » on a map
- Delivering an estimation of the production of the selected « PV installation map » based on historical data and calculated in real-time
- Managing the users' rights and saving the information for each « PV installation map »
- Allowing the access to the different sources of solar irradiation without addressing the problem of several data format proposed by these sources
- Transposing the solar irradiation data according to the orientation and the tilt angle based on a library of proposed methods of transposition (Hay [5], Peres [6], Klein [7], …)
- Generating of solar production data for the « PV installation map » based on a PV production model
- Comparing different sources of solar irradiation data (SODA [8], MeteoNorm [9], …)

The solar data generation is realized by using S2D (Solar Simulation data producer). The solar data irradiation series used for GreenDataNet is based on the SODA irradiation data series. The transposition model used is the Peres model. First step consists in selecting the simulation sites on the S2D interface. The simulations are done on 4 buildings of the 4 sites as noted before:

- Chambéry, France – Technolac technology center where CEA-INES is located
- Zürich, Switzerland – Crédit Suisse offices
- Barcelona, Spain – some buildings of a local university
- Amsterdam, Holland – ICTroom building

For each site, the buildings that constitute the site are selected. The orientation angle and the tilt angle are chosen for each site according to the position and the orientation of the buildings composing the site. Then, S2D generates the data solar production information according to the chosen orientation and the tilt angle.

Figure 12 presents the Zürich simulation site in the S2D GUI. The total area of buildings constituting this selected site is about 11070 m². The equivalent possible peak power PV installation on this site is 1439 kWp taking into account place really available on the roof and shadow effects between PV modules based on CEA experience.

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[5] Dynamic Global-to-Direct Irradiance Conversion Models---Perez, R., P. Ineichen, E. Maxwell, R. Seals and A. Zelenka, (1992): Dynamic Global-to-Direct Irradiance Conversion Models. ASHRAE Transactions-Research Series, pp. 354-369.

[6] Calculation of monthly mean solar radiation for horizontal and inclined surfaces, E Hay - Solar Energy, 1979 – Elsevier

[7] Calculation of monthly average insolation on tilted surfaces, SA Klein - Solar energy, 1977 - Elsevier

[8] SODA : http://www.soda-is.com/

[9] MeteoNorm: http://www.meteonorm.com/

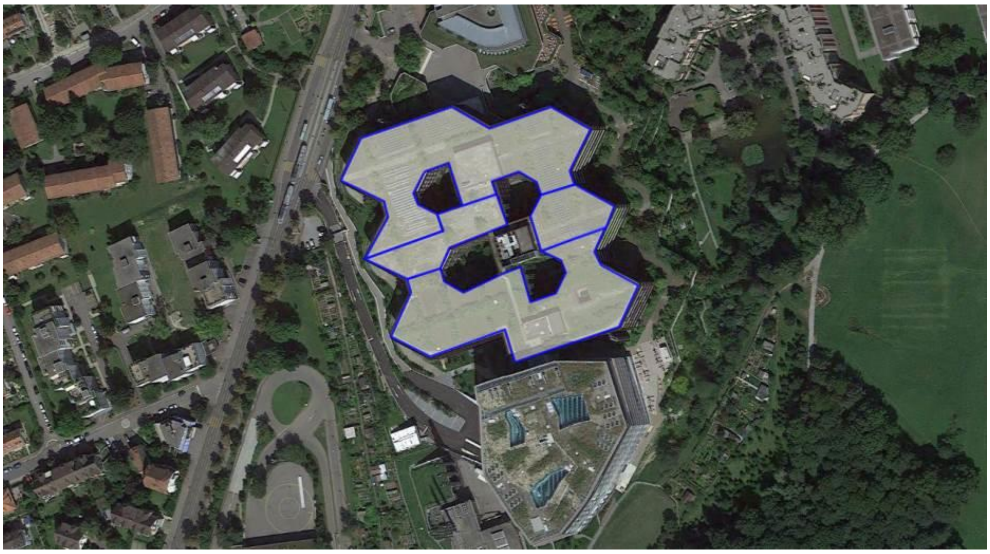

Figure 12 – Selection of the Zürich simulation site in the graphical interface of S2D

Figure 13 presents the solar production data series generated by S2D for Zürich simulation site. The chosen tilt angle for this site is 30° (due to the latitude) and the orientation angle is 45° (orientation toward South-West due to building orientation).

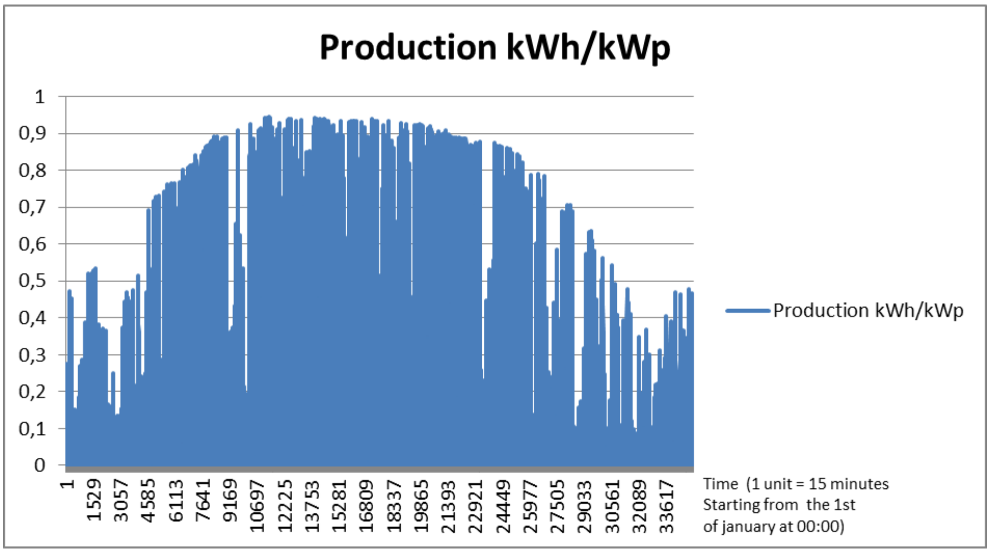

Figure 13 - Production kWh/kWp for Zurich simulation site (tilt: 30°, orientation: 45°)

Whereas, Figure 14 presents the Barcelona simulation site in the S2D GUI. The total area of buildings constituting this site is about 7563 m^2. The equivalent possible peak power PV installation on this site is 983 kWp due to real place available on the roof and shadow effects between PV panels.

Figure 14 - Selection of the Barcelona simulation site in the graphical interface of S2D

Figure 15 presents the solar production data series generated by S2D for Barcelona simulation site. The chosen tilt angle for Barcelona simulation site is also 30° and the orientation angle is 45° (orientation toward South-West due to building orientation).

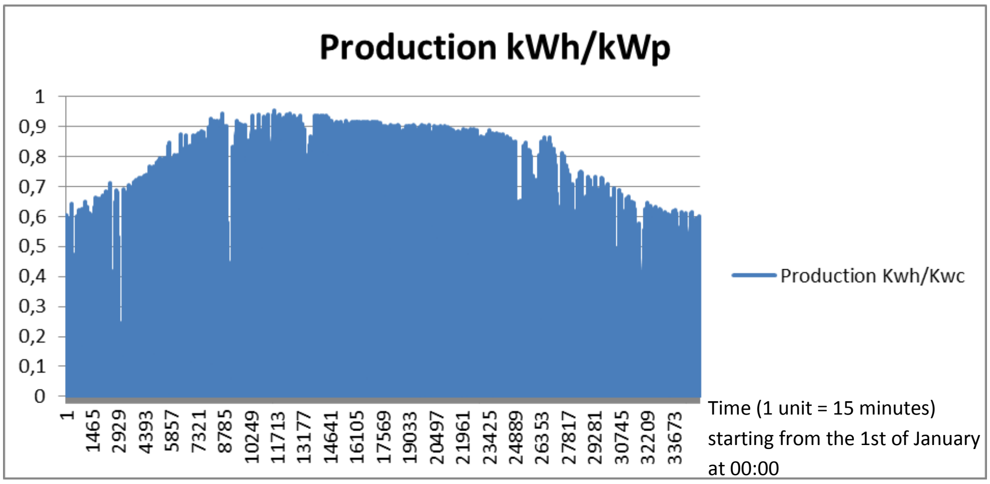

Figure 15 - Production kWh/kWp for Barcelona simulation site (tilt: 30°, orientation: 45°)

Then, Figure 16 presents the Amsterdam simulation site in the S2D GUI. The total area of buildings constituting this site is about 5565 m2. The equivalent possible peak power PV installation on this site is 723 kWp due to real place available on the roof and shadow effects between PV panels.

Figure 16 - Selection of the Amsterdam simulation site in the graphical interface of S2D

Figure 17 presents the solar production data series generated by S2D for Amsterdam simulation site. The chosen tilt angle for this site is 30° and the orientation angle is 45° (orientation toward South-West due to building orientation).

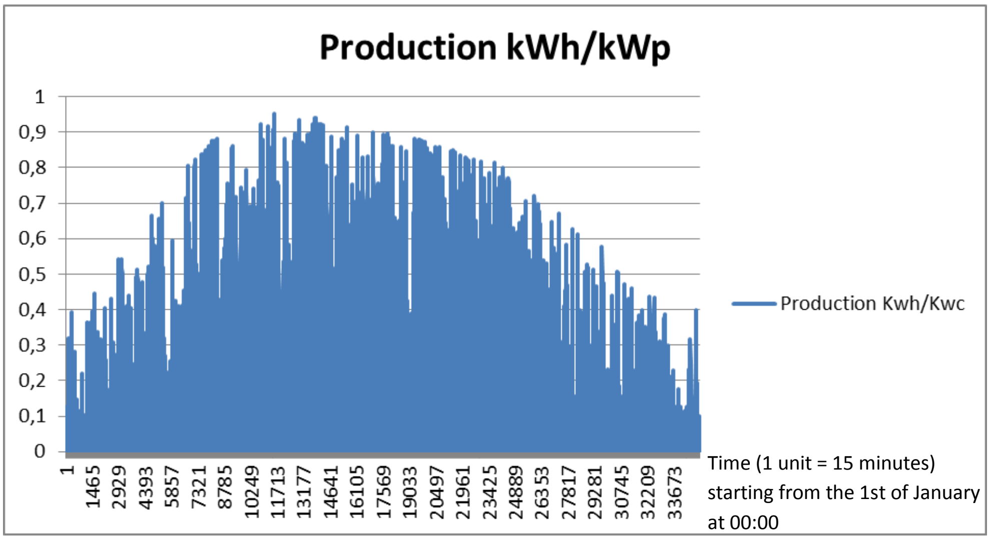

Figure 17 - Production kWh/kWp for Amsterdam simulation site (tilt: 30°, orientation: 45°)

Moreover, Figure 18 presents the Technolac-Chambéry simulation site in the S2D GUI. The total area of buildings constituting this site is 83855 m^2. The equivalent possible peak power PV installation on this site is 10901 kWp due to real place available on the roof and shadow effects between PV panels.

Figure 18 - Selection of Chambery simulation site in the graphical interface of S2D

Figure 19 presents the solar production data series generated by S2D for Chambery simulation site. The chosen tilt angle for this site is 30° and the orientation angle is 0° (orientation toward South to optimize PV production).

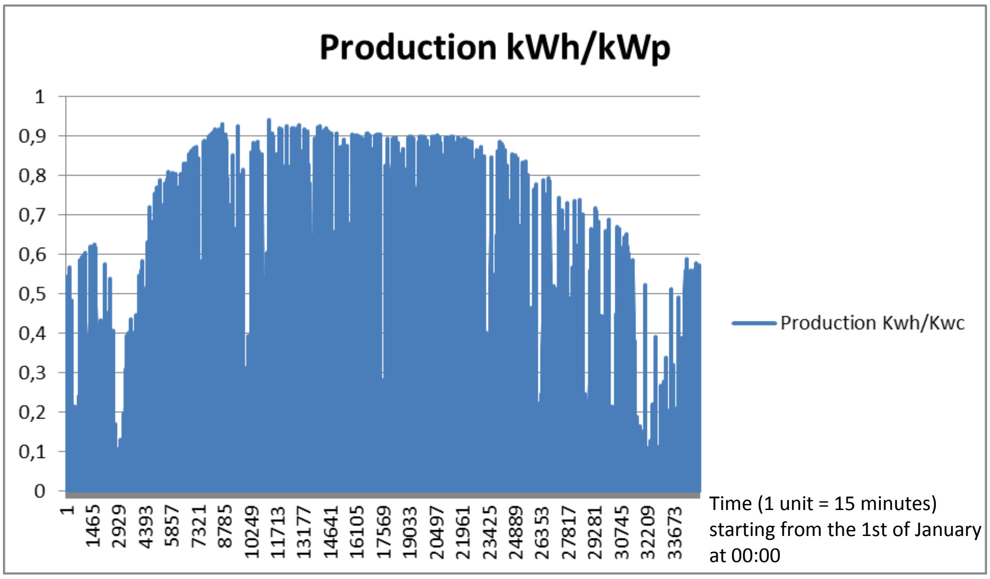

Figure 19 - Production kWh/kWp for Chambery simulation site (tilt: 30°, orientation: 0°)

4.3. SIMULATION AND SIZING OF ENERGY STORAGE AND PEAK POWER FOR PV INSTALLATION

4.3.1. SIMULATION AND SIZING OF ENERGY STORAGE AND PEAK POWER FOR PV INSTALLATION

The sizing is realized using the platform M2C[10,11]. M2C is a simulation platform, developed in CEA, for the development of advanced energy management strategies for combined systems including photovoltaic generation.

4.3.2. M2C SIMULATION PLATFORM

The aim of the M2C platform is to support the development and the comparison between different energy management strategies and different sized of system components. There are plenty of choices of strategies for controlling energy consumption and energy production. The strategy can be treated as an optimization problem, or as a classic control problem, and more generally as an artificial intelligence problem. A strategy has to determine the service's degree of freedom and the optimization method that will be used. The number of strategies is large, so a tool is needed to help decision making for selecting the more adequate strategy. The M2C platform will be presented as a tool for designing and selecting energy management strategies. The M2C platform is used also for sizing and simulating the different components of the system.

M2C is able to consider different power system configurations. As a result, it offers the user the possibility to build its own system by defining its components from a model's library, the simulation and control time frames, and the desired energy management strategy. The software is developed based on an Object Oriented Programming technique.

In a single simulation run, M2C is able to consider different models for the components of the same system. Simplified component models can be used for computing the system control in a reasonable calculation time, while advanced models are used for simulating the operation of the different components, taking those calculated controls into account.

The software architecture is detailed in **Figure 20**. In this figure, the flow chart on the left describes the different steps of the operation of the software, while the right side gives the M2C libraries associated to the different steps.

- The first step consists in defining the system, i.e. the components, the simulation and control time frames, as well as the selection of the adequate strategy. This definition is based on real-world data included in the data library.
- In the second step, the system control is computed from solving the optimization problem defined in the selected strategy. Such strategy is taken from the strategy library, and the mathematical models used for the optimization are described in the component library for control.

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[10] Ha, D. L., Lapierre, B. C., Besson, P., Bourry, F., "Advanced simulation platform M2C for the development of Home Energy Management System". Dubrovnik, Croatia, 2011

[11] Bourry, F., Ha, D.L., "Advanced simulation tool for the optimal management of photovoltaic generation in combined systems". PowerTech (POWERTECH), 2013 IEEE Grenoble , pp.1-6, 16-20 June 2013

- Then, the simulation is carried out from the components' model implemented in the adequate component library.
- Finally, Graphical User Interfaces have been developed for the construction and the visualization of the results, using generic libraries.

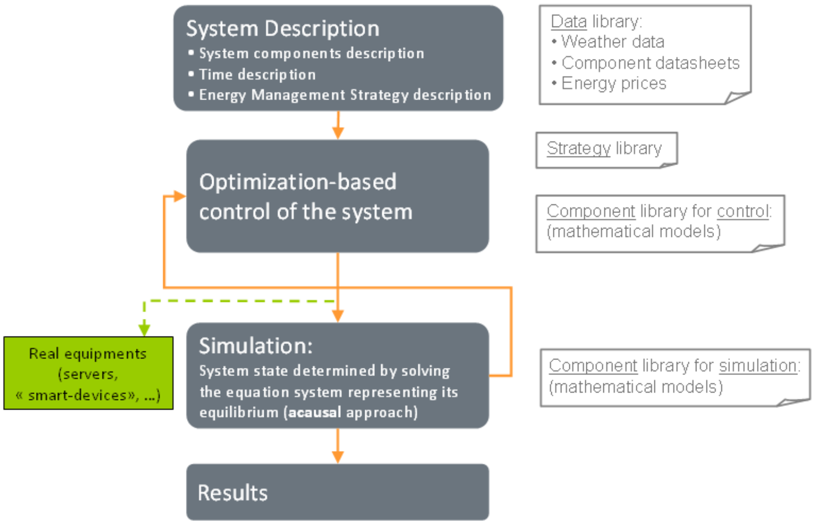

Figure 20 - Architecture of M2C platform

Instead of using M2C platform developed at CEA, commercial tools are also dedicated to energy simulation of electrical systems in order to optimize their running. One of the most known software to simulate microgrids with multiple energy sources (and especially from renewables) is HOMER PRO software from HOMER Energy Company.

The HOMER PRO software has its own solar irradiation data base and the battery model is defined trough generic and independent parameters (capacity, maximum power in charge and in discharge, round-trip efficiency). Moreover only two different energy strategies are available in HOMER PRO, target of a SOC for the battery and load following, and two ways to optimize the running of the energy system, economic or fuel minimization. As it was decided to be able having customized strategy for energy management in GreenDataNet and also different levels of accuracy of models of components, all the simulations have been performed thanks to M2C platform. In this way, a team of the RIT[12] has also developed its proper software in order to improve on HOMER PRO by including more realistic battery modeling (including for instance temperature effects, rate-based variable efficiency and capacity fade).

However in order to compare the performances of HOMER PRO and M2C software four examples of simulation with a DC of 20kW in Barcelona and the four self-production goals (20%, 40%, 60% and 80%) are given in 6. Appendix. For the two software the results appear very close with a difference of more or less 2%. Hence the accuracy of M2C platform is comparable to the one of world-recognized commercial simulation software for hybrid systems and smart grids but it permits in the same time a greater freedom of choice for defining energy strategy and realistic battery modelling.

[12] Hittinger, E., Wiley, T., Kluza, J., Whitcare, J. , "Evaluating the value of batteries in microgrid electricity systems using an improved Energy Systems Model". Energy Conversion and Management, vol. 89, pp.458-472, 2015

4.3.3. MODELLING OF SYSTEM

For the performed simulations the selected strategy allows to charge batteries as soon as an extra PV production is observed in order to minimize the consumption of electricity from the network. The charge of the batteries is used for the next day energy needs (daily recycling). In general, this strategy extends the autonomy of the site and increases the rate of self-production.

4.3.3.1. ENERGY STORAGE SYSTEM (ESS) MODEL

The ESS is modeled through its delivered or absorbed power (P_{ESS}) on the AC side of the ESS and its State of Energy (SOE); the power P_{ESS} is taken positive when the ESS is delivering power (discharge) to the system (here the DC), and alternatively negative when absorbing power (charge) from the system. Nominal energy as well as nominal power and charge and in discharge are also defined in the model for the battery and of the ESS (including conversion).

The constraints associated to P_{ESS} and SOE are the following:

- [SOE definition and evolution]:

$$SOE(t+1) = SOE(t) - \left[\eta\left(SOE(t), P_{ESS}(t+1)\right) \times P_{ESS}(t+1) \times dt \right] / Esto$$

  - $SOE(t+1)$ is the SOE at the simulation time t+1; $P_{ESS}(t+1)$ is the delivered or absorbed power during the period $[t, t+1]$.
  - $\eta\left(SOE(t), P_{ESS}(t+1)\right)$: The ESS efficiency η is a function of the actual SOE and the delivered or absorbed power. Such efficiency takes into account the whole ESS including electrochemical storage, the auxiliaries and the converters associated to the ESS.
  - dt is the simulation time step;
  - $Esto$ is the considered energy size of the ESS

Note that the energy storage size $Esto$ can vary along the simulation period. This variation is due to ageing. Consequently, the energy size could be a function of the time. More precisely, it could be a function of the ESS operation in order to take into account both the cycle ageing and calendar ageing.

- [SOE bounds]:

$$SOE_{min} \leq SOE \leq SOE_{max}$$

- [P_{ESS} bounds]:

  $P_{ESS-chmax\_SOE}(SOE) \leq P_{ESS} \leq P_{ESS-dchmax\_SOE}(SOE)$

  - $P_{ESS-chmax\_SOE}$ is the maximal charging power for the ESS; it is a function of the SOE; $P_{ESS-chmax\_SOE}$ is given relatively to the maximal charging power for the ESS $P_{ESS-chmax}$, which is independent from the SOE.
  - Similarly, $P_{ESS-dchmax\_SOE}$ is the maximal discharging power for the ESS; it is a function of the SOE; $P_{ESS-dchmax\_SOE}$ is given relatively to the maximal charging power for the ESS $P_{ESS-dchmax}$, which is independent from the SOE.

The technologies considered in simulation performed for this deliverable are detailed hereafter: the values of the different model parameters and functions presented above will be provided from the analysis of the experimental results of the operation of a commercial lithium-ion ESS with $Li_{(1-x)}(Ni,Co,Al)O_2/Li_xC_6$ technology (also named NCA/C).

The Nissan Leaf lithium-ion battery, which will be used for GreenDataNet project, is based on a slightly different technology of lithium-ion battery, $A*Li_{(1-x)}Mn_2O_4 + B*Li_{(1-y)}NiO_2/Li_{(Ax+By)}C_6$. The values of efficiency in charge and in discharge and the limitations of power in charge and in discharge could be different from the values chosen for this set of simulations but would be very close; in the framework of Deliverable this assumption is more than sufficient to give a first approximation of PV power and ESS size required for different DC powers (IT consumption) at different locations.

4.3.3.2. PV MODEL

The PV system can be modeled from the global irradiation on the plan of the PV panel, as well as the ambient temperature[13]:

$$P_{PV} = \alpha \times P_{Pk} \times {}^{G_{Glob}}/_{G_{ref}} \times \left(1 + \beta \times \left(T_a - T_{ref} + (T_{NOCT} - 20) \times {}^{G_{Glob}}/_{G_{NOCT}}\right)\right)$$

- P_{PV} : time series of the delivered AC power from the PV system (kW)
- P_{Pk} : installed power (peak power) (kWp)
- α : efficiency (p.u.)
- β : temperature coefficient (° C^{-1})
- G_{Glob} : time series of global irradiation on the PV module plan (W/m^2)
- G_{ref} : reference irradiation (1000 W/m^2)

[13] Skoplaki, E., et J.A. Palyvos. « On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations ». Solar Energy 83, no. 5 (May 2009): 614-624

- G_{NOCT} : "nominal" irradiation (800 W/m^2)
- T_a : time series of ambient temperature (°C)
- T_{ref} : reference temperature(25 °C)
- T_{NOCT} : nominal operating cell temperature (47 °C)

Such model is based on the time series of the global irradiation on the plan of the PV module G_{Glob} and of the ambient temperature T_a. The period of these time series has to cover the simulation period. The time series time step can be different from the simulation time step. If the G_{Glob} or T_a time series time step is lower than the simulation time step, the mean value of the time series during the simulation time step will be considered. Alternatively, if the G_{Glob} or T_a time series time step is higher than the simulation time step, the time series will be interpolated (linearly) to the simulation time step. The power delivered by the PV to the system (here the DC) P_{PV} is always positive.

4.3.3.3. GRID MODEL

The grid is modeled through its power P_{grid} delivered by or injected to the system (here the DC). The power is taken positive when delivered by the grid to the system (grid is considered as a source), and negative when injected to the grid from the system (grid is considered as a load).

- [P_{grid} limits]:

$$P_{gridLoad\ max}(t) \leq P_{grid} \leq P_{gridSource\ max}(t)$$

  - $P_{gridLoad\ max}(t)$: Maximum power injected to the grid. This value can vary depending on the time of the simulation. It can for example depend on the hour of the day.
  - $P_{gridSource\ max}(t)$: Maximum power in delivered by the grid. This value can vary depending on the time of the simulation. It can for example depend on the hour of the day.

4.3.3.4. SIMULATION TIME-STEP AND PERIOD

The sizing tool is based on a simulation of the operation of the system. Such simulation gives the energy delivered or absorbed by the different components for each time step of the simulation period. Consequently, the simulation time step dt (in seconds) and the simulation period T (in days) are some parameters of the M2C. Also, the simulation is based on either the time series of the PV production, or the times series of the global irradiation and the ambient temperature. Such time series may cover a time range which is wider than the simulation period. Consequently, the start time, which is the time from which the simulation is started, is another parameter (the date format will be given in yyyy-mm-dd HH:MM). Note that the simulation end time corresponds to the addition of the start time and the simulation period. Generally, the simulation period will be set to one year for sizing purpose, in order to consider the seasonal aspect of the PV generation. Consequently, common parameters for the start time and simulation period will be:

$$dt = 3600\ (s)\ startTime = \ yyyy/01/01 \text{ and } T = \ 365\ (d)$$

4.3.3.5. GOALS OF THE SIMULATION

Before listing the goals of the simulation, the notions of self-production and self-consumption must be introduced. The self-consumption rate is the share of local electricity production (here PV production for the DC) that is directly consumed by the local loads [*PV consu site*] regarding the total local electricity production [*PV tot site*]; this rate can be increased for instance by using Energy Storage System (ESS) or by shifting the loads in phase with the local electricity production.

$$Self\ consumption\ rate = \frac{E_{\text{PV consu site}}}{E_{\text{PV tot site}}} = 1 - \frac{E_{\text{injected to grid}}}{E_{\text{PV tot site}}}$$

The maximum value of self-consumption rate for a given site with PV and loads is the minimal value between 1 (i.e. for 100%) and the result of the division of the total electricity consumption by the loads of the site per the total local electricity production (here from PV).

The self-production rate is the share of local electricity production (here PV production for the DC) that is directly consumed by the local loads [*PV consu site*] regarding the total electricity consumption of the local loads [*load tot site*].

$$Self\ production\ rate = \frac{E_{\text{PV consu site}}}{E_{\text{load tot site}}} = 1 - \frac{E_{\text{supplied by grid}}}{E_{\text{load tot site}}}$$

The maximum value of self-production rate for a given site with PV and loads is the minimal value between 1 (i.e. for 100%) and the result of the division of the total local electricity production (here from PV) per the total electricity consumption by the loads.

The self-production rate could be considered as the electrical part of the GEC indicators, and is equal to it if no thermal energy is considered and if only local green electricity production is taken into account (no purchase of electricity with green certificates to the network electricity provider).

As explained before, four types of simulation directed by four goals were considered:

- Goal 1: optimal sizing of energy storage and PV installation in order to attempt 20% of self-production and maximize the self-consumption.
- Goal 2: optimal sizing of energy storage and PV installation in order to attempt 40% of self-production and maximize the self-consumption.
- Goal 3: optimal sizing of energy storage and PV installation in order to attempt 60% of self-production and maximize the self-consumption.
- Goal 4: optimal sizing of energy storage and PV installation in order to attempt 80% of self-production and maximize the self-consumption.

The simulations are done based on four sizes of DCs as explained in 3.6:

- Small DC (Type I): 20kW
- Medium DC (Type II): 80kW, 160 kW, 220kW

The same power consumption profile is used for each DC size and the normalized power consumption profile of Data Centre for a year (see Figure 21) is just up scaled depending on the DC nominal power. This data comes from real monitoring of a large Data Centre which is not in line with the DC defined for GreenDataNet; nevertheless the average P.U.E about 1.6 make this profile valuable for the small and medium sizes Data Centre defined in GreenDataNet.

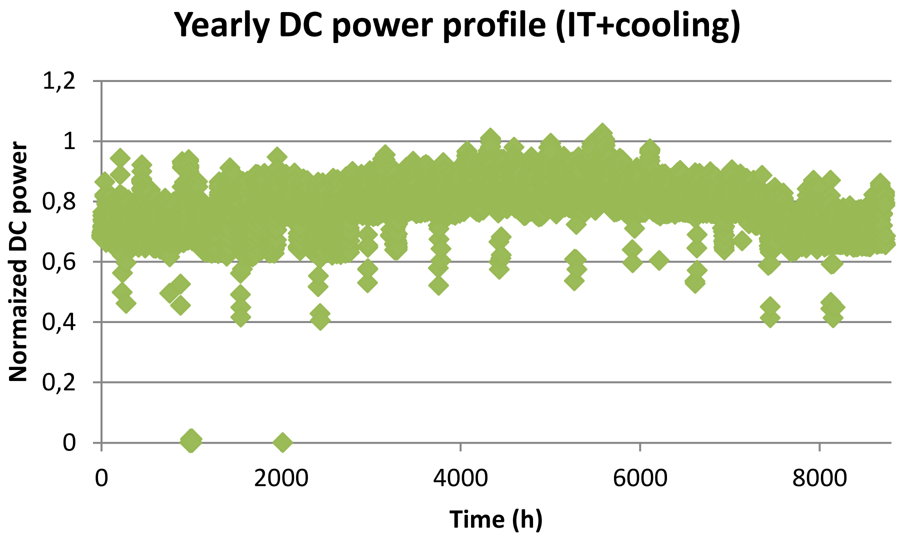

Figure 21 – Normalized Data Centre power profile for a year including IT loads, cooling loads, and auxiliary loads (transformers, UPS, lighting) based on real measurement on a DC located in Switzerland (Source: GreenDataNet)

It can be observed in the figure here above that the total power consumption of a Data Centre for professional application is almost constant all over the year; The daily or weekly variations of DC power consumption is of more or less 10% and this variation is mainly due to cooling system start and stop depending on the cooling storage, the use of DC and the ambient temperature. Indeed the monthly variations of IT loads are in average below 1%. A seasonal effect can be observed due to cooling requirement higher in summer than in winter; the values of P.U.E in winter are about 1.3 to 1.4 whereas in summer they are about 1.8 to 1.9. It has to be kept in mind that these values of P.U.E for this Data Centre vary depending on the location and so are higher for Data Centre located in warmer weather; but as the impact of the four selected locations on this cooling requirement (and P.U.E value) are difficult to estimate the hypothesis of the same cooling needs for the four locations was considered because the seasonal variations is only about more or less 10% for a location in the centre of Europe. This hypothesis permits to have sufficient overview of the PV and storage requirements for different sizes of DC and different locations which is the aim of this deliverable.

The results of the four locations of DC are presented in the following sections. For each site, the results of simulations are presented with the different combinations of parameters. The results of the simulations in the case of Barcelona are detailed as it represents the most important solar production site among the simulated cases, whereas only selected simulations are presented for the three other places. It has to be noted that the number of simulations done to obtain the results for each location is 160 simulations (4 DC sizes * 4 goals * 10 simulations to converge thanks to heuristic algorithms) and the execution time for each simulation is about 20 minutes.

The convergence found for each simulation gives a good overview of the required sizes of PV and storage installations; nevertheless it has to be underlined that it is not proven to be the optimal global solution between PV size and battery size regarding the DC size and the given location. A wider simulation plan with a more accurate optimization algorithm is required to find this optimal global sizing of PV and storage, but such work was not performed as it is not the aim of the Deliverable 1.3 that deals with software tools for PV and storage installation.

This optimization method to size correctly the renewable sources (here the PV) and the storage has to be applied as soon as more accurate data are available and/or fixed for the simulation regarding the ESS (battery efficiency, battery limitations in power, converter(s) efficiency), the electrical topology, the ratio power/energy for sizing, the need for cooling (PUE…) … Nevertheless to get an overview of the impacts on PV and ESS sizes of the DC power and of the energy supply from renewables that is wanted, the heuristic optimization method applied for this deliverable is enough efficient and adapted.

4.4. CASE OF BARCELONA

In this section, the values of the simulation based on Barcelona data series are presented in details (graphs and tables of values for the small and medium DC (size 20 kW and 80 kW), and only tables of values for the DCs having the sizes of 160 kW and 220 kW). The first subsection presents the simulations of a DC having the size of 20 kW, where simulations directed by the four goals are detailed (80% self- production, 60% self- production, 40% self- production, 20% self- production). The second subsection presents the simulations of a medium DC having the size of 80 kW. The third subsection presents the simulations of a DC having the size of 160 kW. The fourth subsection presents the simulations of a DC having the size of 220 kW. A conclusion of the results of the simulations is done in this case of Barcelona in the fifth subsection.

4.4.1. SIMULATIONS 20KW

This subsection presents the simulations of a small DC having the size of 20 kW.

4.4.1.1. SIMULATIONS 20% - 20KW

Table 1 presents the simulation results in the case of a small DC directed by the goal of 20% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
15	1	19,97	99,76
17	1	22,56	99,71
16	1	21,27	99,74

Table 1 - Simulation results (Goal: 20% self-production, DC size: 20 kW)

The ideal case is achieved by the combination between peak power of 15 kWp and without using large Energy Storage System (ESS). The self-production in this case is 19,97 %.

Figure 22 presents the variation of power consumed, charged to batteries, and injected to the network. The first subfigure from the top presents the PV production values (in yellow) over the year. In this subfigure, the total consumption of the loads is shown in red. The loads represent in this case the DC system consumption (in brown) as there are no controlled loads in this case of data center (Mload in red dashed line). The blue line represents the batteries usage; the negative values represent the battery recharging stage and the positive ones represent the battery injection to the system (For this simulation case there are not observable variations because of the small size of the ESS but it can be well observed in the next simulation cases).

The second subfigure presents the power injected from the grid to the system. As mentioned before, the value is positive when the power is injected from the grid to the system and negative otherwise.

The third subfigure from the top represents the electricity price variation but the energy management strategy does not take into account this parameter in the performed simulations of this deliverable.

The subfigure 4 from the top presents the battery state of energy (100% with full ESS and 0% for empty state). The subfigure in the bottom presents the variation of the daily auto consumption rate in green and the daily auto-production rate is yellow.

The total load power of DC is almost always superior to PV production power (first subfigure from the top in Figure 22) and this configuration permits to reach very high values of self-consumption rate. The strategy to use the ESS could not be observed here as there is no need to have an ESS (ESS energy set to 1kWh) for reaching 20% of self-production; the impact of the chosen strategy will be more visible and explained in the following parts with higher target of self-production rate (and especially in the part with a goal of 80% of self-production for a 20kW DC).

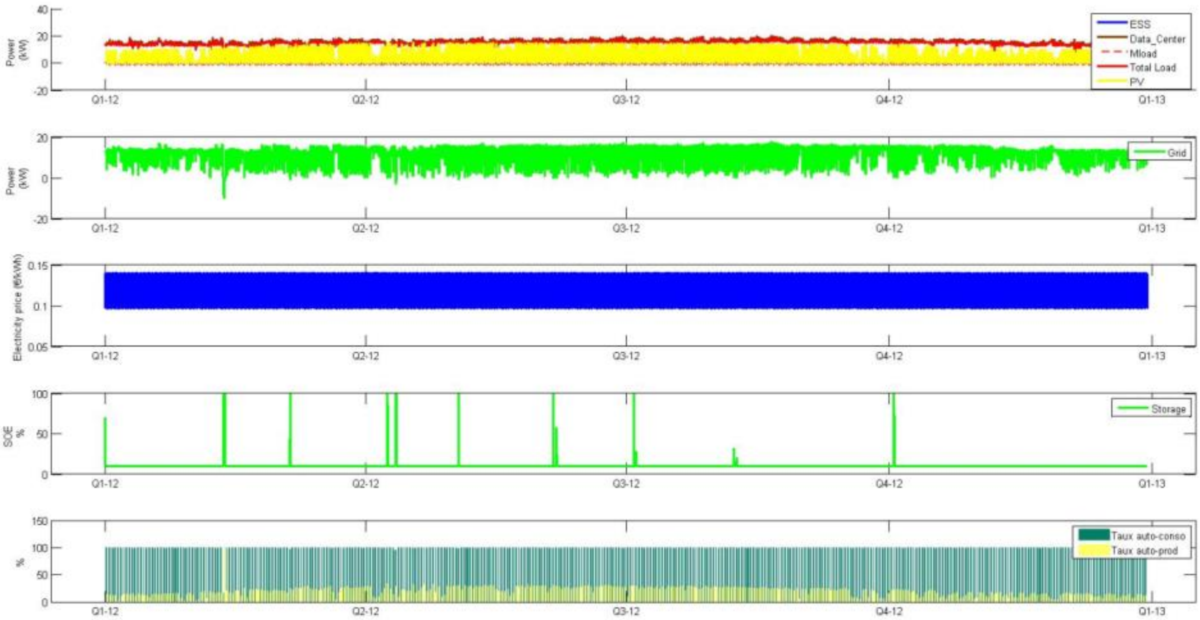

Figure 22 - Power consumed, charged to batteries, and injected to network

Table 2 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 20% self-production.

Consumed energy (kWh)	128027
PV production (kWh)	27338
Self-consumption (%)	99,74
Self-production (%)	21,27
Stored energy (nb of full charges)	9,9
Energy discharged (nb of full disch)	10,6
Nb of cycles	10,2
Losses in storage (kWh)	2,7

Table 2 - Information of consumption, storage, production in the ideal case

4.4.1.2. SIMULATIONS 40% - 20KW

Table 3 presents the simulation results in the case of a small DC directed by the goal of 40% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
30	30	37,16	98,51
40	30	42,57	88,58
35	1	35,61	82,54
35	30	40,37	94,02

Table 3 - Simulation results (Goal: 40% self-production, DC size: 20 kW)

The ideal case is achieved by the combination between peak power of 35 kWp and storage size of 30 kWh. The expected self-production in this case is about 40,37 %. Figure 23 presents the variation of self-production and self-consumption values according to the size of energy storage system (ESS) and to the peak power. It can be observed the variations of the simulation's results before reaching a convergence to the goal of obtaining 40% of self-production.

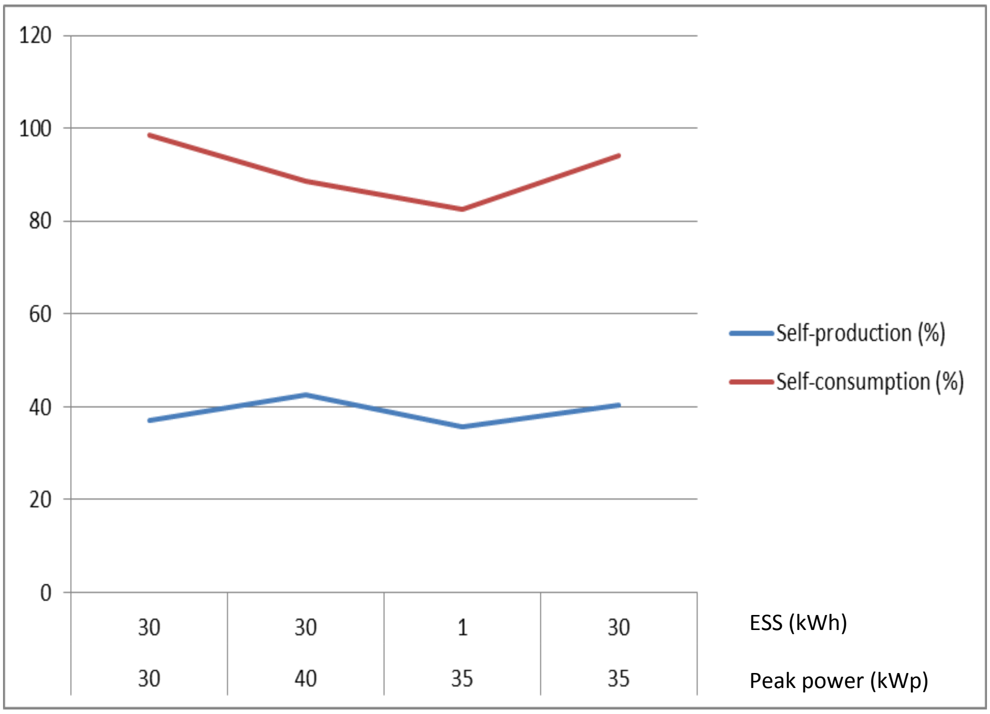

Figure 23 - Variation of Self-production and Self-consumption with the ESS and peak power values

Figure 24 presents the evolution of power consumed, charged to batteries, and injected to the network. It can be noticed that in winter season the installed PV capacity is not enough important to power supply the DC during the day and to charge the ESS in the same day time in order to supply the DC during the night thanks to stored PV energy. On the contrary, the ESS is often fully charged during the summer days and can supply energy to the DC during the night. Consequently the injection of power to the grid occurs only during the summer due to excess of PV production once the ESS is fully charged. Some periods of several days with empty ESS (green curve of the fourth graph from the top close to 0%) could also be observed due to bad weather.

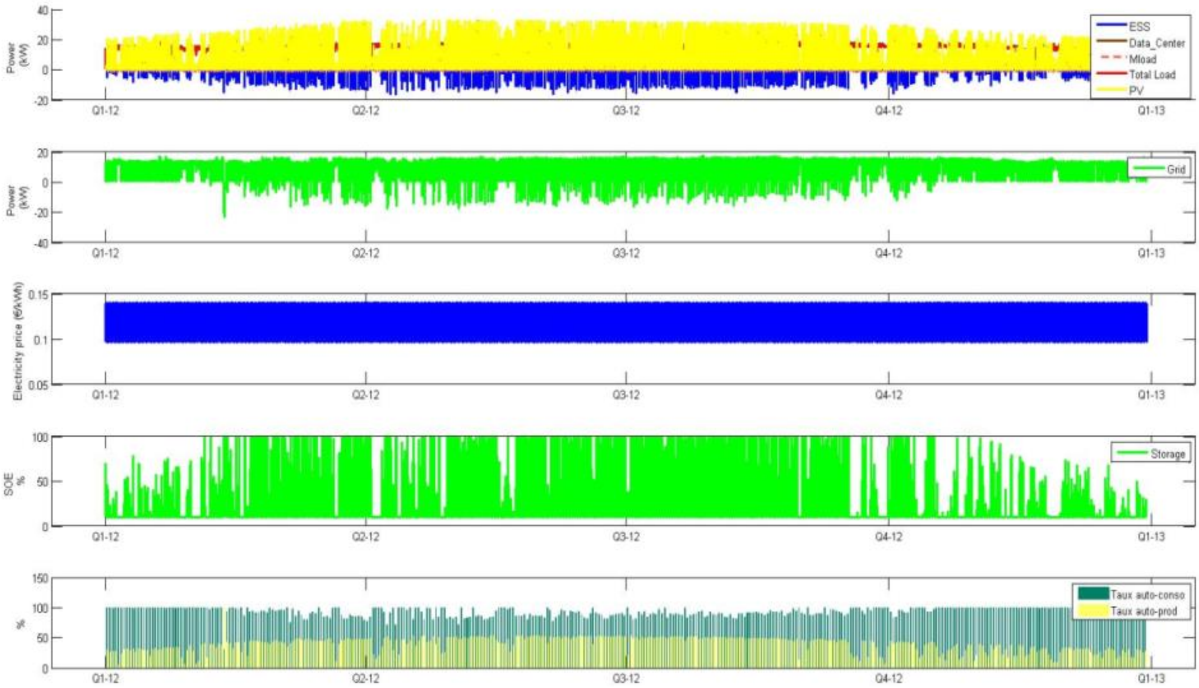

Figure 24 - Power consumed, charged to batteries, and injected to network

Table 4 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 40% self-production.

Consumed energy (kWh)	134504
PV production (kWh)	59803
Self-consumption (%)	94,02
Self-production (%)	40,37
Stored energy (nb of full charges)	243,6
Energy discharged (nb of full disch)	244,3
Nb of cycles	243,9
Losses in storage (kWh)	1942

Table 4 - Information of consumption, storage, production in the ideal case

4.4.1.3. SIMULATIONS 60% - 20KW

Table 6 presents the simulation results in the case of a small DC directed by the goal of 60% self-production rate and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
50	135	57,34	98,82
55	100	56,95	90,95
55	110	57,98	92,63
60	110	59,76	89
70	135	65,68	86,41
60	115	60,31	89,84

Table 5 - Simulation results (Goal: 60% self-production, DC size: 20 kW)

The ideal case found for this study is achieved by the combination between peak power of 60 kWp and storage size of 115 kWh. The self-production in this case is about 60,31 %. Figure 25 presents the variation of self-production and self-consumption values according to the simulated sizes of energy storage system (ESS) and of PV the peak power. The variation of the two rates for the different simulations before convergence to the goal of obtaining 60% of self-production can be observed.

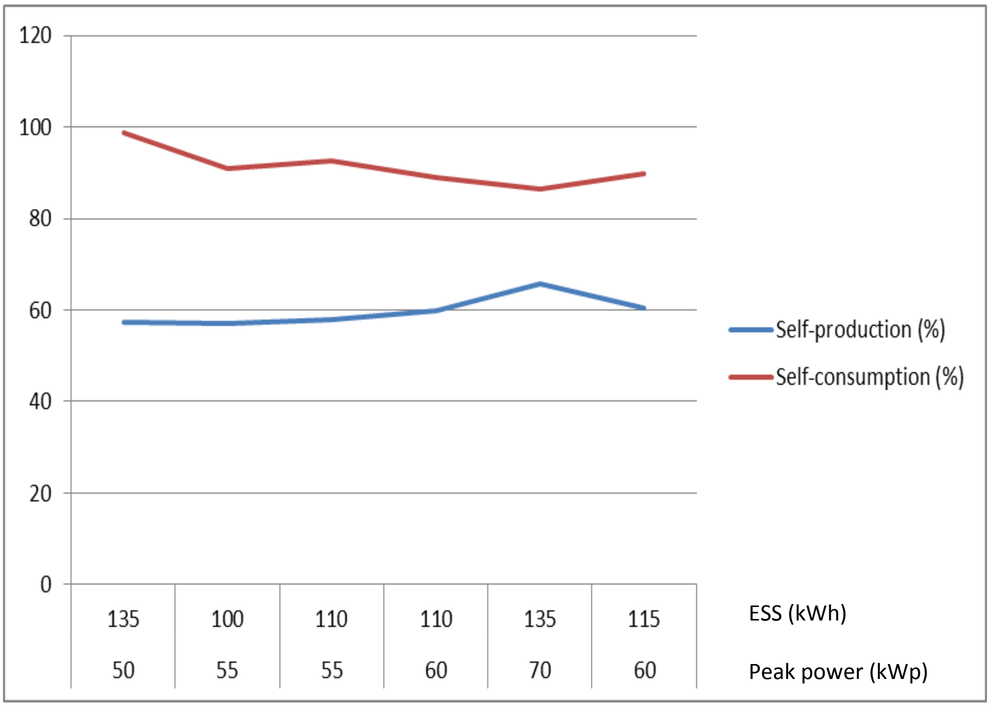

Figure 25 - Variation of Self-production and Self-consumption with the ESS and peak power values

Figure 26 presents the evolution of power consumed, charged to batteries, and injected to the network. It can be observed that PV production (in yellow in the first graph from the top) is always higher during the day with a factor of about two, even in winter, than the load curve of DC (in red in the first graph from the top); this configuration permits to get a high value of self-production for the data center, which has an almost constant power consumption. The required ESS has an important energy size to store the excess of PV energy during the day and then to use it during the night. In winter the ESS is not fully charged and then the self-consumption rate is close to 100%, whereas for spring and summer the ESS is often at full State of Energy (SOE) then PV production is injected to the grid at high power and the self-consumption rate decreases.

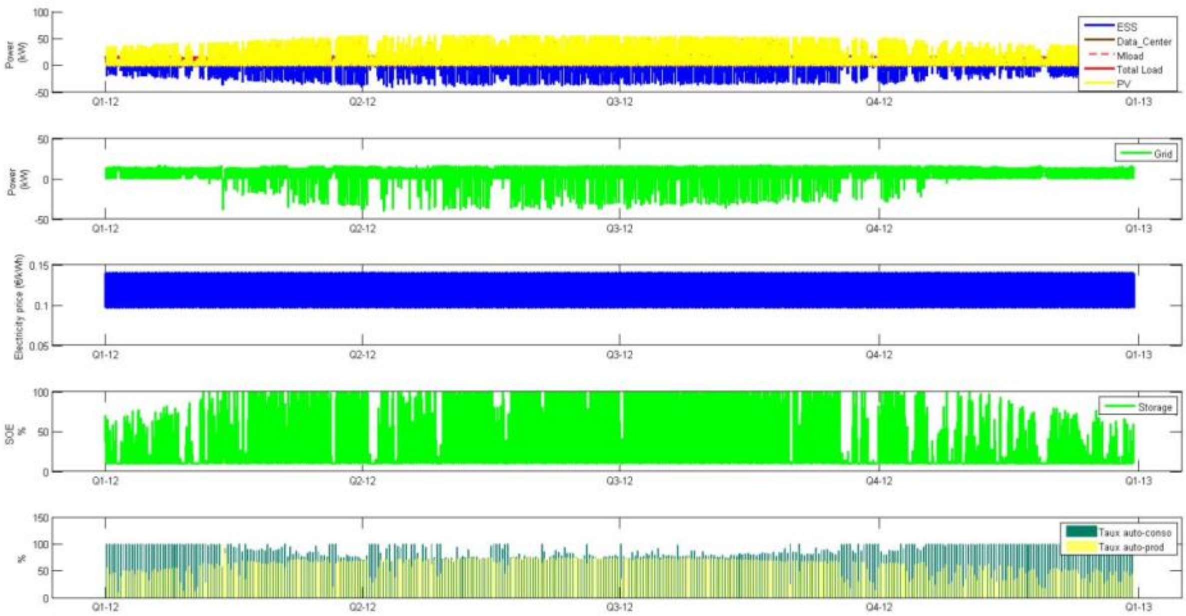

Figure 26 - Power consumed, charged to batteries, and injected to network

Table 6 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 60% self-production.

Consumed energy (kWh)	144283
PV production (kWh)	102520
Self-consumption (%)	89,84
Self-production (%)	60,31
Stored energy (nb of full charges)	268,7
Energy discharged (nb of full disch)	269,3
Nb of cycles	269
Losses in storage (kWh)	8213

Table 6 - Information of consumption, storage, production in the ideal case

4.4.1.4. SIMULATIONS 80% - 20KW

Table 7 presents the simulation results in the case of a small DC directed by the goal of 80% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
70	200	71,9	94,83
100	150	73,38	71,95
80	225	77,54	92,28
80	235	78,3	93,3
90	200	78,07	84,43
90	215	79,54	86,22
90	235	81,36	88,45
100	200	80,21	79,7

Table 7 - Simulation results (Goal: 80% self-production, DC size: 20 kW)

The ideal case is achieved by the combination between peak power of 100 kWp and storage size of 200 kWh. The self-production in this case is about 80,21 %. A part of the energy produced is injected to the network. Figure 27 presents the variation of self-production and self-consumption values according to the size of energy storage system (ESS) and to the peak power. The variation of the two rates for the different simulations before reaching a convergence to the goal of obtaining 80% of self-production can be observed.

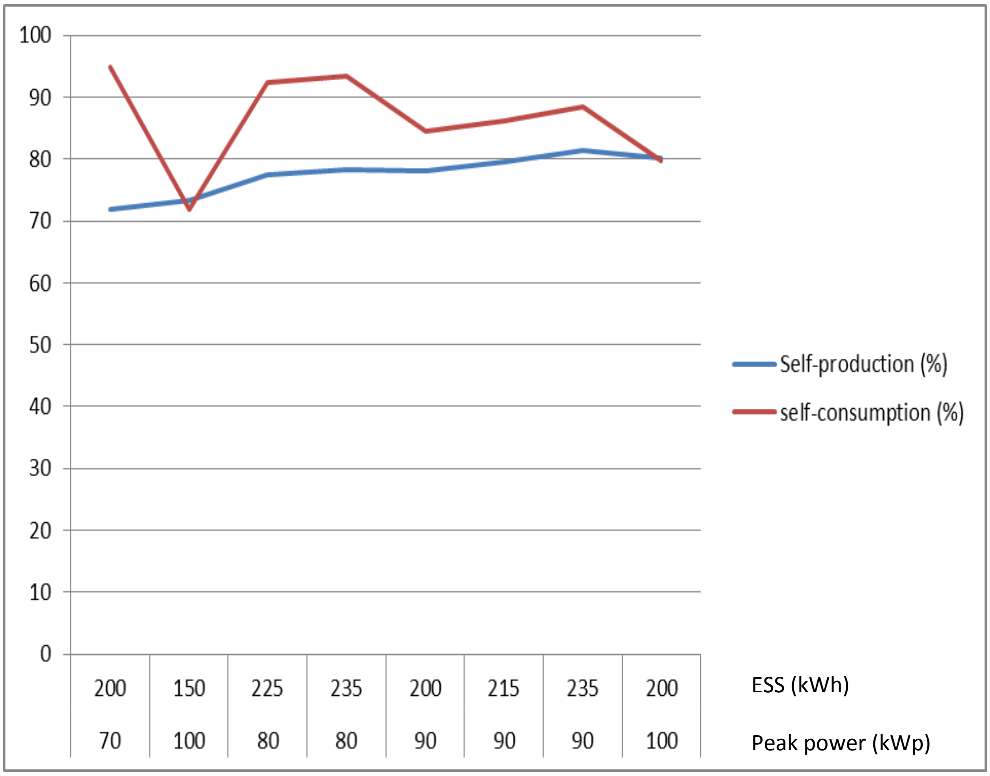

Figure 27 - Variation of Self-production and Self-consumption with the ESS and peak power values

Figure 28 presents the evolution of power consumed, charged to batteries and injected to the network.

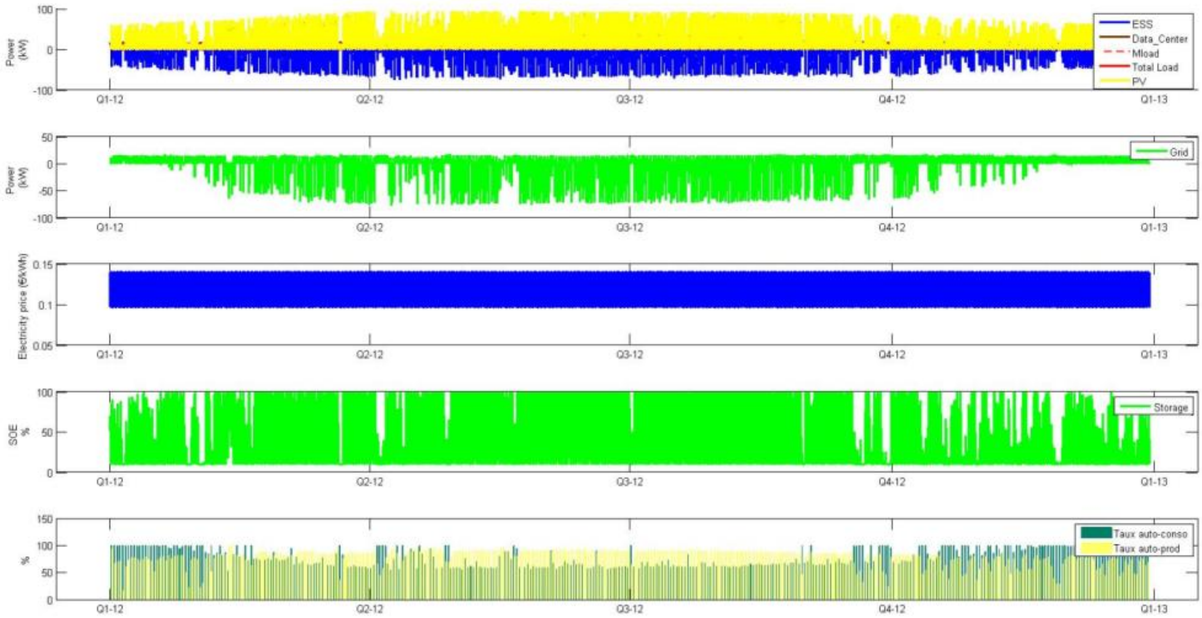

Figure 28 - Power consumed, charged to batteries, and injected to network

Figure 29 presents the evolution of energy consumed, charged to batteries, and injected to the grid during 7 days (from 2nd of February to 8th of February). It can be observed the strategy of charging batteries to 100% of their capacity or nominal energy (fourth graph from the top) during the day and then injecting the rest of energy produced by the PVs to the network (P_{grid} <0 in the second graph from the top). A 'problem' happened during the day of 2/05 due to decrease of solar irradiation and thus decrease of PV production; hence the ESS could not be fully charge during this day.

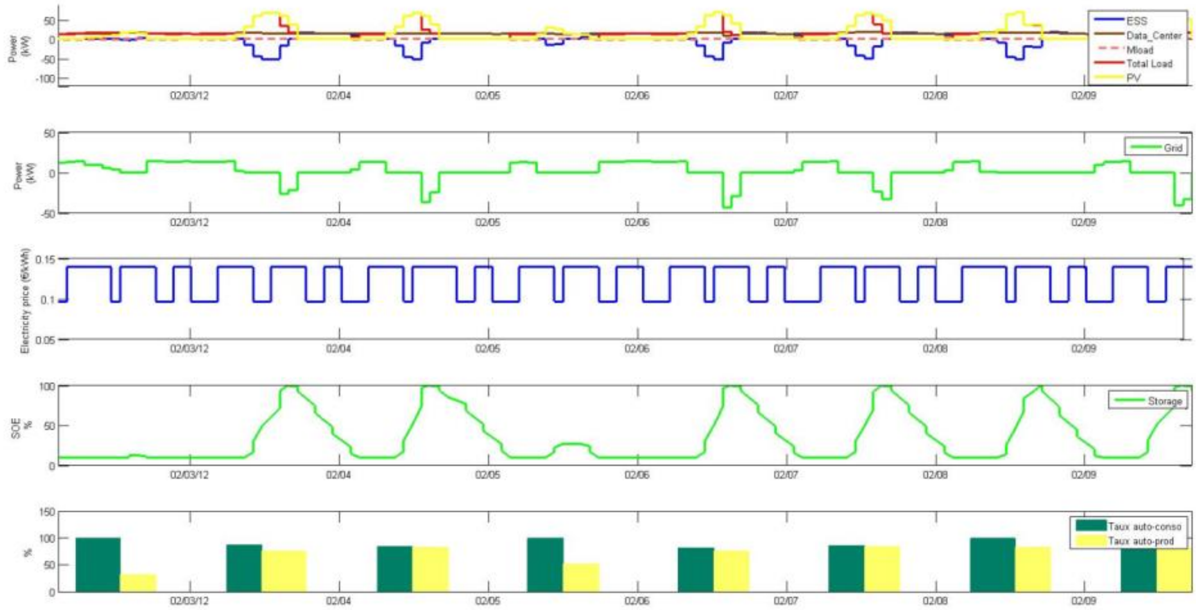

Figure 29 - Power consumed, charged to batteries and injected to network

Table 8 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 80% self-production.

Consumed energy (kWh)	154718,55
PV production (kWh)	170867

Self-consumption (%)	79,7
Self-production (%)	80,21
Stored energy (nb of full charges)	299,5
Energy discharged (nb of full disch)	300
Nb of cycles	299,8
Losses in storage (kWh)	15918

Table 8 - Information of consumption, storage, production in the ideal case

4.4.2. SIMULATIONS 80 KW

This subsection presents the simulations of a medium DC having the size of 80 kW.

4.4.2.1. SIMULATIONS 20% - 80 KW

Table 9 presents the simulation results in the case of a medium DC directed by the goal of 20% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
80	1	25,06	98,94
80	110	25,31	99,84
60	1	19,09	99,69
65	1	20,64	99,64

Table 9 - Simulation results (Goal: 20% self-production, DC size: 80 kW)

An ideal case is achieved by the combination between peak power of 65 kWp (slightly lower than maximum power of DC) and almost without using battery storage. The self-production in this case is about 20,64 %.

Figure 30 presents the evolution of power consumed, charged to batteries, and injected to the network. As the load curve of DC (in red in first figure from the top) is almost always higher than PV production power (in yellow in first figure from the top), small amount of power is injected to the grid and self-consumption rate is very high.

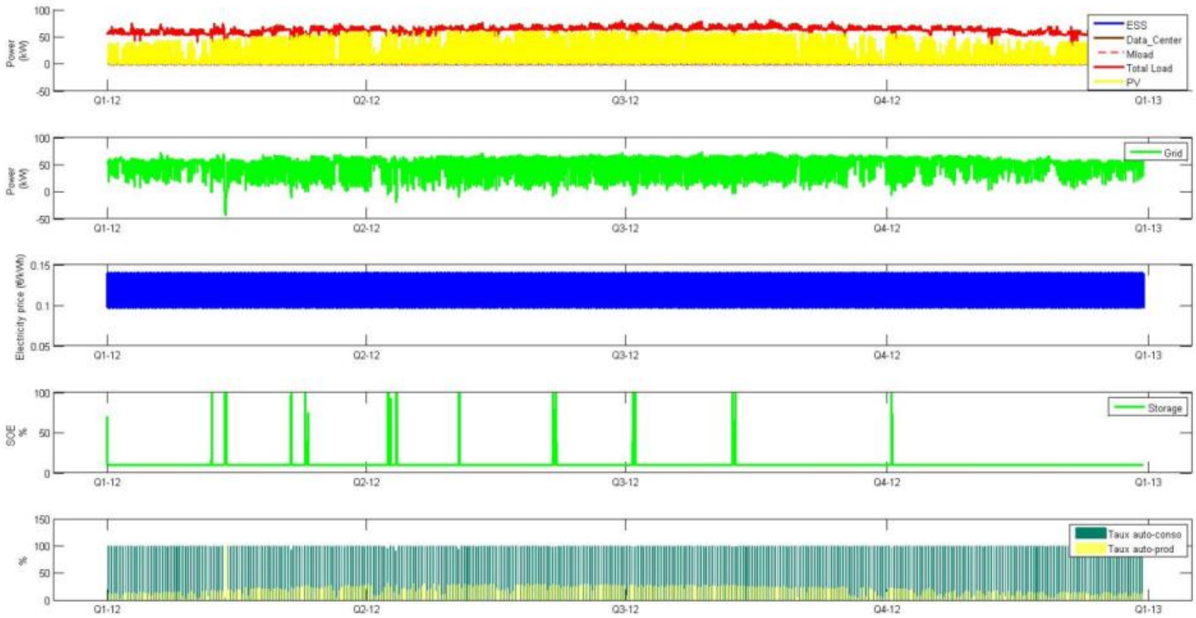

Figure 30 - Power consumed, charged to batteries, and injected to network

Table 10 presents the details of consumed and produced energy and battery storage information in the ideal simulation case in order to reach the goal of 20% self-production.

Consumed energy (kWh)	535849
PV production (kWh)	111063
Self-consumption (%)	99,64
Self-production (%)	20,6
Stored energy (nb of full charges)	19,6
Energy discharged (nb of full disch)	20
Nb of cycles	19,9
Losses in storage (kWh)	5,3

Table 10 - Information of consumption, storage, production in the ideal case

4.4.2.2. SIMULATIONS 40% - 80 KW

Table 11 presents the simulation results in the case of a medium DC directed by the goal of 40% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
200	120	43,75	76,08
160	120	41,08	87
150	120	40,13	89,87

Table 11 - Simulation results (Goal: 40% self-production, DC size: 80 kW)

An ideal case is achieved by the combination between peak power of 150 kWp and storage size of 120 kWh. The self-production in this case is about 40,13 %. As for the case with a 20kW DC and a self-production target of 40%, the PV peak power is about 1,7 to 1,8 times the power of considered DC (here 80kW), and the ESS size is about 0.8 times the PV power.

Figure 31 presents the evolution of power consumed, charged to batteries, and injected to the network.

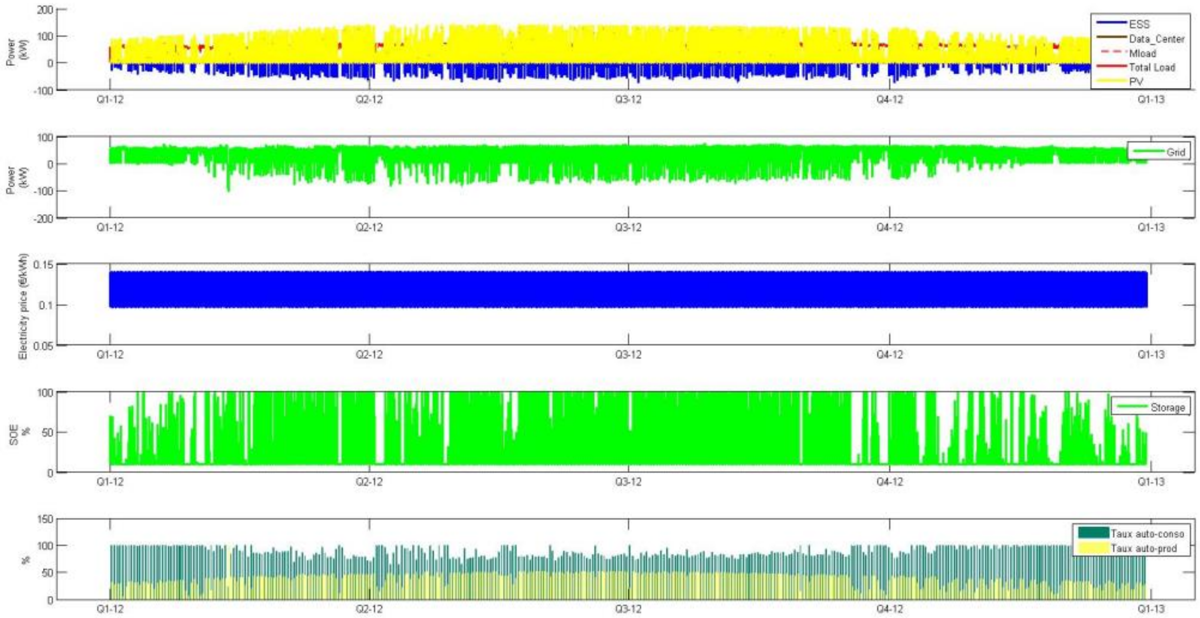

Figure 31 - Power consumed, charged to batteries, and injected to network

Table 12 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 40% self-production.

Consumed energy (kWh)	549248
PV production (kWh)	256300
Self-consumption (%)	89,87
Self-production (%)	40,13
Stored energy (nb of full charges)	270,3
Energy discharged (nb of full disch)	270,9
Nb of cycles	270,6
Losses in storage (kWh)	8619

Table 12 - Information of consumption, storage, production in the ideal case

4.4.2.3. SIMULATIONS 60% - 80 KW

Table 13 presents the simulation results in the case of a medium DC directed by the goal of 60% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
200	300	51,15	88,99
275	410	59,86	79,33
280	340	57,5	75,05
280	380	59,07	77,11
250	320	55,35	79,7
270	400	59,28	79,83
260	390	58,41	81,28
260	400	58,74	81,71
270	410	59,6	80,25
270	405	59,45	80,04

Table 13 - Simulation results (Goal: 60% self-production, DC size: 80 kW)

An ideal case is achieved by the combination between peak power of 275 kWp and storage size of 410 kWh. The self-production in this case is 59,86 %. A part of the energy produced is injected to the network. **Figure 32** presents the variation of self-production and self-consumption values according to the size of energy storage system (ESS) and to the peak power. The variation of the two rates for the different simulations before a convergence to the goal of obtaining 60% of self-production can be observed.

Figure 32 - Variation of Self-production and Self-consumption with the ESS and peak power values

Figure 33 presents the evolution of power consumed, charged to batteries, and injected to the network (maximum power of injection superior than 150kW whereas electrical power supply from the grid is about 50kW).

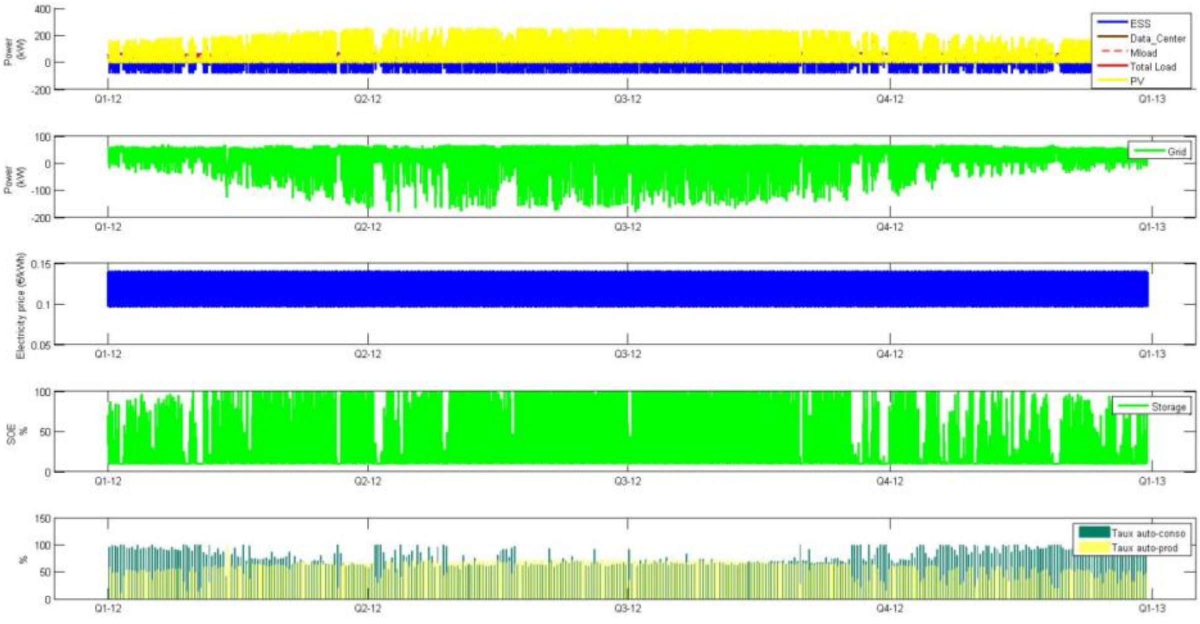

Figure 33 - Power consumed, charged to batteries, and injected to network

Table 14 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 60% of self-production.

Consumed energy (kWh)	575158
PV production (kWh)	461341
Self-consumption (%)	80,04
Self-production (%)	59,45
Stored energy (nb of full charges)	291
Energy discharged (nb of full disch)	291
Nb of cycles	291
Losses in storage (kWh)	31334

Table 14 - Information of consumption, storage, production for the ideal case

4.4.2.4. SIMULATIONS 80% - 80 KW

Table 15 presents the simulation results in the case of a medium DC directed by the goal of 80% self-production and maximizing the self-consumption.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
450	610	71,91	61,59
450	700	73,63	62,91
550	610	74,17	53,1
700	610	76,52	44
750	700	79,46	42,9
750	750	80,36	43,3

Table 15 - Simulation results (Goal: 80% self-production, DC size: 80 kW)

An optimal case is achieved by the combination between peak power of 750 kWp and storage size of 750 kWh. The self-production in this case is about 80,36 %. A part of the energy produced is injected to the network. Figure 34 presents the evolution of power consumed, charged to batteries, and injected to the network.

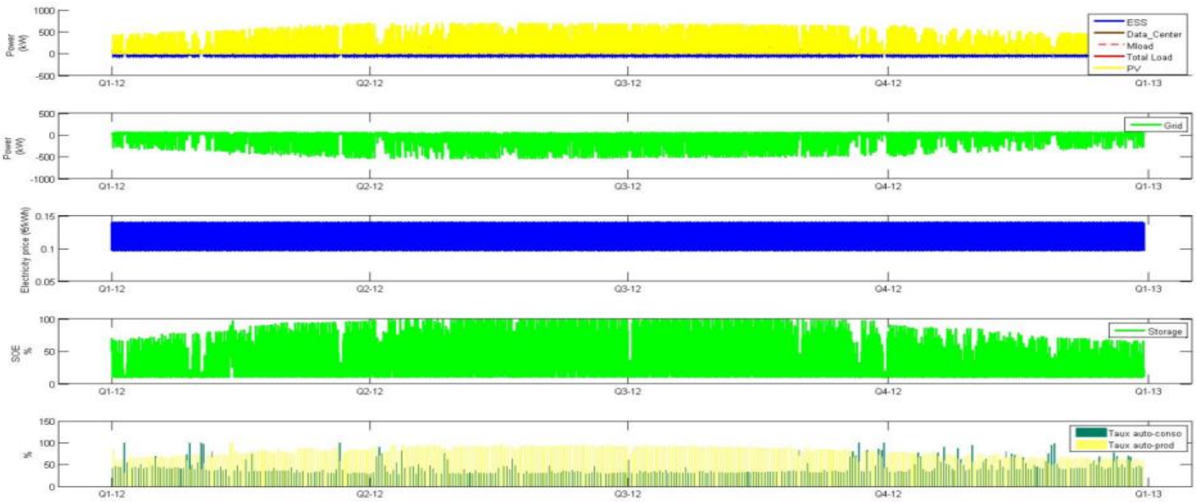

Figure 34 - Power consumed, charged to batteries, and injected to network

Table 16 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 80% self-production.

Consumed energy (kWh)	604588
PV production (kWh)	1281503
Self-consumption (%)	43,38
Self-production (%)	80,36
Stored energy (nb of full charges)	289
Energy discharged (nb of full disch)	289,9
Nb of cycles	289
Losses in storage (kWh)	57667

Table 16 - Information of consumption, storage, production in the ideal case

4.4.3. SIMULATIONS 160 KW

This subsection presents the simulations of a large DC having the size of 160 kW.

4.4.3.1. SIMULATIONS 20% - 160 KW

Table 17 presents the simulation results in the case of a large DC directed by the goal of 20% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 110 kWp without using batteries for storage. The self-production in this case is 19,8 %.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
100	1	18,06	99,7
110	1	19,8	99,6
120	1	21,6	99,5

Table 17 - Simulation results (Goal: 20% self-production, DC size: 160 Kw)

4.4.3.2. SIMULATIONS 40% - 160 KW

Table 18 presents the simulation results in the case of a large DC directed by the goal of 40% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 280 kWp and storage size of 200 kWh. The self-production in this case is 40,26 %.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
200	100	33,76	95,45
280	200	40,26	86,3

Table 18 - Simulation results (Goal: 40% self-production, DC size: 160 Kw)

4.4.3.3. SIMULATIONS 60% - 160 KW

Table 19 presents the simulation results in the case of a large DC directed by the goal of 60% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 850 kWp and storage size of 750 kWh. The self-production in this case is 59,55 %. We note that the convergence to 60% is slow in the case of a large DC.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
600	500	53,07	64,25
650	650	55,94	62,72
700	750	57,48	60,17
800	750	58,94	54,67
850	750	59,55	52,27

Table 19 - Simulation results (Goal: 60% self-production, DC size: 160 Kw)

4.4.3.4. SIMULATIONS 80% - 160 KW

Table 20 presents the simulation results in the case of a large DC directed by the goal of 80% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 3500 kWp and storage size of 1100 kWh. The self-production in this case is 72,03 %. It can be underlined that the convergence to 80% is very slow in the case of a large DC.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
2500	2200	69,70	22,26
3500	1100	72,03	16,56
4000	1000	72,84	14,69

Table 20 - Simulation results (Goal: 80% self-production, DC size: 160 Kw)

4.4.4. SIMULATIONS 220 KW

This subsection presents the simulations of an extra-large DC having the size of 220 kW.

4.4.4.1. SIMULATIONS 20% - 220 KW

Table 21 presents the simulation results in the case of an extra-large DC directed by the goal of 20% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 180 kWp without using batteries for storage. The self-production in this case is 20,5 %.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
180	1	20,59	99,61
190	1	21,70	99,54
200	400	22,89	99,88

Table 21 - Simulation results (Goal: 20% self-production, DC size: 220 Kw)

4.4.4.2. SIMULATIONS 40% - 220 KW

Table 22 presents the simulation results in the case of an extra-large DC directed by the goal of 40% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 450 kWp and storage size of 250 kWh. The self-production in this case is 39,71 %.

Peak power (KWp)	ESS (KWh)	Self-production (%)	Self-consumption (%)
800	500	49,46	61,27
1000	800	52,69	53,16
800	1000	51,45	63,33
400	100	35,71	82,57
400	200	37,46	86,66
450	250	39,71	82,72

Table 22 - Simulation results (Goal: 40% self-production, DC size: 220 Kw)

4.4.4.3. SIMULATIONS 60% - 220 KW

Table 23 presents the simulation results in the case of an extra-large DC directed by the goal of 60% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 2000 kWp and storage size of 800 kWh. The self-production in this case is 60,04 %. We note that the convergence to 60% is slow in the case of an extra-large DC.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
3000	1000	63,35	22,74
800	600	50,55	62,43
1500	700	57,03	39,58
2000	800	60,04	31,82

Table 23 - Simulation results (Goal: 60% self-production, DC size: 220 Kw)

4.4.4.4. SIMULATIONS 80% - 220 KW

Table 24 presents the simulation results in the case of an extra-large DC directed by the goal of 80% self-production and maximizing the self-consumption. The ideal case is achieved by the combination between peak power of 10000 kWp and storage size of 1000 kWh. The self-production in this case is 69,66 %. We note that the convergence to 80% is very slow in the case of an extra-large DC.

Peak power (kWp)	ESS (kWh)	Self-production (%)	Self-consumption (%)
7000	4000	68,64	10,68
10000	1000	69,66	7,64

Table 24 - Simulation results (Goal: 80% self-production, DC size: 220 Kw)

4.5. CASE OF CHAMBERY

In this section, a small part of results of simulation based on Chambery data series is presented; the simulation case of a medium DC having the size of 80 kW directed by the goal of 40% self-production is detailed here after. The ideal case is achieved by the combination between peak power of 220 kWp and storage size of 140 kWh. The self-production in this case is 39,9 %. Figure 35 presents the evolution of power consumed, charged to batteries, and injected to the network.

Much more variations of PV production can be observed in comparison with the case of Barcelona, and then the ESS faces more periods with a deficit of PV production regarding the DC load; this leads to several periods with an empty state of energy (SOE).

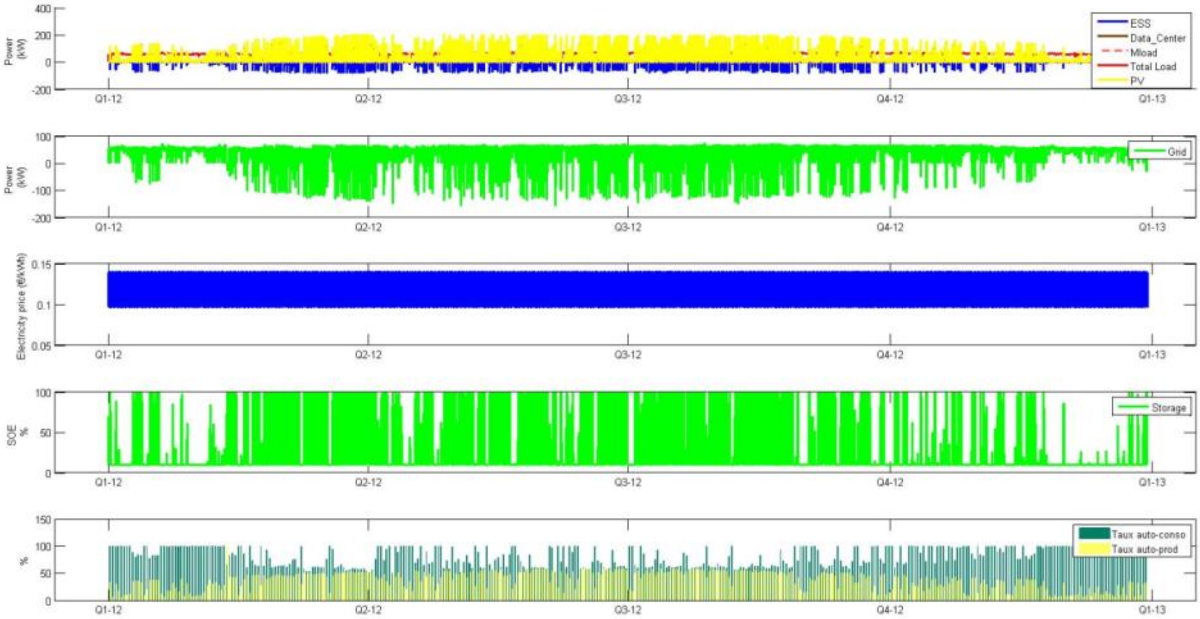

Figure 35 - Power consumed, charged to batteries, and injected to network

Table 25 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 40% self-production.

Consumed energy (kWh)	549370
PV production (kWh)	300480
Self-consumption (%)	81,96
Self-production (%)	39,95
Stored Energy (nb of full charges)	238,4
Energy discharged (nb of full disch)	239,1
Nb of cycles	238,7
Losses in storage (kWh)	8872

Table 25 - Information of consumption, storage, production in the ideal case

4.6. CASE OF ZURICH

In this section, the simulation of a medium DC having the size of 80 kW directed by the goal of 40% self-production in Zürich is detailed but the other results of simulation based on Zürich data series are not presented. The ideal case is achieved by the combination between peak power of 280 kWp and storage size of 160 kWh. The self-production in this case is 40,7 %.

There is slightly higher PV production and annual self-consumption rate than Chambéry case but with a higher PV peak power installation, because PV distribution is better in Chambéry.

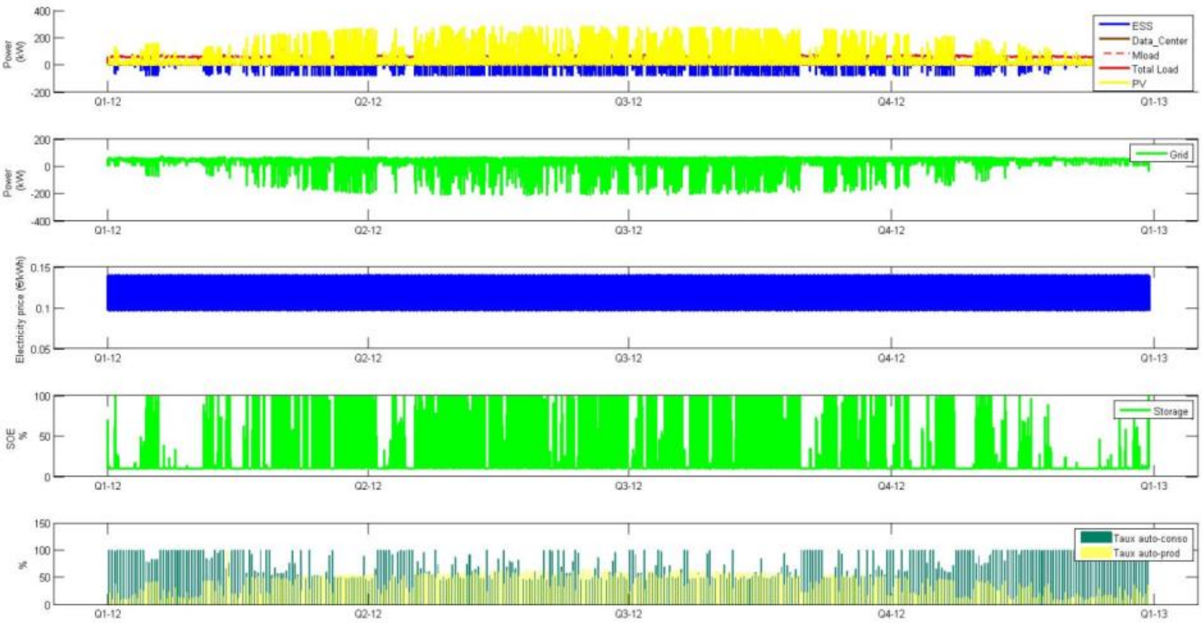

Figure **36** presents the evolution of power consumed, charged to batteries, and injected to the network.

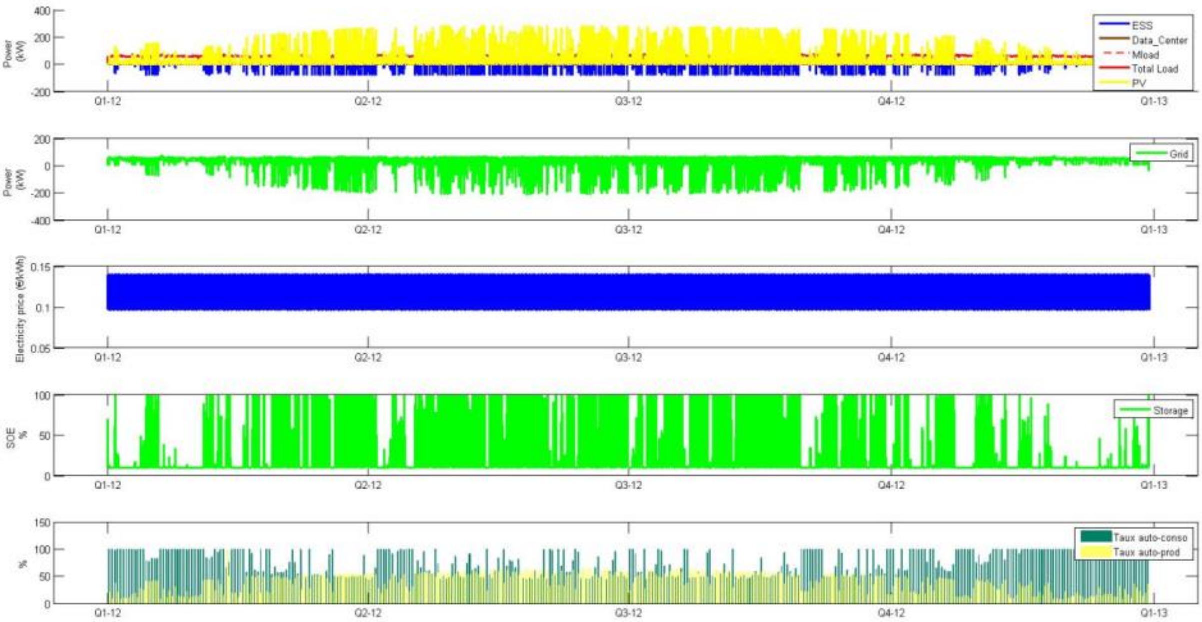

Figure 36 - Power consumed, charged to batteries, and injected to network

Table 26 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 40% self-production.

Consumed energy (kWh)	552661
PV production (kWh)	365401
Self-consumption (%)	88,37
Self-production (%)	40,72
Stored Energy (nb of full charges)	225,1
Energy discharged (nb of full disch)	225,7
Nb of cycles	225,4
Losses in storage (kWh)	11966

Table 26 - Information of consumption, storage, production in the ideal case

4.7. CASE OF AMSTERDAM

In this section, we present the results of simulation based on Amsterdam data series. We present the simulation of a medium DC having the size of 80 kW directed by the goal of 40% self-production. The ideal case is achieved by the combination between peak power of 310 kWp and storage size of 180 kWh. The self-production in this case is 40,47 %. Figure 37 presents the evolution of power consumed, charged to batteries, and injected to the network.

The need for PV peak power is more important than for the three other locations due to poorest solar irradiation in Amsterdam in comparison to the three other locations.

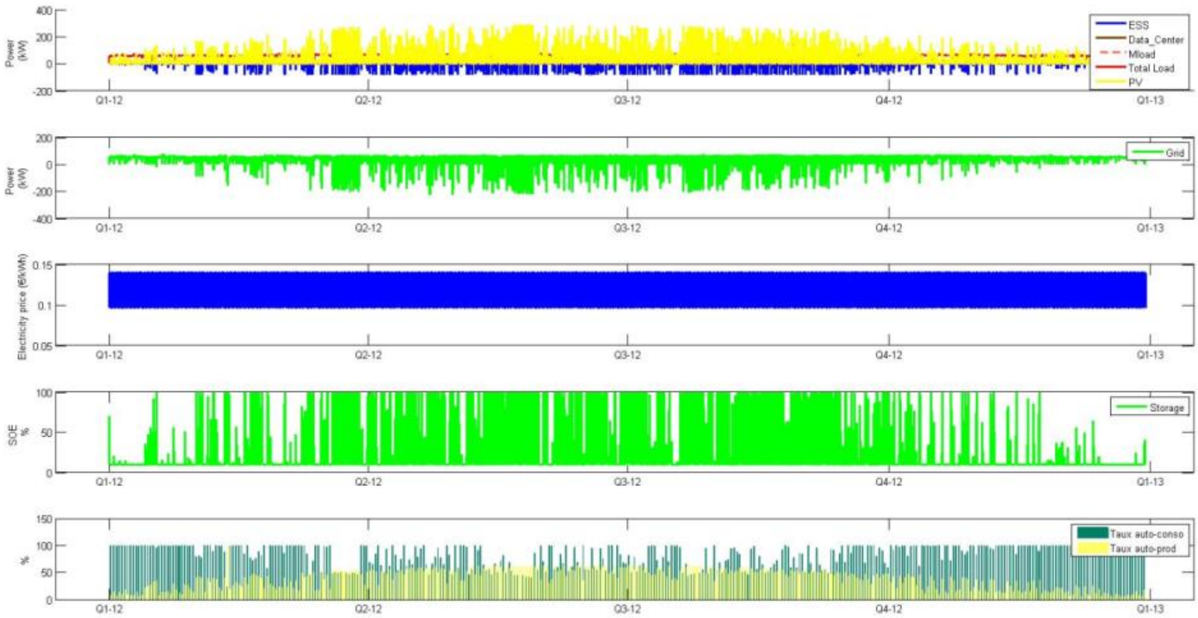

Figure 37 - Power consumed, charged to batteries, and injected to network

Table 27 presents the details of consumed and produced energy and battery storage information in the ideal simulation in order to reach the goal of 40% self-production.

Consumed energy (kWh)	551056
PV production (kWh)	321130
Self-consumption (%)	83,70
Self-production (%)	40,48
Stored Energy (nb of full charges)	221
Energy discharged (nb of full disch)	221,6
Nb of cycles	221,3
Losses in storage (kWh)	10575

Table 27 - Information of consumption, storage, production in the ideal case

5. CONCLUSION

Firstly in this deliverable a tool (based on QGIS open-source platform) and an associated method a QGIS tool have been detailed and could be used as as a powerful decision support tool for Data Centre developpers. It allows to import various data for a given area but also maps, and consequently permits to merge different kind of information (energetic, environmental, economic), to weight them and to vizualize the results of this merging on the considerd area to define the best place for the Data Centre. As it is not in the framework of the GreenDataNet project to build maps and library of data for renewables' potential (biomass, hydraulic, solar, wind), for greenhouse gases emissions, or for economical electricity market framework and considering accurate data are not free of xharge, it has been decided to build a Europe map of best place to build a Data Centre taking into account free data. Hence the presented map in this deliverable do not aim to be the final decision map of a Data Centre developper but to give an overview of a decision map with real data. This approach with the used data is more adapted to look for a location for a large data centre, for which the location is only chosen regarding optimization criteria, than for a small or medium size urban Data Centre as defined in GreenDataNet Deliverable 1.1. Indeed the location of this deliverable is more dependant of customers' locations, existing infrastructure and support thant the large one. Nevertheless the presented tool and applied method could be easily duplicated in a more restricted area with more accurate data in order to take into account all the locat specificities of a urban Data Centre.

This decision support tool has been used to integrate data of renewable ressources potential that can be installed in a urban Data Centre location (i.e. wind and PV) and of ambiant temperature that impacts the need of cooling. Four ideal locations in Europe have been selected regarding the data available (local effects could not be considered) and the hypothesis of GreenDataNet project. This four locations cover different representative cases in Europe with higher PV resources but higher cooling requirements, lower PV resources but lower cooling requirments, and medium PV resources and cooling requirements.

Then for these four specific locations building areas to implement the Data Centre have been defined to calculate the available area to install a PV plant and the annual production of PV based on historical data. This selection and calculations are possible thanks to a web-based software developed for GreenDataNet project. These PV resources for each location associated to a Data Centre consumption profile up scaled to four different DC sizes (20kW, 80kW, 160kW, 220kW) permit to simulate the requirement of PV power and ESS size to reach different self-production targets (20%, 40%, 60% and 80%). Thanks to a heuristic method an ideal sizing of PV and ESS to reach the goal has been defined for each couple of location and DC size as presented in the figures here after.

However, it is important to underline that most interesting result presented for each simulation case does not represent the global optimal sizing combination between the battery system size and the PV installation size that accomplish the goal. Indeed, deeper analysis of the results and wider simulation plan with accurate optimization algorithm (and not a heuristic algorithm as used for the simulations presented here) is required to be sure to reach the global optimal between PV size and ESS size regarding a given location and a self-production target. This kind of analysis is not in the framework of the Deliverable 1.3 but would be performed for some specific cases later during the GreenDataNet project as well as specific technical and economic analysis.

Figure 38 presents the variation of the battery size in ideal simulation cases based on Barcelona data series with the different goals (80 % self-production, 60% self-production, 40 % self-production, 20% self-production). An expected result with a higher size of ESS to increase the self-production rate is observed. But it can also be noticed that for small DC size, the size of storage increase slowly with the value of self-production on the contrary of bigger DC. The ideal simulation case in order to attempt 20% self-production seems to be achieved without using batteries regardless the DC size because of the natural matching between PV production and DC consumption.

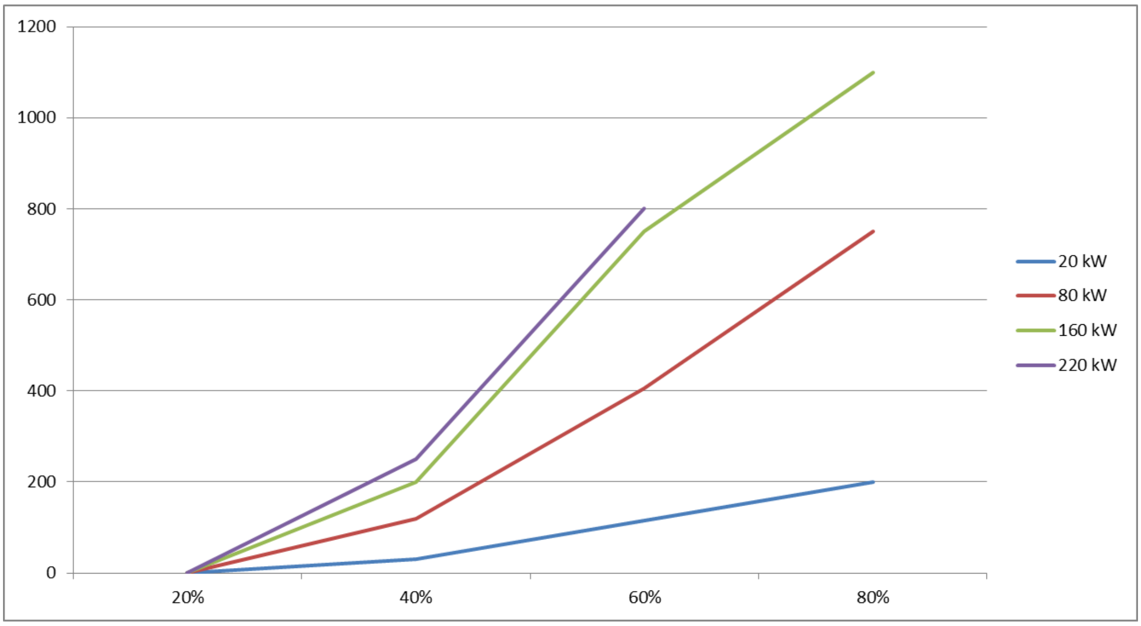

Figure 38 - Variation of storage size (vertical axis - in kWh) with different self-production goals and for the four sizes of DC

Figure 39 presents the variation of the PV peak power size with the different goals for the four sizes of simulated DCs. The value of the required PV peak power seems to increase exponentially for a goal of self-production higher than 60%.

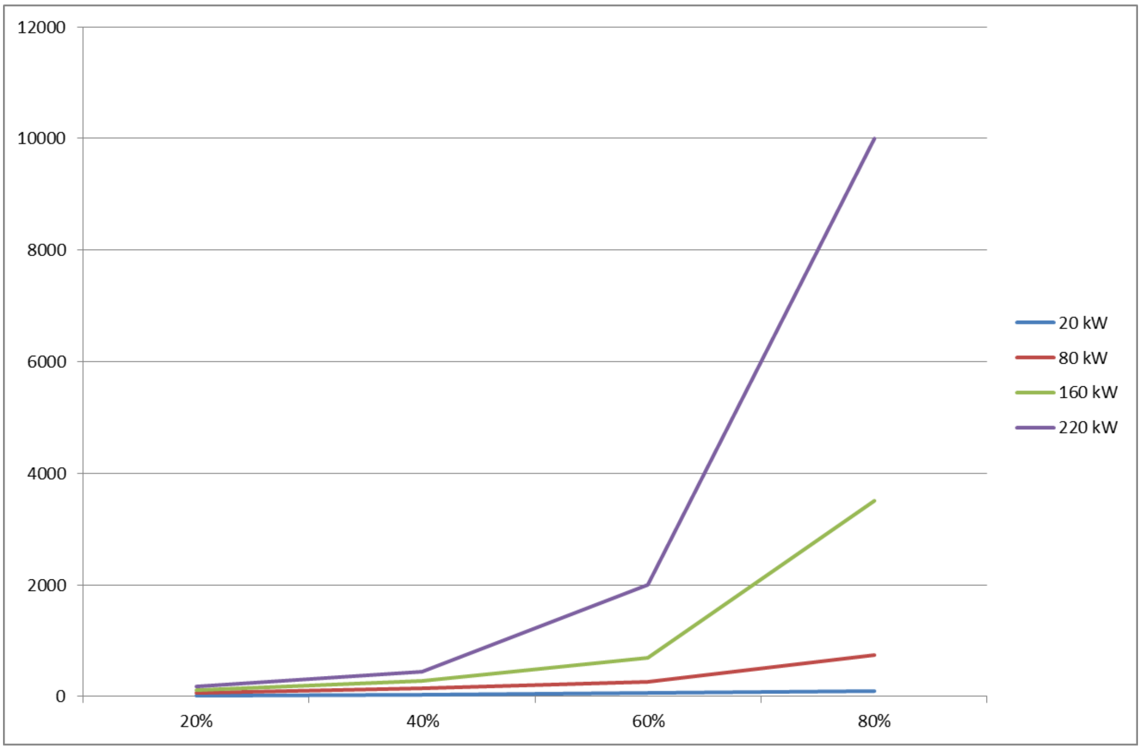

Figure 39 - Variation of PV peak power size (vertical axis – in kWp) with different self-production goals and for the four sizes of DC

Figure 40 presents a comparison between the results for the different cases (Barcelona, Chambery, Zürich, and Amsterdam) of the simulation of a medium DC having the size of 80 kW directed by the goal of 40% self-production. An ideal case is achieved by the combination between peak power of 150 kWp and storage size of 120 kWh in Barcelona, whereas a multiple value of peak-power and storage size (310 kWp, 180 kWh) is needed to achieve an ideal simulation case in Amsterdam.

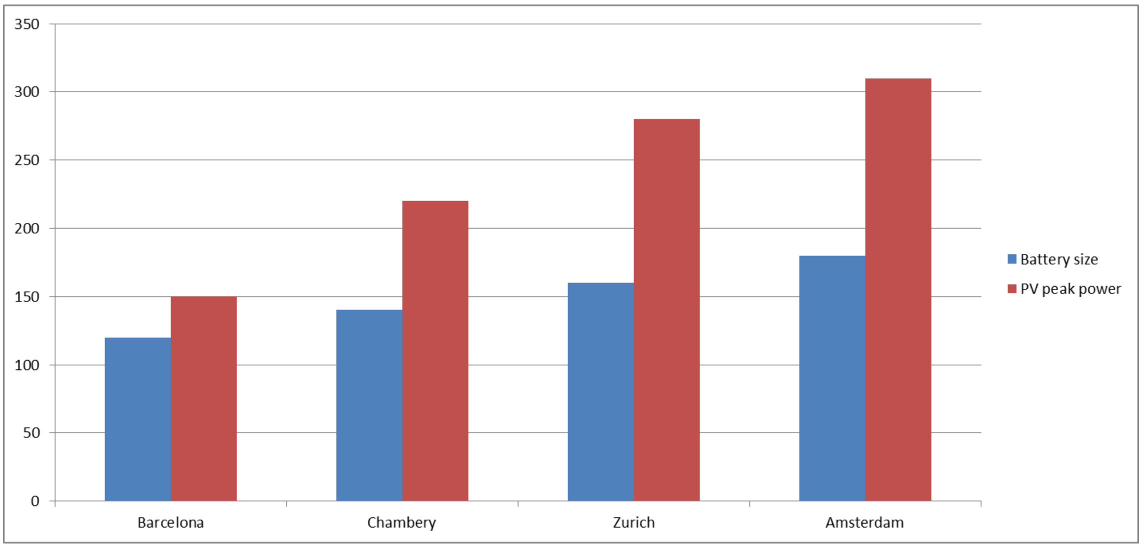

Figure 40 - Comparison of battery energy (in kWh) and PV installed peak power (in kWp) between four DC locations and for the case of simulation with DC power of 80 kW and a self-production goal of 40%

The last part of the Deliverable 1.3 and this results presented in the conclusion presents how to evaluate the PV potential for a location, to compare it with the power consumption of 4 different sizes of data centers, and to perform a first rough optimization of PV size and ESS requirements; this rough optimization was performed for four different interesting locations for datacenter installation in Europe and with 4 different targets of self-production rate thanks to local PV production. These rough estimations of PV power and ESS sizes for reaching defined self-production goals give the expected results with a higher size of PV and ESS required for the larger self-production targets. Nevertheless it illustrates the difficulty to cover the DC consumption only with PV resources and even if an ESS is installed. No solution are given in this deliverable to tackle this power supply of the DC with only renewables as it is very specific of a DC, its cooling technology, its location and it requires more accurate data, but all this topic will be browsed in the further steps of GreenDataNet project especially through the design of the Energy Management System.

6. APPENDIX

In this part, the comparison between simulations performed in HOMER PRO and M2C is presented for the case of a DC having the size of 20 kW and located in Barcelona. The first subsection presents the project configuration in Homer Pro while the results of comparison are presented in the second subsection considering the results obtained with M2C and presented in 4.4.1. The four goals of self-production rate were simulated with M2C and HOMER PRO software.

6.1. CONFIGURATION OF HOMER PRO SIMULATION

In the Figure 41, the project setup in the HOMER PRO interface is shown. Two dispatch strategies are available: cycle charging to try reaching a given state of charge for the battery before power supplying the loads (it allows having a given SOC of the battery in case of power failure), and load following to follow the load consumption (it allows to increase the use of PV for directly powering the loads). For the HOMER PRO simulations of GreenDataNet the load following strategy is chosen in order to be similar than the one defined in M2C, and to maximize the use of PV for the loads. The simulation time step is fixed to 1 hour.

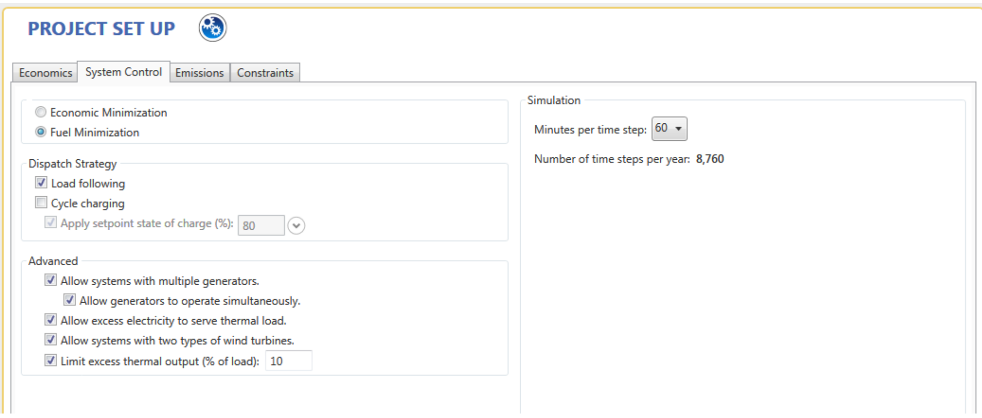

Figure 41 - HOMER PRO simulation project setup

The Figure 42 presents the simulation's location in the HOMER PRO interface (Barcelona in this case). Here city centre is selected whereas the roofs of a local university were selected for M2C but both places are very close.

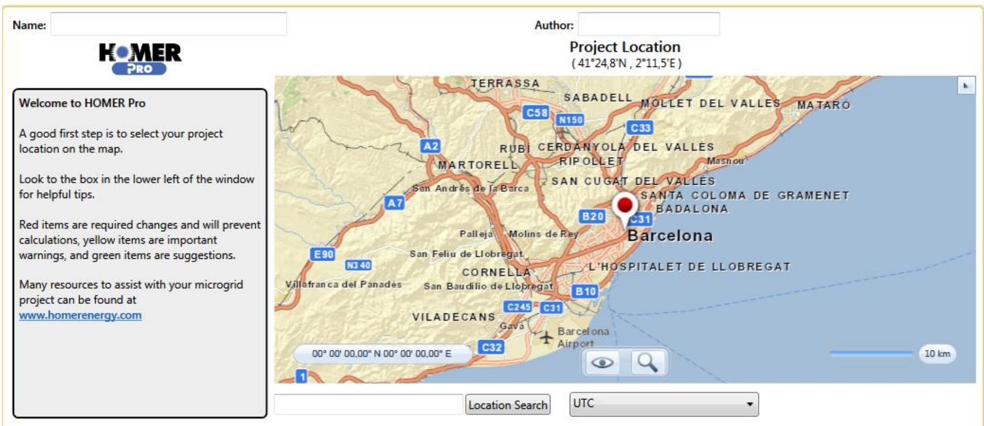

Figure 42 - HOMER PRO simulation's location

The Figure 43 presents the design of the system used for the simulations with a PV plant, a storage, a converter, an AC load (here Data Centre consumptions) and a connection to the Grid.

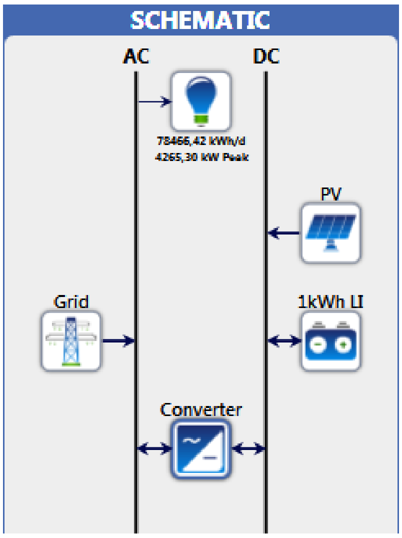

Figure 43 - System design for GreenDataNet simulations in HOMER PRO

HOMER PRO has its own solar irradiation data base based on monthly values and given daily profiles for the selected location, and the values are slightly different than the SoDa hourly data used for solar radiation in M2C. The Scales Annual Average parameter (in kWh/m²/day) is changed from 4.098333 to 4.69779313 in order to match the considered yearly PV resources in HOMER PRO and in M2C. A difference still remains between HOMER PRO and M2C simulations as there is not the same solar profile each day of a month between HOMER PRO and M2C. The Figure 44 presents the monthly irradiation data series used in the simulation with HOMER PRO.

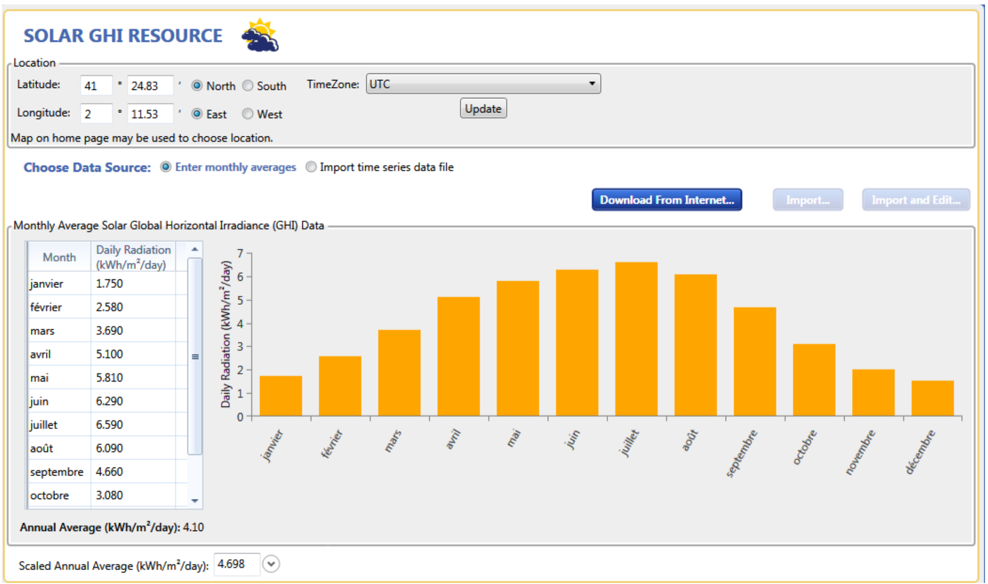

Figure 44 - Irradiation data series for PV component in HOMER PRO

As the strategy, the location, the electrical architecture and the solar resources are fixed, each component of the plant has to be defined as accurately as possible.

The Figure 45 presents the PV component specifications. For the first simulation (goal of 20% of self-production), the size of PV plants used is 15 kWp as shown here after.

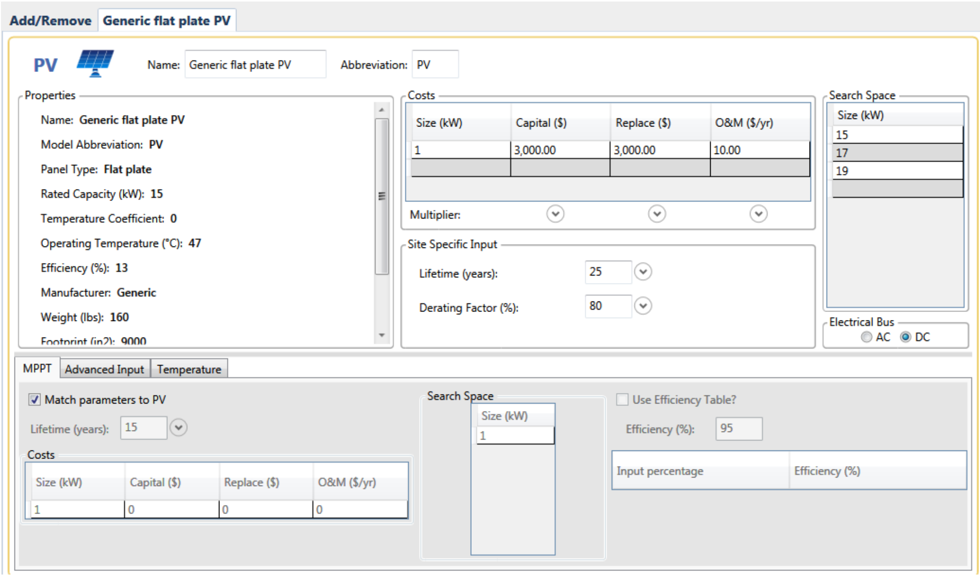

Figure 45 - PV component specification defined in HOMER PRO

The defined storage in HOMER PRO is a generic model of lithium-ion battery with a nominal energy of 1kWh, a maximum discharge current of 500A, maximum charge current of 167A and an energetic round-trip efficiency of 90%. The battery can be cycled between 10% SOC to 100% SOC. The value of nominal voltage and nominal capacity are defined arbitrarily (and are not proper) in order to get a nominal energy of 1kWh whereas nominal voltage of a lithium-ion battery as the one considered for M2C simulations is between 3.6 and 3.7V. The configuration of the battery component of 1kWh used for the simulation is presented in Figure 46 and the number of batteries is chosen for each simulation to reach the right ESS energy.

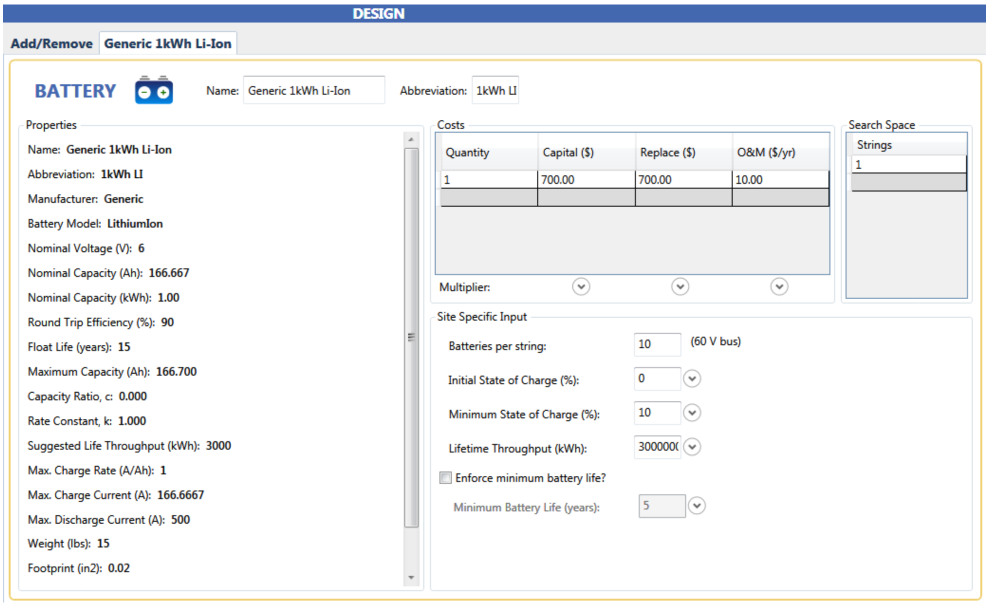

Figure 46 – Lithium-ion battery specification defined in HOMER PRO

The converter is configured as it is shown in Figure 47. Its efficiency is 95%.

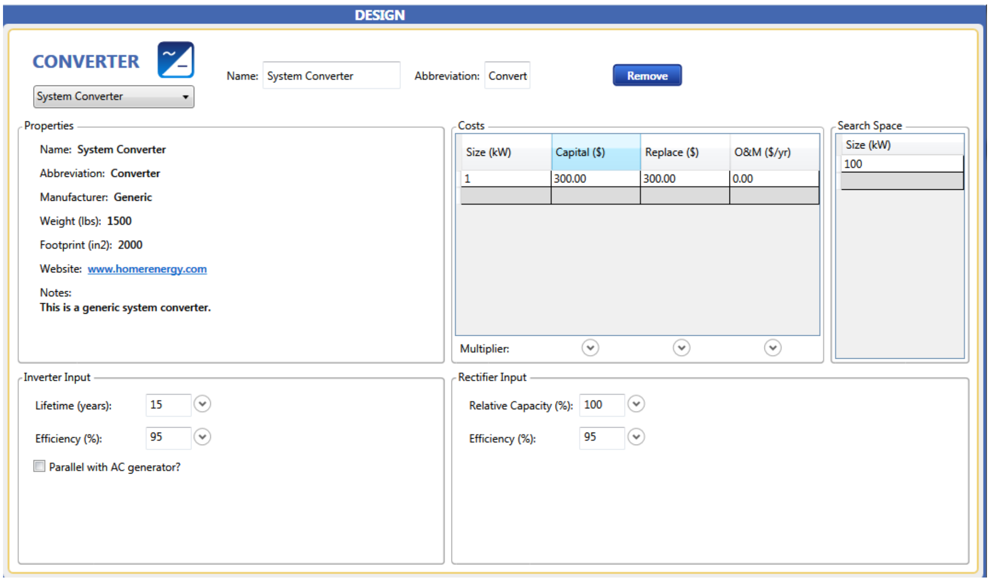

Figure 47 - Converter configuration defined in HOMER PRO

An example of the result data obtained with HOMER PRO is given here after in Figure 48 for three days and with a DC power of 20kW. The DC power consumption is reported in the top graph in red and it fluctuates between 13 to 16kW. In the bottom graph PV power production is reported in red with peak production close to 100kW, the charge power in the battery is reported is brown, and the discharge power from the battery is reported also in red. The load following strategy can be observed with a charge of the battery as soon as the PV production is higher than DC consumption (in the morning) and until the battery SOC is 100%, and a discharge of the battery as soon as PV production is lower than DC consumption (in the evening) and until the battery SOC is 10%.

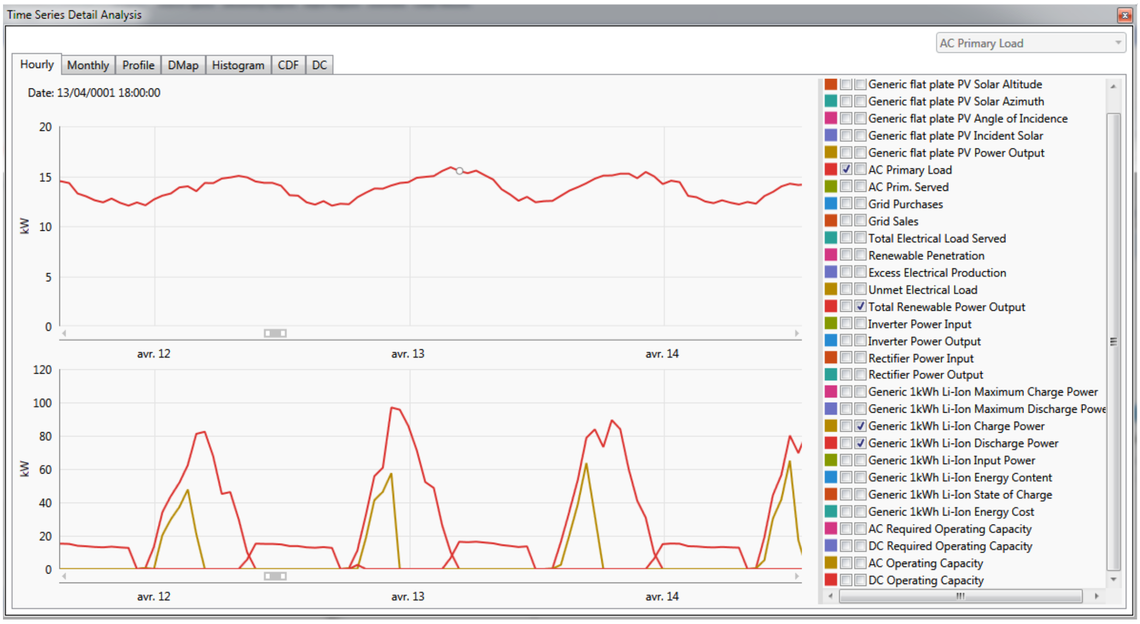

Figure 48 - Batteries charge strategy in HOMER PRO

6.2. RESULTS OF COMPARISON BETWEEN HOMER PRO AND M2C

The Table 28 presents the comparison between the results of the simulation conducted by using HOMER PRO and M2C for the case of a DC having the size of 20 kW. Four goals of self-production rate (DC consumption covered by PV energy directly or thanks to the ESS) were simulated: 20%, 40%, 60% and 80%. The sizes of PV plant and ESS were defined in HOMER PRO in order to be similar than the configuration of components found with M2C to reach the self-production targets. The power of the inverter is set equal to the PV plant power, which is superior to the Data Centre power or for the first case superior to the ESS nominal energy (and so charging and discharging power). More detailed results are presented in the following figures.

Data Centre with 20kW of power	M2C self-production rate	HOMER PRO self-production rate
PV(15kWp), Bat(1kWh), Inverter(15kW)	19.97%	18.6%
PV(35kWp), Bat(30kWh), Inverter(35kW)	40.37%	38.2%
PV(60kWp), Bat(115kWh), Inverter(60kW)	60.3%	59.8%
PV(100kWp), Bat(200kWh), Inverter(100kW)	80.21%	81.3%

Table 28-Comparison of results regarding self-production rate from M2C and HOMER PRO simulations

The first line of the table presents the results of the simulations directed by the goal of 20% self-production and maximizing the self-consumption in M2C and in HOMER PRO. For the configuration of 15 kWp of PV and 1kWh of batteries the obtained self-production value is 19.97% in M2C and 18.6% in HOMER PRO. The detailed results of the Homer simulation directed by the goal of 20% self-production is presented is the Figure 49 (the self-production value is referenced by renewable fraction in the HOMER PRO results presentation).

The second line in the same table presents the results of the simulations directed by the goal of 40% self-production and maximizing the self-consumption in M2C and in HOMER PRO. For the configuration of 35 kWp of PV and 30 kWh of batteries the M2C result is 40.37% and the HOMER PRO self-production result is 38.2%. Figure 50 presents the HOMER PRO simulation results for the simulations directed by the goal of 40% of self-consumption.

The third line in the **Error! Reference source not found.** presents the results of the simulations directed by the goal of 60% self-consumption. The self-consumption result for the configuration of 60 kWp of PV plants and 115 kWh of battery size is 60.3% in M2C and 59.8% in HOMER PRO. The detailed results of Homer simulation for this case are presented in the Figure 51.

The fourth line in the **Error! Reference source not found.** presents the results of the simulations directed by the goal of 80% self-production. For the configuration of 100 kWp of PV plants and 200 kWh of batteries, the self-production value is 80.21% in M2C and 81.3% in Homer. The HOMER PRO simulation results in this case are presented in the Figure 52.

Hence it appears that the results of self-production rates obtained by M2C and HOMER PRO with the same configuration of PV, battery and DC power are very close with more or less 2% of difference. This similar results support the fact that M2C is accurate whereas it is more flexible than HOMER PRO regarding the definition of the battery model, the sources of solar irradiation and the design of the energy strategy.

The results of self-production in HOMER PRO are slightly lower than M2C for the small battery size configurations and slightly higher for large ESS size. This could be explained by the hypothesis of a lower PV production in HOMER PRO or a lower time-matching between PV resources and DC consumption for HOMER PRO simulation and it leads to lower self-production rate for HOMER PRO results; But this is compensated by a better round-trip efficiency of the battery in HOMER PRO which results in increasing the self-production rate for larger battery sizes.

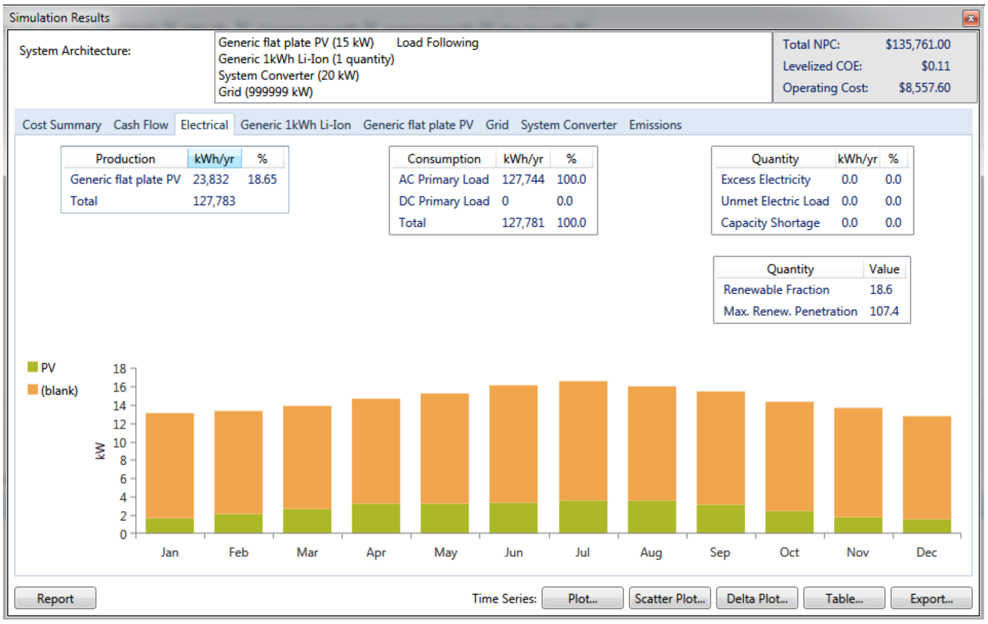

Figure 49- HOMER PRO Simulation results (Goal: 20% self-production, DC size: 20 kW)

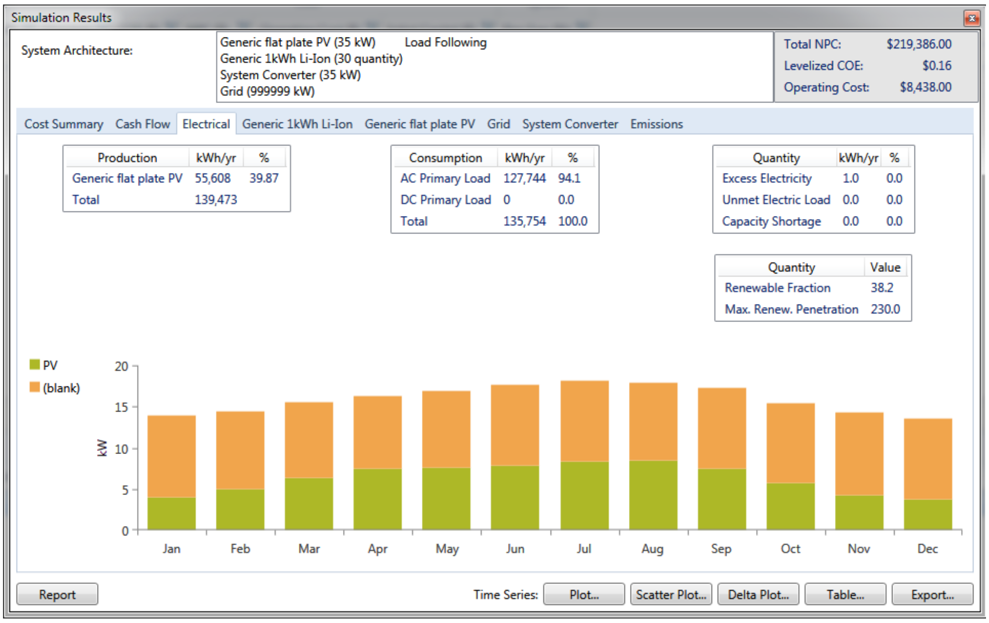

Figure 50- HOMER PRO Simulation results (Goal: 40% self-production, DC size: 20 kW)

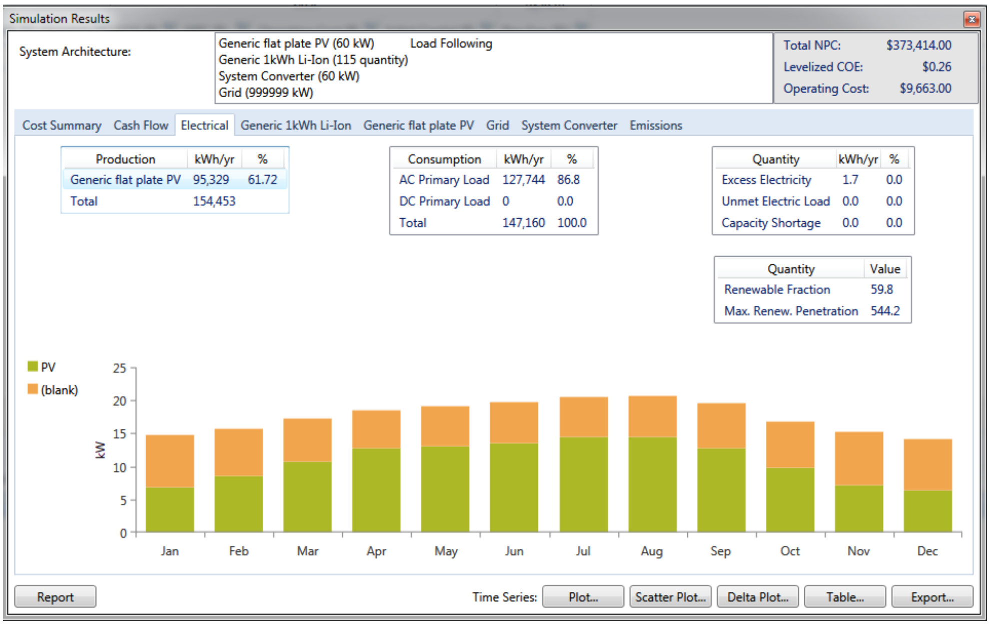

Figure 51- HOMER PRO Simulation results (Goal: 60% self-production, DC size: 20 kW)

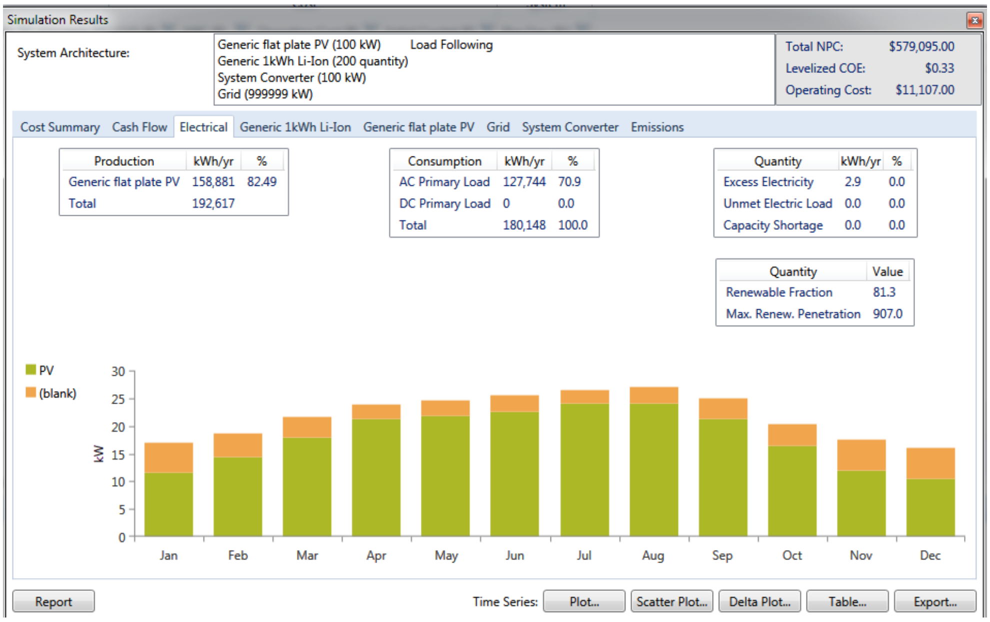

Figure 52- HOMER PRO Simulation results (Goal: 80% self-production, DC size: 20 kW)