Ref. Ares(2021)4936339 - 03/08/2021

eSTABLISHING COMMUNITY RENEWABLE ENERGY WEBS

establishing Community Renewable Energy Webs - Rolling out a business model and operational tool creating webs of households that jointly manage energy to improve efficiency and renewables uptake

Contract No. 890362

Deliverable 3.2: Specification for PV and battery storage simulation and self-consumption assessment

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 890362.

Document Information	
Title	Specification for PV and battery storage simulation and self-consumption assessment
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Dissemination Level	☐ **CO** Confidential, only for members of the consortium (including the Commission Services) ☐ **RE** Restricted to a group specified by the consortium (including the Commission Services) ☐ **PP** Restricted to other programme participants (including the Commission Services) ☒ **PU** Public
Reviewers	☒ EI-JKU ☐ UEAS ☒ GreenPocket ☐ CIRCE ☐ SWH ☐ UNITO ☐ ADEE ☐ IUE ☐ ACEA ☐ AEGEA
Status	☒ Draft ☐ WP Manager accepted ☐ Coordinator accepted
Action requested	☒ to be revised by Partners involved in the preparation of the deliverable ☒ to be reviewed by applicable eCREW Partners ☒ for approval of the WP Manager ☒ for approval of the Project Coordinator
Requested deadline for Action	

Versions			
Version	**Date**	**Change**	**Comment/Editor**
<1.0>	15.07.2021		First draft for review
<2.0>	26.07.2021		Document reviewed
<Final>	30.07.2021		Document ready for submission

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Executive Summary

Deliverable 3.2 describes the mythology to perform economic and energetic feasibility analysis of potential investments in PV for the eCREW participants.

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List of Acronyms

Acronym / Abbreviation	Definition
CBA	Cost-Benefit Analysis
DB	Data base
DoW	Description of Work
EC	European Commission
EM	Exploitation Manager

GA	Grant Agreement
IPR	Intellectual Property Rights
PR	Performance Ratio
PV	Photovoltaic
STM	Scientific and Technology Manager
ToU	Time of Use
WP	Work Package
WPM	Work Package managers
LCoE	Levelized Cost of Energy
NVP	Net Profit Value
IRR	Internal Rate of Return

Objectives and scope

This document describes the work done in task T3.2 to come up with a set of methodologies and functionalities about the new and existing self-consumption PV facility assessment. The new features for eCREW prosumers build on top of the current eCREW user App features and enhance the benefits for community members to maximise the benefit of their own PV assets and those of other community members. The three main new App functionalities around PV self-consumption are i) economic, financial and energetic PV assessment tool for potential new prosumers tailored to the location and users' demand profiles, ii) PV self-consumption monitoring for prosumers and iii) PV optimisation and forecast tool for prosumers.

The scope of the task covers the definition of the functionalities, the calculation modules and algorithms, the data requests and inputs from the users with the default values for standard facilities, the description of the results and outputs with the format (data, table, chart, …) and its units. Limitations and warnings are also remarked. Besides text descriptions, python scripts and functions are also given as a reference for the final app programmers. The algorithms and codes have been tested in non-real conditions. Alternatives for programmers to face lack of data such as historic demand profiles are also given.

The scope of this document does not include the actual integration of the functionalities in the App architecture and the solution of the specific problems derived from this integration, which will be done along task T3.3. The management of the storage devices finally has been taken out of the scope in this first development for several reasons: first, because there is no storage systems among the CREW members at this point in any of the three LCs; second, because the aim of the eCREWs is precisely to make the best use of the available self-generated energy within the community by means of the PV monitoring and awareness forecast and optimisation tools, and by means of the split-incentive mechanisms that pushes for a real-time consumption of the energy surpluses by other eCREW community consumers, rewarding prosumers for those surplus and the consumers for their disposal to consume them at the time they are available.

1 Introduction

Energy Communities are an initiative with an important role for citizens committed to preserving the environment and the local social tissue. The eCREW project aims at activating and fostering the inherent and, so far, underused - forces of community-driven Collective Action Initiatives (CAI). Profitability is not the only motivation for promoters of an energy community and often not the most important. The participants usually have internalized that their energy consumption must be socially and environmentally responsible [1]. The objective of the eCREW Engagement Strategy is to propose and design instruments that stimulate the participation of community citizens by detecting barriers and quantifying their development potential in each Lighthouse demo case (Germany, Spain, and Turkey).

Deliverable D3.2 is part of WP3, whose goal is to implement the functionalities specifically developed to facilitate the eCREW, developing an app software which motivates household to save energy, increase self-consumption of each CREW's renewable production and stimulate investments in PV. In particular, task 3.2 aims to describe a methodology to perform economic feasibility analysis of potential investments in PV for the CREW participants based on the expected solar radiation at the specific location and the historical demand of its members.

This document describes the methodology and functionalities defined so potential users who are interested in participating in PV energy communities can assess the installation from a financial, economic and energy perspective, in a transparent and easy way, in order to reduce uncertainty of the investment and encourage its deployment. Furthermore, other analyses are also proposed to monitor the actual resources obtained by the system once installed, and to obtain recommendations based on the solar radiation forecasts for the following hours.

1.1 Challenges and potential

Given that the aim of the task is to perform an economic feasibility analysis of potential investments in PV, some challenges need to be addressed. On the one hand, the defined methodology must perform an accurate assessment of the PV generation system through an interface which should be easy for users who may not be experts in the field and, therefore, may not know the values of some relevant parameters for the analysis. To overcome this problem, default common values were proposed for most of the parameters, so that users will be able to obtain a first approximation of the assessment without entering all the required values. In addition, they will be able to modify them within the valid ranges in order to improve the accuracy of the analysis. However, since data from the demos are not yet available, it may be necessary to adjust these default values once they finished.

Another challenge is to obtain the historical demand of the users and solar radiation forecasts for the following days on hourly basis. On the one hand, it is not always possible to obtain the hourly consumption of the users through the LCs, so it is necessary to establish a profile that is close to the actual demand. Otherwise, the results provided by the tool may not be accurate enough. On the other hand, there are multiples data sources for historical solar radiation and its future forecasts, such as national and European meteorological services or some private providers. However, they should cover the international application environment, be easy to implement and, if possible, allow free exploitation. The proposed solutions for these points are explained bellow, in the corresponding use cases.

Finally, defining a methodology in a way that is easy to implement by the final app programmers could also be challenging. To address this, most of the algorithms and calculations have been developed in python scripts, to facilitate their integration with the back-end systems and to be able to verify the obtained results. In addition, this approach allowed to assess the analyses proposed for the tool and verify the default parameters.

By means of the defined use cases, users will be able to evaluate PV installations from energy and economic perspectives in order to enhance the benefits for community members and maximise the benefit of their own PV assets and those of other community members based on its specific location, environment and other parameters of the facility. In this way, the aim is to promote the use of photovoltaic energy to achieve economic and energy savings and thereby reduce the environmental impacts and tonnes of CO_2 produced.

1.2 Overview of the app (WP3)

As mentioned above, this deliverable is part of WP3, which aims to develop the functionalities specifically developed to facilitate the eCREW approach, including the back-end processing unit which is the heart of the ICT-to-Human ecosystem and the installation of the tablet/smart phone app. Therefore, D3.2 is related with the tasks in this WP, including deliverables D3.1 and, especially, the back-end development explained in D3.3. The methodology presented in this deliverable will be implemented and integrated into the tool by the final app programmers through this WP.

1.3 Use cases: Expected results and impacts

Three use cases are defined, the first one focused on potential users to install photovoltaic systems and the others to evaluate the installation and obtain recommendations once it is installed:

- Use case 1: economic, financial and energy PV assessment tool for potential new prosumers tailored to the location and demand profiles of the users. This use case provides economical and financial metric, such payback, LCOE or IRR, which allow the user to evaluate the benefit of the installation, as well as the expected energy savings and coverage rate through the lifetime of the solar facility.
- Use case 2: PV self-consumption monitoring for prosumers. The outputs of this module are the actual measures of energy saved and compensated for, as well as their economic valuation, obtained from the data monitored over a certain period of time.
- Use case 3: PV optimisation and forecast tool for prosumers. This use case considers forecasted values of PV generation to estimate the possible energy savings and surpluses in the following hours or days. It can also recommend some actions to improve the self-consumption.

The calculation modules defined for use cases 2 and 3 and its parameters are similar to those applied in the use case 1. Therefore, they are only described in detail in this first case. For the other two, only minor differences will be outlined.

2 Economic feasibility analysis (use case 1)

The economic feasibility was developed to allow users to assess the cost-effectiveness of PV investment. This use case is composed of several modules, some of which were also applied in use cases 2 and 3, which are described below. In this section, the objective, calculation modules, input parameters considered and flowchart, as well as the assumptions and results, are presented.

The economic and energy assessment of the PV installation is computed based on historical demand of the user and radiation at its location. From this data, the PV energy generated over the lifetime of the solar panels is computed, applying the corresponding parameters (efficiency, installed power, etc.), to estimate the energy savings and surplus which will be obtained considering the demand of the user. Based on these estimations, the CBA of the installation is computed, considering costs, tariffs and split incentives, as well as other financial parameters.

2.1 Objective

The aim of this analysis is to assess the economic feasibility of potential investments in PV for the CREW participants, considering the historical solar radiation at the user location and its electricity demand. Based on the local profiles, geographic location and other mandatory or optional inputs, the algorithm allows to evaluate the PV installation dimension (PV Peak power and surface). Therefore, most suitable one could be selected according to the specific criteria of the user, which can be assessed from different perspectives using the provided outputs: payback, total economic savings, energy efficiency, or coverage rate. In addition, the algorithm allows to consider a possible loan, with the corresponding interest, to finance the investment.

2.2 Flowchart

The flowchart of the developed algorithm is presented in Figure 1, where the related calculations and inputs were joined in specific modules and the background of the boxes represents its functionality. Blue boxes are the calculations, where the different algorithms are performed, providing the required outputs, which are displayed with green colour, from the specific inputs. The mandatory inputs, which must be introduced by the user, are displayed with orangish background, whereas the optional inputs are pale pink. If no value is specified by the user, a default value is considered. Finally, yellow background boxes represent databases, some of them previously defined, which contain the required information to perform the calculations.

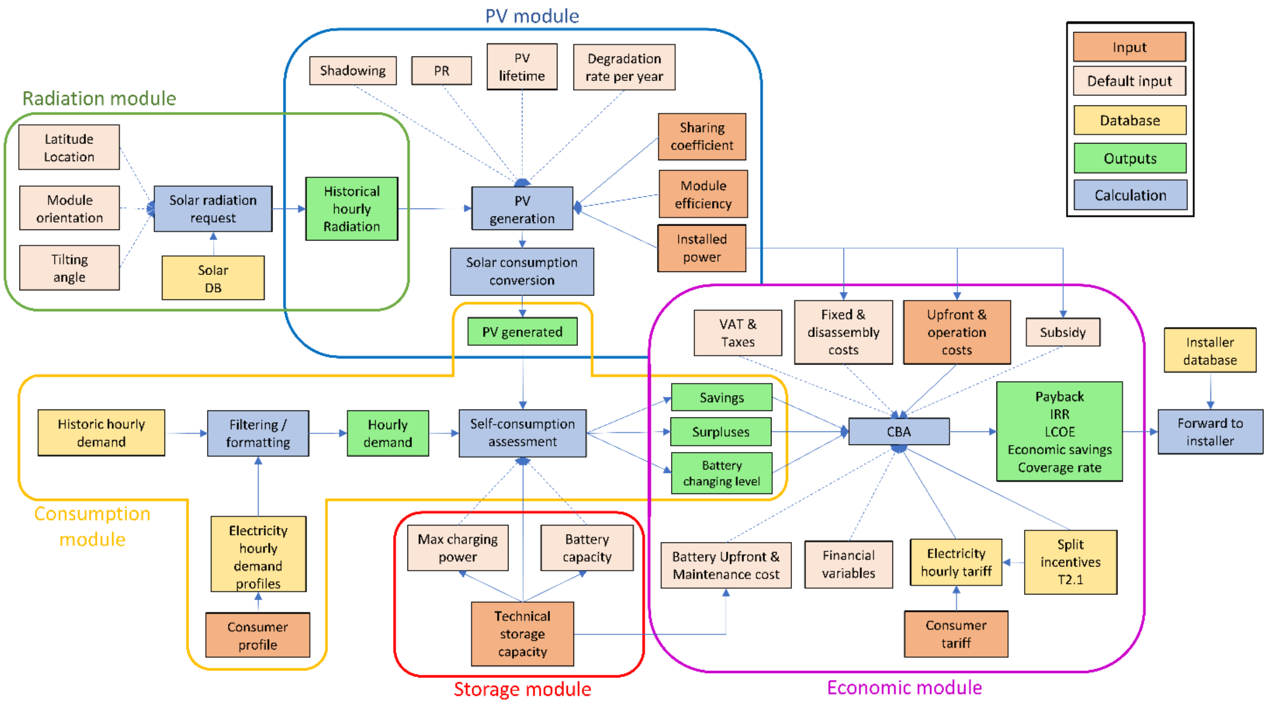

Figure 1 – Flowchart of the economic feasibility analysis including the energy storage module

The flowchart shown in Figure 1 includes the energy storage module, so it considers the use of batteries for the self-consumption assessment. However, as it was explained in the previous section, it was decided not to consider the energy storage in this use case, so this module was not developed. Therefore, the flowchart of the final algorithm flowchart is shown in Figure 2.

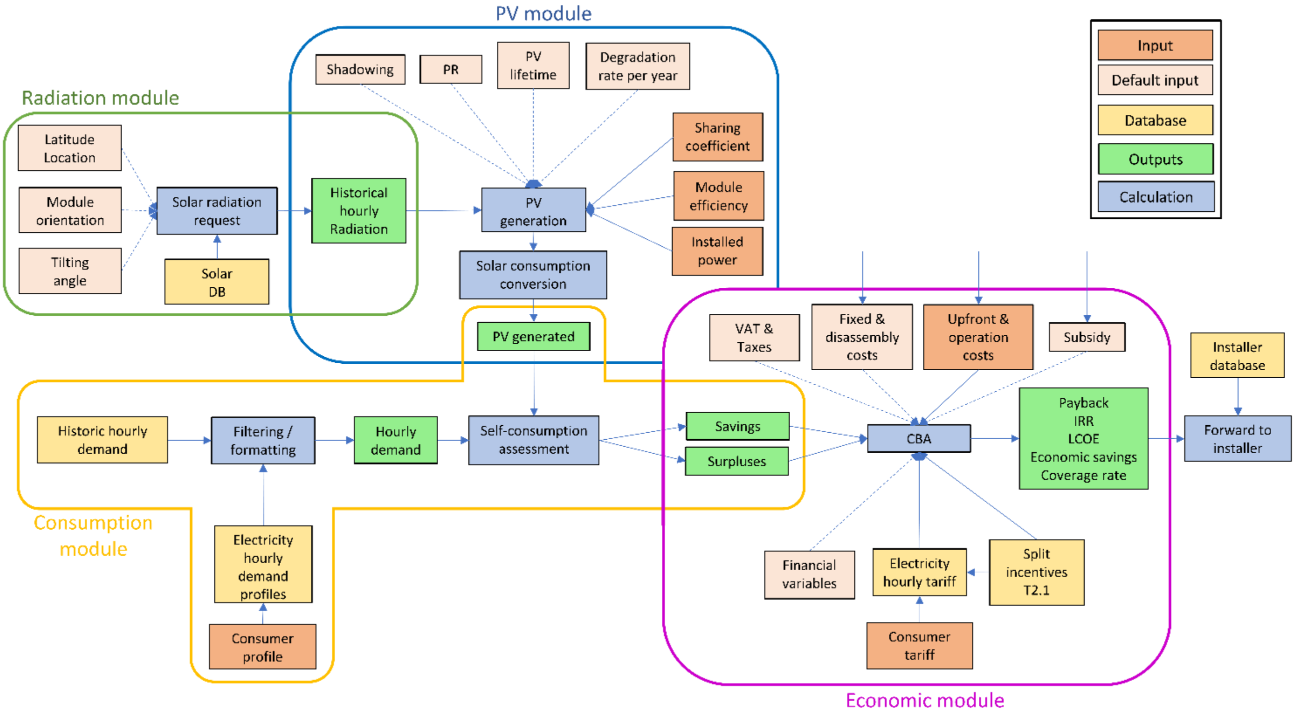

Figure 2 – Flowchart of the economic feasibility analysis without considering the energy storage module

2.3 Modules

The modules developed to obtain the economic evaluation of the PV installation are described in this subsection: purpose, input parameters, equations, and outputs. A brief description of these modules is shown in **Table 1**.

The following subsections describe the input and output parameters defined for each of the modules, providing a summary table with units, default values and proposed valid range, as well as an explanation of the algorithms and equations developed.

Table 1: Modules for the economic feasibility analysis

MODULES	DESCRIPTION
RADIATION	The historical solar radiation of the specific location, orientation and angle is requested to the database. The output of this module is the solar resource per square meter of capturing surface for an average year on an hourly basis in UTC time.
PV	This module computes the expected hourly PV generation for one year, considering the selected PV Peak Power, which will affect the dimension of the installation, and applying different coefficients: shadowing losses, performance ratio, module efficiency, degradation rate per year, the sharing coefficient within the eCrew community and PV lifetime. The output is the expected hourly PV generation for the lifetime of the modules in the local time of the chosen location.
CONSUMPTION	

	The historical demand of the user is adapted or estimated for one generic year on an hourly basis and performs the self-consumption assessment considering the PV estimations provided by the PV module. The outputs are the expected savings and surplus for the year also on an hourly basis.
STORAGE	This module provides all the required inputs so the battery storage could be considered in the self-consumption assessment: capacity, max charging power and level, max discharging power and level and degradation rate per year.
ECONOMIC	The economic assessment of the PV system is computed, considering the expected monetary savings and surplus over its lifetime as well as the electricity tariff prices and the split incentive scheme. The outputs are financial and energetic parameters, which allow the user to evaluate the specific installation from different perspectives.

2.3.1 Radiation module

This module provides the historical amount of solar resource per square meter of capturing surface (W/m^2) available at the location (latitude) provided by the user and considering the module orientation and the tilting angle. The output is the hourly radiation for at least one full year. The zoom of the flowchart of this module is shown in Figure 2Figure 3.

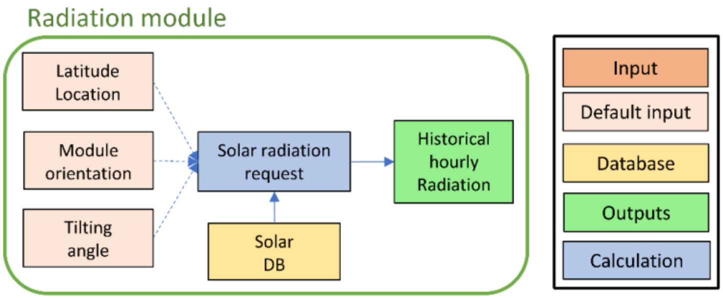

Figure 3 – Radiation module in the economic feasibility analysis

2.3.1.1 Input data

- Latitude of the location: It chooses the solar radiation map according to the geographical location of the PV facility. Northern latitude in degrees north. By default, the Northern latitudes of the three LC cities: Alginet, Hassfurt and Bursa.
- Module orientation (Azimuth angle) or orientation with respect to the South direction. By default, 0º South.
- Tilting angle or leaning angle of the modules. By default, the optimal tilting angle to maximise generation at the latitude of the location.

Table 2: Input and output parameters of the radiation module

Modules	Source	Varn name	Units	Default value	Type	Valid range	Temporal resolution
Radiation	user \ default	Latitude or location	º	LC location	float		
	user \ default	Module orientation	º	south	float	0-180	
	user \ default	Inclination	º	optimal by latitude	float	0-90	
Radiation \ PV	From solar DB	Historical hourly radiation	W/m2	-	array of float	0 - 2000	hour

2.3.1.2 Equations and algorithms

The developed algorithm requests the historical radiation for the chosen location, orientation and tilting angle. Several data sources were considered to obtain the historical hourly radiation, as well as its forecasting values, so they could be applied in the use case 3, as it is detailed in section 4. However, since only historical data were needed for this module, PVGis repository was finally selected as the final repository, because the API is well documented and the data provided is widely used in the industry.

The developed algorithm downloads the historical hourly incident solar radiation to PVGis through its API. The API call includes the location latitude, the module orientation in azimuth degrees and the module lean angle in degrees. Data are requested in the widest date range available, from January 2005 to December 2015, in order to perform a more robust estimation of an average year.

2.3.1.3 Output data

The output is a table with the solar energy falling upon every square meter of solar panels installed as average per hour throughout an average year in UTC time. An example of the output is shown in Figure 4.

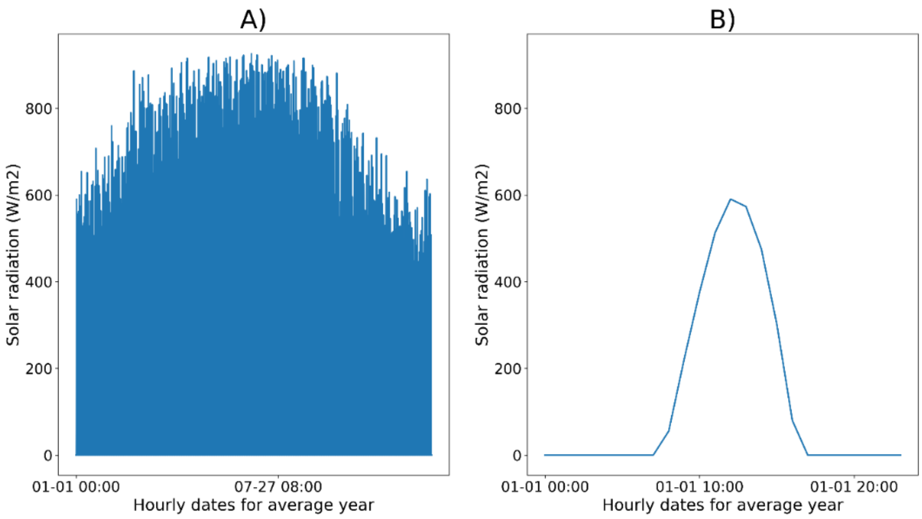

Figure 4 – Hourly radiation at Alginet location for an average year in UTC time. A) Full year; B) Zoom on one day

2.3.2 PV generation module

It converts the solar radiation into an estimation of electricity generation given a type of PV modules, yields and performance ratios entered as parameters by the user.

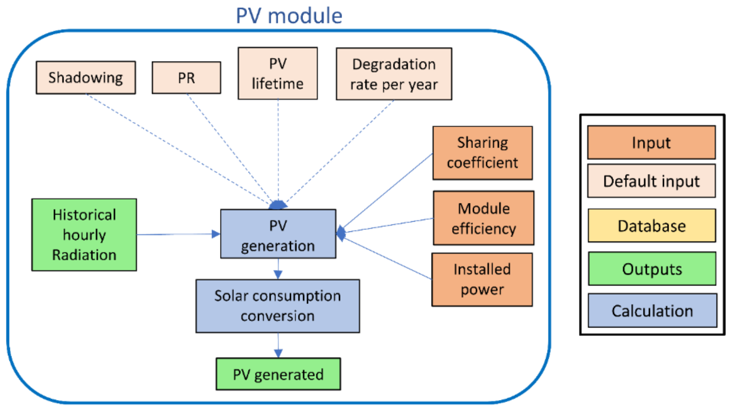

Figure 5 – PV generation module in the economic feasibility analysis

2.3.2.1 Input data

- Hourly radiation per square meter, calculated by the radiation module previously, in W/m^2.
- Shadowing rate, as a percentage of solar radiation in no shadow conditions. To be estimated and entered by the user. By default, no shadowing.
- Performance ratio (PR): losses throughout the facility including cabling, inverter, transforming units, etc. It does not include shadowing and module efficiency, that are accounted separately. By default, 85%
- PV asset expected lifetime in years. By default, 20 years
- Degradation rate per year: Loss of facility efficiency over lifetime. By default, 0.4%.
- Sharing Coefficient. In case of a collective facility, the amount of energy that is not allocated to the user.
- Module Efficiency: amount of solar radiation converted into DC current energy in percentage per square meter. Depends on the technology and quality of the chosen modules. By default, 15%.
- Power per area: The power that can be obtained from the solar panels according to the peak power of the radiation incident on each square meter. This parameter is fixed: 0.18 kWp/m^2.
- Installed Power: It is the amount of PV peak power installed, in kWp, with the module efficiency. It is easy to deduce the number of capturing square meters installed for the required installed power.

Table 3: Input and output parameters of the PV module

Modules	Source	Varn name	Units	Default value	Type	Valid range	Temporal resolution
Radiation \ PV	From solar DB	Historical hourly radiation	W/m2	-	array of float	0 - 2000	hour
PV	user \ default	Shadowing losses per year	%	0	float	0-100	
	user \ default	Performance ratio	%	85	float	0-100	
	user \ default	PV lifetime	years	20	float	0-31	
	user \ default	Module degradation rate per year	%	0,4	float	0-100	
	user	PV sharing coefficient	%	0	float	0-100	
	user	Module efficiency	%	15	float	0-100	
	fixed param	Power per area	kWp/m2	0,18	float	0-10	
PV \ Economic	user	PV Peak power	kWp	-	float	0,01 - 10^12	
PV \ Consumption	From PV generation calculation	Expected hourly PV generation during one year	kWh	-	array of float	0 - Inf	hour

2.3.2.2 Equations and algorithms

The PV generation per hour and square meter of capturing modules is computed by applying the different yield coefficients of the photovoltaic according to the following equations. First, the installation performance and the installed surface of the system are computed, Equation 1 and Equation 2 These factors are applied in Equation 3 to every sample of the solar radiation energy array, so the PV generation, in kWh, is computed in an array of the same length. The PV energy allocated to the user is computed in Equation 4 multiplying the *sharing coefficient*.

$$Installed\ surface\ (m^2) = \frac{Installed\ \ Power\ (kWp)}{Power\ per\ area\ \left(\frac{kWp}{m^2}\right)}$$

Equation 1

$$Performance\ (\%) = PR\ (\%) \cdot Module\ efficiency\ (\%) \cdot (100 - \ Shadowing\ (\%))$$

Equation 2

$$PV\ generation\ (kWh) = \frac{Solar\ radiation\ \left(\frac{Wh}{m^2}\right)}{1000} \cdot Installed\ surface(m^2) \cdot \frac{Performance(\%)}{100}$$

Equation 3

$$User\ PV\ generation\ (kWh) = PV\ generation\ (kWh) \cdot \left(1 - \frac{Sharing\ coefficient(\%)}{100}\right)$$

Equation 4

Once the PV energy generated for the user is computed for one full year, the array is replicated for the lifetime of the installation, applying the degradation of the efficiency of the facility that takes place every year, as it is shown in Equation 5. Finally, the UTC time of the radiation data, provided by the previous module, is shifted to the local time of the user.

$$User\ PV\ in\ year\ N\ (kWh) = User\ PV\ (kWh) \cdot \left(1 - \frac{Degradation\ rate(\%)}{100}\right)^N$$

Equation 5

2.3.2.3 Output data

The output of the module is the estimated PV generation of active altern current (kWh) ready for consumption of the user for every hour of the year throughout a full lifetime of the facility. The output is also shifted to match the location local time. An example of output and vector displacement is shown in the Figure 6.

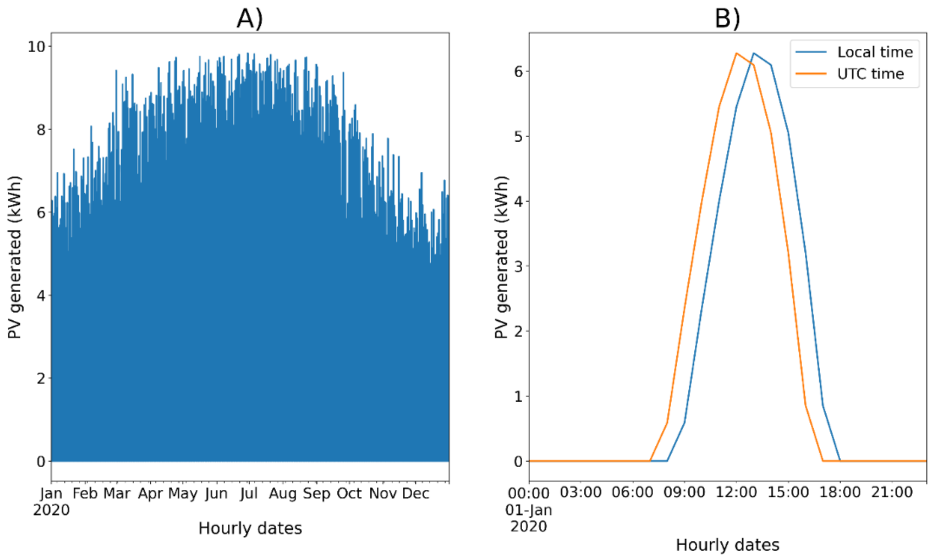

Figure 6 – PV energy estimation for the first year of facility at Alginet location. A) Full year; B) One day comparison between UTC time and local time.

2.3.3 Consumption module

This module compares the expected electricity demand of every hour of a generic year, based on historic data, with the PV hourly electricity generation to assess energy savings and energy surplus in kWh/h throughout a full year time.

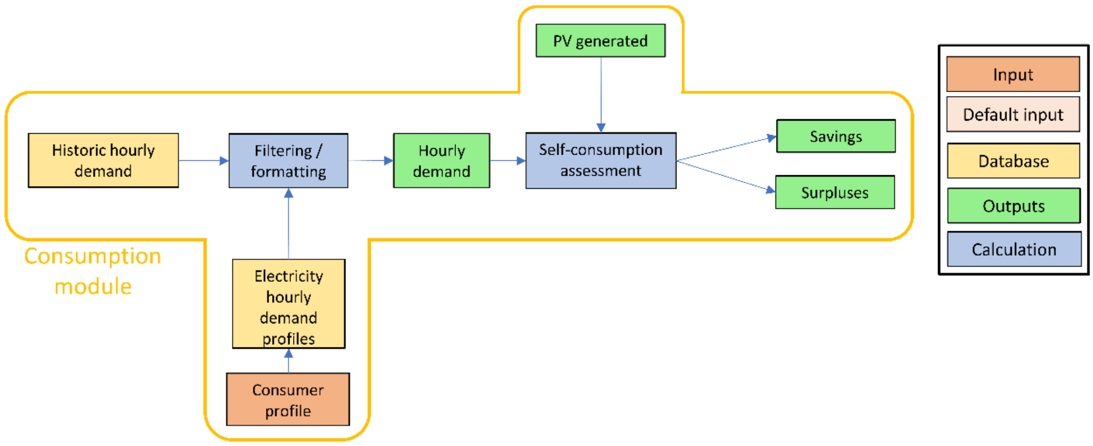

Figure 7 – Consumption module in the economic feasibility analysis

2.3.3.1 Input data

- Historic hourly demand, as hourly averages of energy consumption of a given user based on historic load profiles for the same hour of the year, in kW.
- PV generation per hour from the PV generation module in kW

Table 4: Input and output parameters of the Consumption module

Modules	Source	Varn name	Units	Default value	Type	Valid range	Temporal resolution
PV \ Consumption	From PV generation calculation	Expected hourly PV generation during one year	kWh	-	array of float	0 - Inf	hour
Consumption	proviced by LC	Historic hourly demand	kWh	-	array of float		hour \ month
	user	User demand profile	-	-	string		
	From filtering \ formatting calculation	Hourly demand	kWh	-	array of float	0 - Inf	hourly
Consumption \ Economic	From self-consumption assessment	Savings	kWh	-	array of float	0 - Inf	hourly
		Surpluses	kWh	-	array of float	0 - Inf	hourly

2.3.3.2 Equations and algorithms

This module consists of two calculation algorithms. The first one computes demand of the user on an hourly basis for a generic year, whereas the second one uses this result and the PV estimation provided by the PV module to assess the self-consumption throughout the lifetime of the solar panels, providing the energy savings and surplus.

The behaviour of the filtering and formatting algorithm depends on the temporal resolution of the input data provided by the LC. If they are hourly or with higher resolution, they are simply averaged to obtain a consumption over a generic year, removing corrupted data and applying linear interpolation to fill the missing values. Otherwise, if the data provided by the LC reflects only the monthly consumption, it is necessary to establish the demand profile of the user, since it may have a considerable impact on the assessment of self-consumption. This issue has been discussed together with GreenPocket, as it may increase the complexity of the interface. Different solutions were proposed:

- GreenPocket studied and explained us the Ardakanian, et al. (2014) paper [2] where consumers were classified on the basis of a questionnaire and estimated their consumption profile by benchmarking against a database. However, our opinion is that it would be necessary to obtain a large database, which also reflects the particularities of each region, weather conditions and culture.
- Other papers developed algorithms which can estimate the demand from household factors and energy behaviours, which also could be filled through a questionnaire, and a smaller database [3, 4]. The problem is that they reported 33 parameters to be asked in order to get a proper approximation, which may discourage the users from completing it and stop using the tool.
- Let the user to totally customize its consumption profile, entering the values for the 24 hours. Nevertheless, these values could be not accurate, since users could be no expert in this field.
- Provide the user with a set of predefined profiles, the most common ones, to choose from. Figure 8 shows an example of four possible generic profiles, computed as the actual average consumption provided by *Red Eléctrica de España*, which establishes four categories of consumers (A, B, C and D) based on their habits [5].

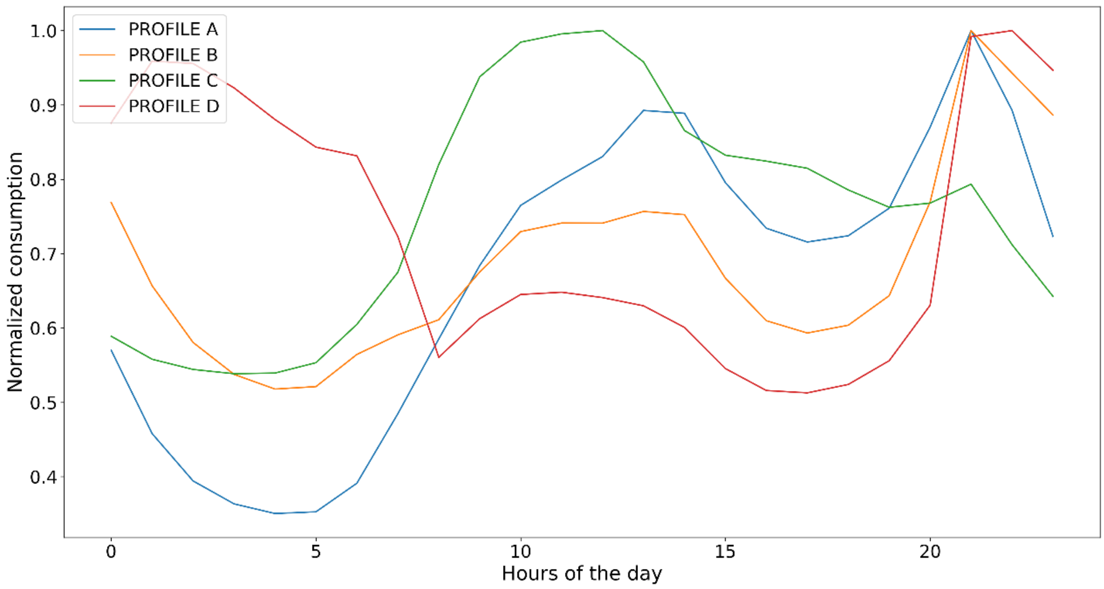

Figure 8 – Averaged and normalised actual consumption of 4 different categories of consumers during April 2021. Data obtained from *Red Eléctrica de España* [5]

In this case, users could choose the profile that best reflects their consumption habits. If the accuracy is to be improved, it would also be necessary to differentiate between seasons, weekdays and holidays. Besides, demand profiles should be shifted to reflect timetables differences in distinct regions.

- A hybrid solution would let the user to define the level of consumption during different moments of the day (night, morning, afternoon and evening), instead of the 24 hours, and fill in a short questionnaire to adjust these values (number of people at home, type of heating, etc.).

At this point, it is difficult to foresee which of these methods will be more suitable in terms of user interface simplicity and feasibility due to data availability. For the first version, we suggest starting with the simplest version, where the user would directly choose between different predefined demand profiles. Further on, a more advanced interface could be developed, which allows users to adjust the demand at different moments of the day or specific hours and may be complemented with a short questionnaire.

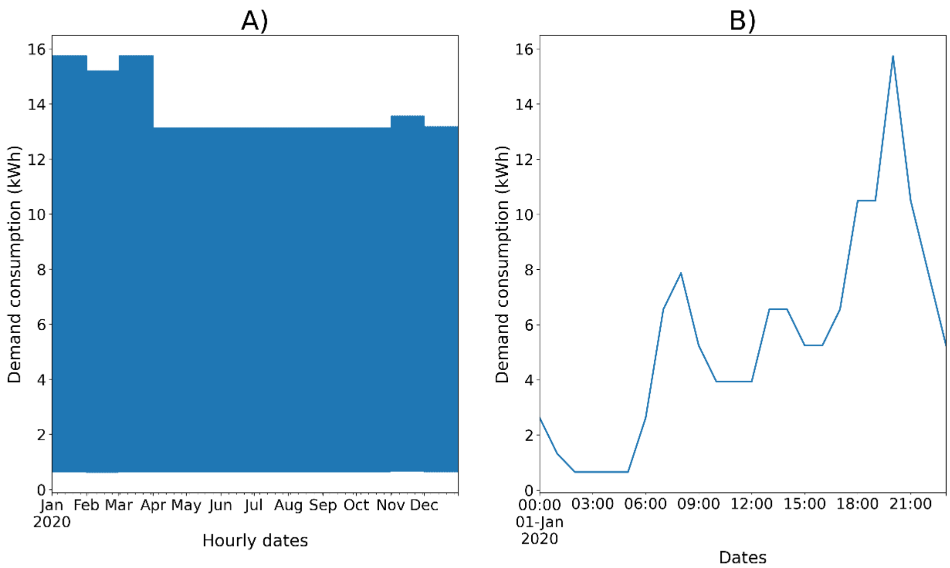

Figure 9 – Example of demand of a user artificially generated, based on actual consumption and predefined profiles. A) Full year; B) Zoom on one day.

Once the user generic demand is computed, the following equations are applied in the self-consumption assessment to obtain the energy savings and surplus, according to the estimated PV energy generated. As in the previous case, these calculations are performed for the hourly values independently:

- Energy savings (Equation 6): Energy saved by the user by consuming energy from the PV installation instead of from the grid.
- Energy surplus (Equation 7): Energy that is left over when generation is greater than demand. It may be fed into the grid or share it through the eCrew community.
- Grid demand with PV (Equation 8): It is the actual consumption of the grid by the user when the PV is installed. It is necessary to demand energy from the grid when the demand cannot be covered by solar generation.

$$Energy\ savings\ (kWh) = \min\left(User\ demand\ (kWh), User\ PV\ generated\ (kWh)\right)$$

Equation 6

$$Energy\ excess\ (kWh) = \ User\ PV\ generated\ (kWh) - Energy\ savings\ (kWh)$$

Equation 7

$$Grid\ demand\ with\ PV\ (kWh) = \ User\ demand\ (kWh) - Energy\ excess\ (kWh)$$

Equation 8

2.3.3.3 Output data

The output of this module is the self-consumption assessment for the expected lifetime of the solar facility. The previous equations provide the energy savings and surplus on hourly bases, as well as the grid demand for the user when the PV is installed. The sum of the array values provides the total saved, surplus and grid demanded energy over the lifetime of the installation. Figure 10 shows an example for the self-consumption one-day assessment.

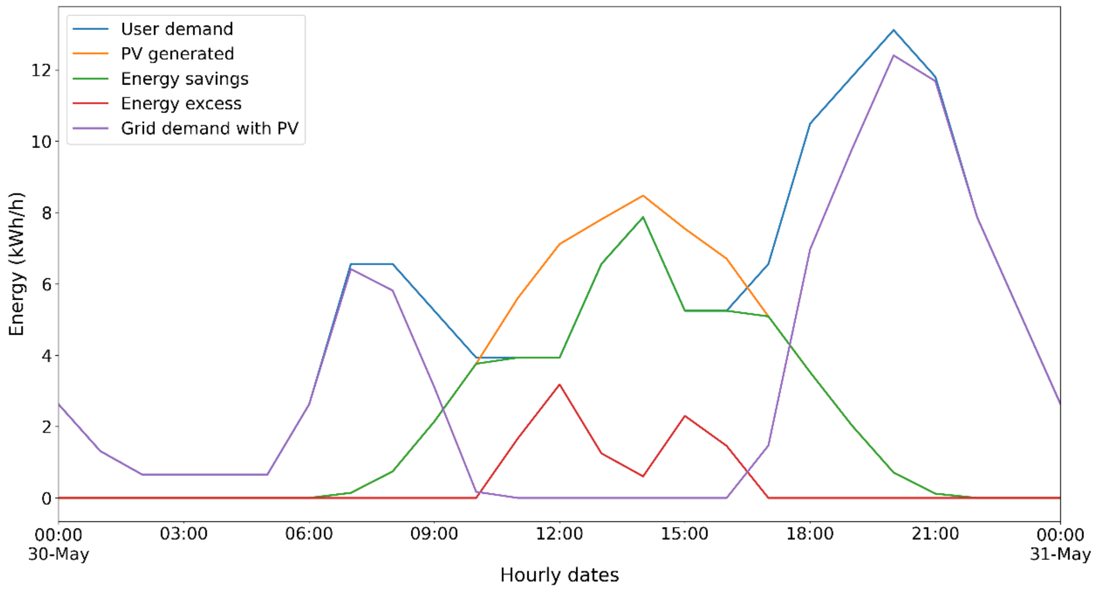

Figure 10 – Example of self-consumption analysis for one day

2.3.4 Economic module

The economic module converts the hourly energy balances into full lifetime aggregated economic and financial metrics that give information about the economic feasibility of the PV asset investment made by an individual or group of individuals. The calculation flowchart is shown in Figure 11.

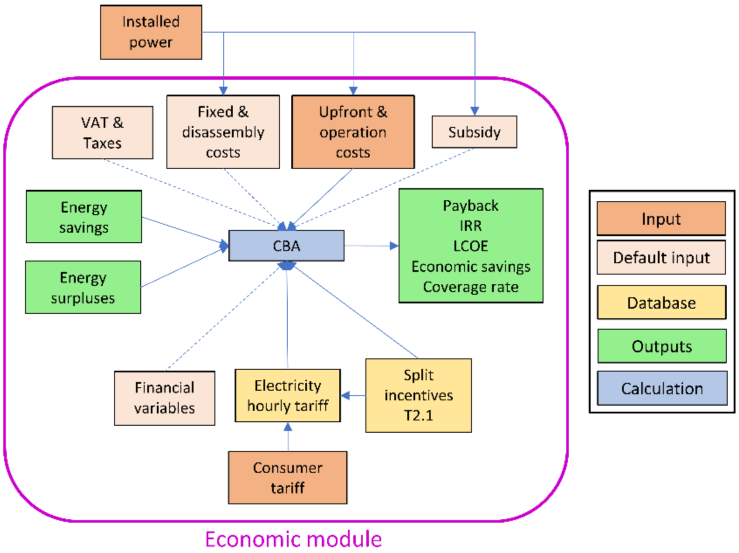

Figure 11 – Consumption module in the economic feasibility analysis

2.3.4.1 Input data

The Cost-Benefit Analysis (CBA) module has the following input data:

- Energy savings at every hour of the lifetime of the facility. This is the energy demand supplied by self-generation estimated by the PV consumption module, in kWh/h.
- Energy surplus at every hour of the lifetime of the facility. This is the energy surplus from the generation equipment that remains after meeting the energy demand at that hour. It is also measured by the consumption module, in kWh/h.
- Financing variables. This group of advanced variables define the type of debt structure to calculate the effect that such variables have on the equity cost-benefit analysis. These variables are:
  - Percentage of equity in the debt structure. The rest is assumed to come from external loan.
  - Interest rate of the third-party financing loan, in fixed percent per year.
  - Loan repayment period. It is the period in years for the repayment of the loan capital to the financing institution.
- Expected inflation rate for the estimated lifetime period of the PV asset. This value is used to calculate cost variations of recurrent payments such as operation and maintenance. It is also used to calculate the time effect of money value (currency depreciation). By default, 2% annual.
- Expected electricity price increase. This reflects the electricity annual price variation index. By default, it is equal to the inflation.
- Value added tax percentages of the installation and the electricity, as well as its taxes.
- PV Upfront costs. It reflects the one-time acquisition and installation costs of the PV asset. It is given in €/Wp and it is provided by the App user.
- PV Maintenance costs. It reflects the recurrent maintenance and operation costs of the PV asset on annual basis. It is given in €/Wp per year.
- PV fixed investment costs, in €.
- Disassembly costs, disposal and other end of life costs, in €, at the end of the PV asset lifetime.

- Electricity hourly tariff. Is the variable electricity price of the supply at every hour of the year, taxes included. It is given in €/kWh in for every hour and provided by the LC CAE, as retailer, or manually by the app user.
- Energy Surplus Compensation Prices. These prices reflect the remuneration perceived by the prosumer for the surplus of energy that is poured into the grid. It may be fix price or variable per hour. It is provided by the LC CAE as retailer, given by default by the self-consumption regulation in force, or manually by the app user. It is an array, since its values may vary at different times of the day, weekdays or seasons.
- Split incentive scheme: it is the additional incentive provided and managed by the CAE as a retailer for the surplus of energy that is generated and consumed locally within the CREW. This extra benefit completes the supply tariffs or default compensation schemes for consumers and prosumers. It is provided by the LC CAE as manager of the split-incentive programme. It is an array, since its values may vary at different times of the day, weekdays or seasons.
- Subsidies and aids percentage. It is the percentage of the upfront costs that is subsidised or comes from public or private financing aids. Upfront costs are then diminished by the subsidy percentage chosen by the App user.

Table 5: Input and output parameters of the Economic module

Modules	Source	Varn name	Units	Default value	Type	Valid range	Temporal resolution
PV \ Economic	user	Installed power	kWp	-	float	0,01 - 10^12	
Consumption \ Economic	From self-consumption assessment	Savings	kWh	-	array of float	0 - Inf	hourly
		Surpluses	kWh	-	array of float	0 - Inf	hourly
Economic (Financial variables)	user \ default	% equity	%	0	float	0-100	
	user \ default	Loan repayment term	years	0	float	1-31	
	user \ default	Interest	%	5	float	0-100	
	user \ default	Inflation rate	%	2	float	-100 - 100	
	user \ default	Electricity price increase	%	2	float	-100 - 100	
Economic (VAT and Taxes)	user \ default	Electricity VAT	%	0	float	0-100	
	user \ default	Installation VAT	%	0	float	0-100	
	user \ default	Electricity taxes	%	0	float	0-100	
Economic (PV costs)	user	PV upfront cost	€/Wp	-	float	0,1-100	
	user	PV maintenance cost	€/Wp and year	-	float	0,01 - 1	
	user \ default	PV fixed investment cost	€	0	float	0-100000	
	user \ default	Disassembly costs	€ / Wp	0,03	float	0-1000	
Economic	user	Consumer tariff	-	-	string		
	user \ default	Subsidies of total investement	%	0	float	0 -100	
	provided by LC	User tariff	€/kWh	-	table	0 - 1	hourly
	provided by LC	Electricity tariff prices	€/kWh	-	table	0 - 1	hourly
	provided by LC	Split incentive scheme	€/kWh	-	table	0 - 1	hourly
	From CBA calculation	Payback time	years	-	float	0 - 1000	
		IRR	% per year	-	array of float	-Inf - Inf	yearly
		LCOE					
		Economic savings and revenues (NPV)	€	-	float	-Inf - Inf	
		Coverage rate	%	-	float	0-Inf	

2.3.4.2 Equations and algorithms

The following equations are applied to obtain the estimated annual cash flows of the PV facility through its lifetime. To this end, it is necessary to apply the inflation rate to the installation costs, the electricity price increase and loan interests, as well as the electricity taxes. The monetary units are represented are represented by the symbol € for simplicity, but are analogous to the other currencies, applying the corresponding conversions.

Before estimating the monetary savings and compensations obtained through the PV installation, the electricity and compensation prices are computed taking into account taxes and the annual increase in electricity according to Equation 10 and Equation 11.

$$Taxes\ rate\ (unit.) = \left(1 + \frac{Electricity\ taxes\ (\%)}{100}\right) \cdot \left(1 + \frac{Electricity\ VAT\ (\%)}{100}\right)$$

Equation 9

$$Electricity\ price\ at\ year\ N\ \left(\frac{€}{kWh}\right) = User\ tarif\ \left(\frac{€}{kWh}\right) \cdot Taxes\ rate(unit.) \cdot \left(1 + \frac{Electricity\ price\ increase\ (\%)}{100}\right)^N$$

Equation 10

$$Compensation\ price\ at\ year\ N\ \left(\frac{€}{kWh}\right) = Split\ incentive\left(\frac{€}{kWh}\right) \cdot Taxes\ rate(unit.) \cdot \left(1 + \frac{Electricity\ price\ increase\ (\%)}{100}\right)^N$$

Equation 11

Both prices are applied to the hourly values of the energy flow arrays, which were computed in the self-consumption module. The energy flows are estimated for the whole lifetime of the facility, to take into account the degradation rate of the panels, so it is necessary to apply the corresponding prices for each year., following the Equation 12 and Equation 13

$$Monetary\ savings\ at\ year\ N\ (€) = Electricity\ price\ at\ year\ N\ \left(\frac{€}{kWh}\right) \cdot Energy\ savings\ (kWh)$$

Equation 12

$$Monetary\ compensation\ at\ year\ N(€) = Compensation\ price\ at\ year\ N\left(\frac{€}{kWh}\right) \cdot Energy\ excess(kWh)$$

Equation 13

The costs of the facility, at the beginning and at the end of the installation, as well as the maintenance costs over the lifetime, must also be considered to calculate the annual cash flows. Besides, these costs are also expected to increase due to inflation over the years. Therefore, it is also considered in Equation 16 and Equation 17.

$$Investment\ (€) = \ PV\ fixed\ investment\ cost\ (€) + \frac{PV\ peak\ power(kWp)}{1000} \cdot\ PV\ upfront\ cost\ (\frac{€}{Wp})$$

Equation 14

$$User\ investment\ (€) = \ Investment\ (€) \cdot \left(1 - \frac{Installation\ VAT\ (\%)}{100}\right) \cdot \left(1 - \frac{Subsidies\ (\%)}{100}\right)$$

Equation 15

$$Maintenance\ cost\ at\ year\ N(€) = \frac{PV\ peak\ power(kWp)}{1000} \cdot\ Maintenance\ cost\ \left(\frac{€}{Wp}\right) \cdot \left(1 + \frac{Inflation\ rate\ (\%)}{100}\right)^N$$

Equation 16

$$Dissasembly\ cost\ (€) = \frac{PV\ peak\ power(kWp)}{1000} \cdot\ Dissasembly\ costs\ \left(\frac{€}{Wp}\right) \cdot \left(1 + \frac{Inflation\ rate\ (\%)}{100}\right)^{(Lifetime+1)}$$

Equation 17

If the user has considered a loan to finance the investment, the interest is also applied in this cash flow equation, considering the percentage of the investment, the interest rate and the years of payment. Thus, the annual cash is shown in Equation 18. Besides, the cost of the installation to the user (Equation 15) must be included in the first year, as well as the disassembly costs (Equation 17) at the end of the lifetime.

$$\begin{aligned} Cash\ flow\ at\ year\ N\ (€) \\ &= Monetary\ savings\ at\ year\ N\ (€) + Monetary\ compensation\ at\ year\ N(€) \\ &- Maintenance\ costs\ at\ year\ N\ (€) - Investment\ payment\ at\ year\ N\ (€) \end{aligned}$$

Equation 18

Once the annual cash flows are estimated for the lifetime of the facility, the investment is evaluated using the following standard economic metrics:

- Net profit value (NPV): It provides the total aggregated net value of the cash flows along the project lifetime, discounted at the expected annual inflation rate.
- Payback: Time required to recoup the funds expended in an investment. It corresponds to the time when cash flows, discounted to present value, are equal to or greater than zero.
- Internal rate of return (IRR): It is the value of the interest rate that makes the NPV zero. It expresses the percentage yield obtained on the invested capital.
- Levelized cost of electricity (LCOE): It is the life cycle cost of the PV facility divided by the levelized PV generation expected along the lifetime, in €/kWh.

2.3.4.3 Output data

The result that come out from this module is the cost-benefit assessment, which are calculated from the PV project point of view. The analysis includes the economic metrics mentioned in the previous section (NPV, Payback, IRR and LCOE) as well as the estimated monetary savings and surplus compensation and the coverage rate for the lifetime of the facility, computed from the energy flows provided by the consumption module. An example of the cash flows over the years is shown in Figure 12 and the estimated economic flows for one day in Figure 13.

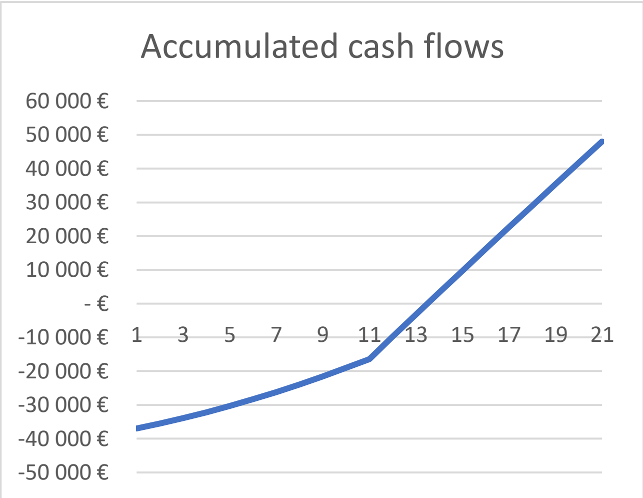

Figure 12– Consumption module in the economic feasibility analysis

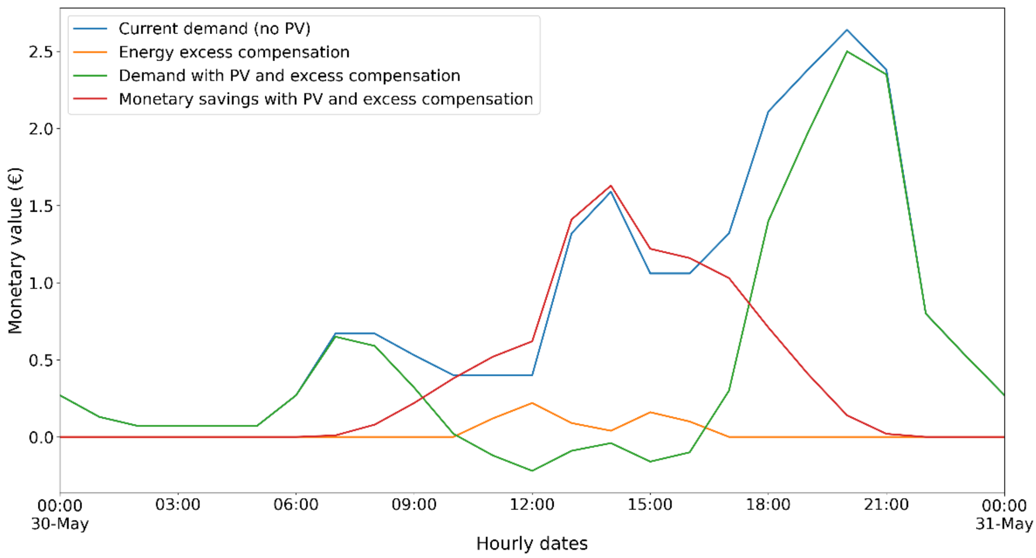

Figure 13– Example of self-consumption analysis for one day

2.4 Electricity Tariffs and Split Incentives

The hourly energy balance, energy savings and energy surplus, is calculated in energy terms per hour throughout a full year. The economic module, however, requires annual economic balances. Hence, the conversion into economic value of both energy streams, energy saved and energy surplus, has to be made monetising the energy flows and aggregating them along the full year assessment. The conversion factors are given by means of the electricity tariffs and the split incentive schemes in place, both provided by the retail company, in this case, the Community Administrative Entity (CAE).

Economic savings are calculated by multiplying the amount of energy saved in a given hour (energy demand supplied by self-generation estimated by the PV calculation module) and the hourly price applicable to the supply energy at that same hour. This is given in the variable terms of the Electricity Tariffs, taxes included. Tariffs may be fix price, two-period tariffs, tree-period tariffs, or even variable tariffs under the Time of Use (ToU) approach. In this sense, saving energy at peak periods (higher energy prices) entail larger economic savings for prosumers. Tariffs shall be provided by the CAEs according to the eCREW member identity or directly requested to consumers (if they are no customers or want to make simulations with different electricity tariffs.

Energy surplus, on the contrary, are retributed at a sales or compensation price, fixed or hourly, given by the self-consumption regulation in force in the country, or by the agreements reached by the user with the retail company or utility. These compensations or sale prices are an input to be provided by the CAE or by the user indistinctively and apply to generated energy surplus by the prosumer.

This market default compensation price for the surplus energy poured into the grid by prosumers can be complemented by a split-incentive scheme governed by the CAE, that offers a slightly higher retribution to the community prosumers in exchange for the provision of clean and local energy to the rest of the community consumers. This incentive awards both prosumers, that receive an extra price for their energy surplus, and the consumers that commit to consume the surplus onsite within the community. The overall benefit is the generation and consumption of locally produced energy by the community prosumers and consumers. For more details, see D2.2 “Definition of the split-incentives approach in LCs”.

A split-incentive scheme will be implemented in tested in Hassfurt by the German LC CAE. In this case, the standard energy tariffs for consumers will benefit of the incentive for instant surplus consumption, whereas prosumers will receive an additional incentive to the surplus energy, managed and paid by the CAE. For community members taking part in the split-incentive schemes the electricity tariffs and the compensation prices will be modified according to the incentive programme designed. It is important to notice that the consumers' energy demand will benefit of the incentive programme for an amount of energy less or equal to the surplus available at that precise hour, the rest of the supply being charged at the contracted electricity tariffs.

2.5 Results

The methodology developed for this use case allows the economic and energetic analysis of PV facilities, being able to assess different dimensions of the installation (installed power) and vary other parameters. One of the main goals was to simplify the user interface as much as possible, requesting the minimum number of parameters. In this sense, only a few parameters remain mandatory and must be introduced by the user, whereas the others have default realistic values. In this way, users can perform the analysis by entering only a few parameters and also specify some of the default value in order to obtain more accurate results.

The algorithms of the use case were developed in python to facilitate their explanation to the project partners, especially for their implementation within the WP3 app. Besides, some relevant testing was carried out to validate the methodology, the proposed equations and the default values chosen.

3 PV installation performance (use case 2)

This use case allows participants who already have the PV system installed to evaluate its economic and energy performance. The calculation modules are similar to those applied in the previous use case and are described below. The energy and economic evaluation are based on actual consumption data and energy generated by the PV system during a certain period.

The outputs of this module are the actual measures of energy saved and compensated for, as well as their economic assessment. Calculations will depend on the availability of monitored PV generation data. In case it is impossible to obtain them, they would be estimated from the actual solar radiation measured at that location.

3.1 Objective

The aim of this module are the actual measures of energy saved and compensated, as well as their economic valuation, obtained from the data monitored over a certain period of time. If it is not possible to obtain these actual measures on hourly basis, an estimation of this value is performed, as accurate as possible, following the approach explained in the previous use case.

3.2 Flowchart

Two flowcharts are differentiated depending on whether the monitoring data of the actual generated PV energy is available, Figure 14, or it is necessary to estimate it from the real solar radiation obtained at the specific location, applying the equations described in the previous section, Figure 15. The flowcharts shown below represent the calculations, inputs and outputs with the same legend that was used before. Calculations are shown in blue, outputs in green, mandatory inputs in orange, optional inputs in pale pink and DB in yellow.

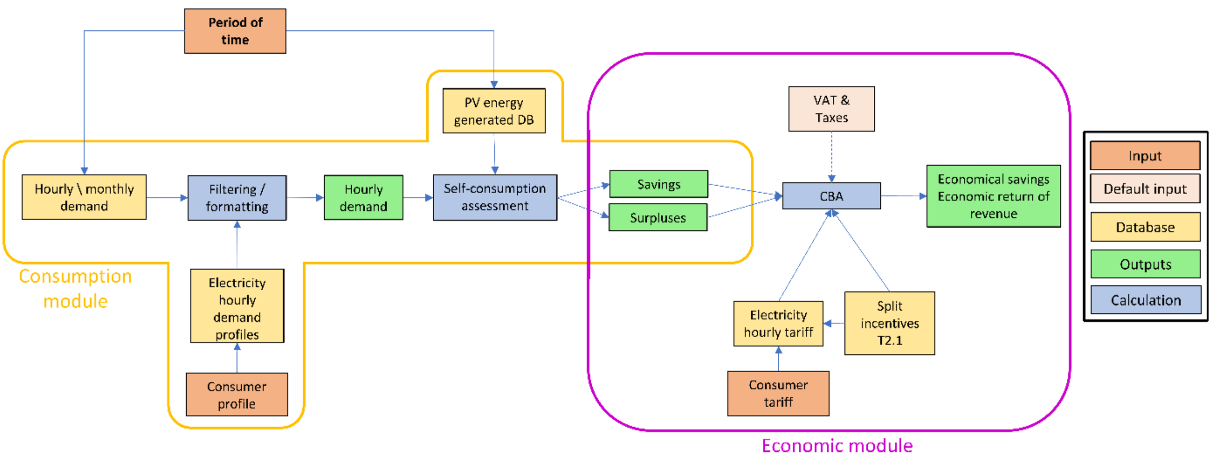

Figure 14 – Flowchart of the PV installation performance analysis with monitoring data of actual PV generated

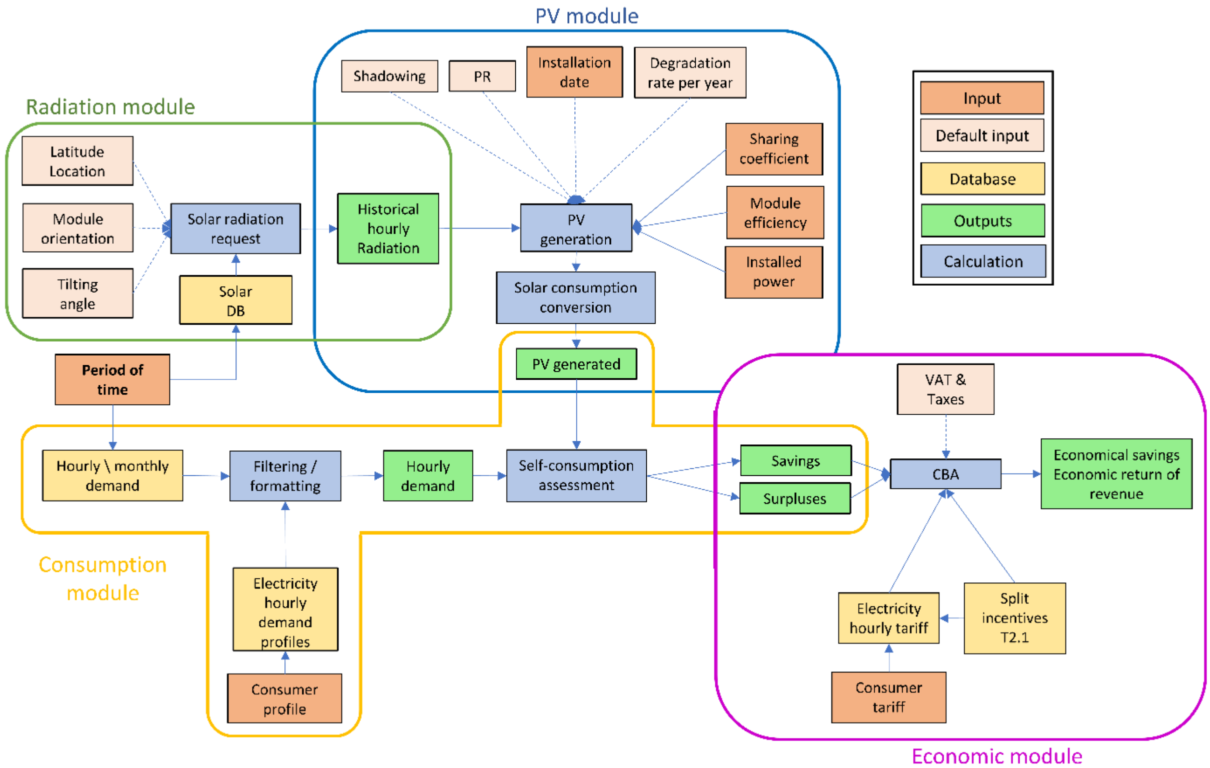

Figure 15 – Flowchart of the PV installation performance analysis, estimating the generated PV energy from the actual solar radiation

3.3 Calculation modules

There are two main calculation modules that support this use case: the consumption module, which computes the balance between actual energy generated and demanded in every hour of the requested period, the economic module, which converts the energy flows into economic flows using economic conversion factors (in force tariffs). The only prerequisite is that the assessment period contains valid stored metering data of the electricity demand and, if possible, of the PV generation. If the latter are not available, it is necessary to include the radiation and PV modules, in order to estimate the PV energy generated from the actual measured radiation at the facility location.

The differences between the calculations performed in this use case and the previous one are, on the one hand, that they are performed within the period of time set by the user, so the hourly arrays may have different durations, and, on the other, that facility costs and financing are not taken into account.

3.3.1 Solar radiation and PV generation modules

As mentioned above, these modules are only necessary if PV generation monitoring data is not available, as shown in the flowchart in Figure 15. In this scenario, the actual radiation obtained at that location is requested on an hourly basis during the selected period of time. The equations and parameters of these modules are the same as those described in subsections 2.3.1 and 2.3.2, so its explanation is not repeated below. Only one parameter is changed, the lifetime of the facility, which is replaced by the installation date in order to estimate the accumulated degradation of the solar panels.

3.3.1.1 Input data

The parameters which are different from those mentioned in subsections 2.3.1.1 and 2.3.2.1 are:

- Start and end of the assessment period. It should be from 1 hour to 1 year.
- Installation date of the PV facility, which is used to calculate the number of years the facility has been installed.

3.3.1.2 Equations and algorithms

As mentioned above, the calculations performed are the same as those described in the corresponding sections of use case 1, although the hourly energy flow arrays are defined within the specific dates set by the user. However, it is not possible to obtain recent solar radiation data through the PVGis API, since the repository only covers the years between 2005 and 2016. This issue has been discussed with GreenPocket, and different solutions were proposed:

- Obtain data from national meteorological agencies, which do provide recent radiation measurements and they also usually have predictions for the next few days. Moreover, they are usually free of charge, e.g., AEMET in Spain. The disadvantage of this approach is that the data would have to be requested through different APIs, once per each agency, which would hinder the development and international deployment of the tool.
- Request the data to the European Centre for Medium-Range Weather Forecasts (ECMWF [6]), which is both a research institute and a 24/7 operational service. This centre produces global numerical weather predictions and measurements. Most of the European national agencies collaborate with this centre and, according to its website and publications, they provide high resolution and quality data and predictions. However, the subscription is not free of charge, so an extra cost should be added to the exploitation of the eCREW app.
- Some private tools, which provide real-time and historical radiation data and predictions, have been consulted and tested. As in the previous approach, the data provided have a high temporal resolution, but it is not free of charge. One of the analysed tools is Solcast [7], which, in addition to the forecasted values, provides a confidence interval in the predictions, which could add more functionalities for the use case 3.

Regardless of the selected tool to request the data, the radiation data obtained will be converted to the appropriate format and units required in this analysis. The output of the radiation module must be an hourly array with the actual radiation measurements at the specific location on the selected dates, in W/m^2. This array is the input of the PV module, from which the energy generated on those dates is estimated by applying the equations described in the subsection 2.3.2.2. The accumulated degradation of the modules is also applied, considering the years that have elapsed since the installation of the system, Equation 5.

3.3.1.3 Output data

The output is the estimated hourly PV energy in the period of time selected by the user based on the actual radiation measured at the location of the facility.

3.3.2 Consumption module

The energy balance of self-consumption is computed applying the same equations described for use case 1. As mentioned above, the PV generation may be the actual monitoring values or an estimation from the radiation measured at the specific location. The calculations applied in this module are the same, regardless of how the PV generation data is obtained.

3.3.2.1 Input data

All the parameters are the same than those mentioned in subsection 2.3.3.1. The only difference is that the electricity demand and PV generation arrays are defined over a certain period of time, instead of the lifetime of the installation.

3.3.2.2 Equations and algorithms

The equations and procedures are the same as those described in subsection 2.3.4.2, but applied to the actual electricity demand in the period selected by the user. In this use case, the demand data may also be provided in monthly basis, rather than hourly. Therefore, it may still be necessary to establish a generic demand profile for the user, so that the hourly array can be generated based on the measured monthly consumptions.

3.3.2.3 Output data

The output of this module is the energy savings and surplus on an hourly basis in the period selected by the user. An example of the daily analysis is shown in Figure 10.

3.3.3 Economic module

This module is also similar to the economic module described in use case 1, but simpler as it is not necessary to consider costs nor financing parameters, as it is shown in the flowcharts of this use case.

3.3.3.1 Input data

The input data are the same as those used in subsection 2.3.4.1, but without considering costs or financing parameters.

3.3.3.2 Equations and algorithms

Since calculations are simplified in this use case, only the equations related to the energy saving price and the surplus compensations are applied, Equation 9 to Equation 13.

3.3.3.3 Output data

The outputs of this module are the monetary savings and compensations within the selected period.

3.4 Results

The methodology developed for this use case allows the economic and energetic analysis of the PV installation performance, simplifying the user interface and reducing the number of requested parameters as much as possible, as discussed in the previous use case.

Furthermore, if the user entered information regarding the investment of the facility and maintenance costs, some metrics may be also computed in order to provide the percentage of annual maintenance and the total investment recovered during the selected period.

4 Forecast and recommendations (use case 3)

This use case considers forecasted values of PV generation to estimate the possible energy savings and surpluses in the following hours or days and provide recommendation to improve the self-consumption. The calculation modules are similar to those applied in the previous use case and are described below.

The forecast of solar radiation for the coming hours or days is very complex and beyond the scope of this task. The proposed solution is to request this data to specialised tools or agencies in order to estimate the expected PV energy. Accurate forecasting of user demand is also a complex calculation, addressed by different methods in several papers. Therefore, the recommendations to improve self-consumption refer to the specific moments when more PV generation is expected and therefore it is advisable to concentrate the energy consumption.

4.1 Objective

The aim of this module is to estimate the energy generated by the PV system in the coming hours and to propose recommendations to the user to increase the self-consumption.

4.2 Flowchart

The flowchart of the forecast and recommendations use case is shown in Figure 16, using the same legend that was used in the previous cases.

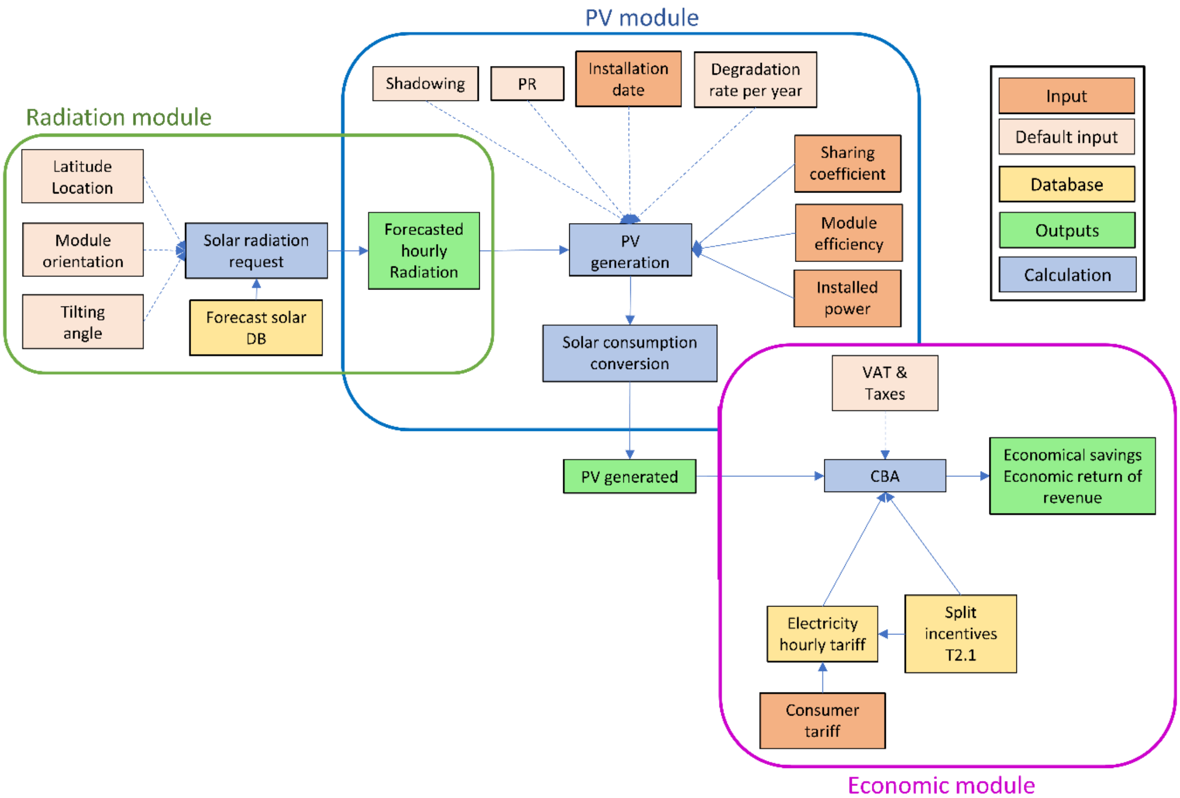

Figure 16 – Flowchart of the forecast and recommendations use case

4.3 Calculation modules

There are two main differences between this use case and the previous ones. First, the solar radiation considered is the estimated solar radiation for the next hour or days, so the array will be defined only for those hours. The other one is that the energy consumption module is not taken into account since, as mentioned above, the economic estimations are computed based on the expected energy to be generated by the PV facility.

4.3.1 Radiation forecast module

In this use case, the radiation module requests the forecasting radiation data at the specific location instead of historical data.

4.3.1.1 Input data

All the parameters are the same than those mentioned in subsection 2.3.1.1, to specify the location and the orientation and tilting angle of the panels.

4.3.1.2 Equations and algorithms

It is necessary to request the radiation forecast to external tools or agencies. As discussed above, in use case 2, most of those external repositories provide both recent and forecasted data, so it would be advisable to use the same API to obtain them. In this scenario, the API provides an array of the hourly solar radiation forecast for hours or days ahead at the facility location.

4.3.1.3 Output data

The output expected here is an array with the hourly distribution of expected solar radiation in W/m^2 for the next hours or days.

4.3.2 PV generation

This module is the same as the one described in the previous use case but applied to the forecasted radiation data. The accumulative degradation of the solar panels, considering the years that have elapsed since the installation of the facility, is also considered, applying the Equation 5. The output is also an array on an hourly basis, representing the expected PV energy for the next hours or days.

4.3.3 Economic module

This module converts the available energy generation forecast into economic savings assuming a full usage of the PV generated energy. Results can be provided hourly, in €/h, or for the full day, in €/day.

4.3.3.1 Input data

The input data are the same as those used in subsection 2.3.4.1, but without considering costs or financing parameters.

4.3.3.2 Equations and algorithms

Since a full usage of the PV generated energy is assumed, calculations are simplified in this use case, only the equations related to the energy saving price and are applied. The energy surplus compensations could also be considered in order to compare the economic benefit if all of the energy provided by the system is self-consumed.

4.3.3.3 Output data

Maximum economic benefits expected for the full usage of the PV energy forecast. The recommendations will refer to this output, so user can schedule its demand and optimize as much as possible the self-consumption.

4.4 Results

The output of this use case is the chart with the hourly distribution of expected electricity generation in W or kW for every daytime hour, to create awareness of the self-consumption potential on the hours or days ahead, and recommendations for an optimal scheduling of appliances to make the best of the available energy and reduce surplus, maximising the savings and the economic benefit of the PV facility. Additionally, an equivalent of power in type and number of average appliances may be given (not recommended as it might lead to confusion).

5 Conclusions

One of the most important targets of energy communities, notably RES communities, is the joint effort of consumers and prosumers to generate and self-consume the energy locally. These are the basis of the distributed generation that reduce the stress on the transport and distribution networks, keep distribution losses to a minimum, and enable the participation of citizens in the energy market by becoming active actors in the market.

Despite the cost drop of the new RES distributed generation assets, there is still a low penetration of small-scale renewable facilities in many countries in Europe. The presence of prosumers in eCREW-like communities is important to generate savings and economic benefits for both prosumers and consumers within a community managed by a market retailer CAE. The initial assessment in the three eCREW demo sites is that only in Germany there seems to be a good enough number of self-consumption PV facilities to make the best of the eCREW split-incentive schemes. A higher number of PV electricity producers would yield an important benefit for all the community members.

However though, making an accurate economic assessment of a possible privately promoted investment in a PV asset is difficult due to the many uncertainties making part of the economic and financial revenue streams. The regulatory framework is just one of them but also the size and type of installation, the solar resource availability in the chosen location, and the energy demand and generation matching determine the amount of energy saved and the energy surplus to be consumed by other community consumers.

The purpose of the enhanced app functionality developed in this task is to break this uncertainty to attract interest of potential community prosumers to invest in individual or collective self-consumption facilities. Existing prosumers may also benefit of the App by monitoring the self-consumption and autarky levels for a given period based on hourly generation and demand data stored in the eCREW data platform.

Finally, saving money is always more interesting for prosumers than the compensation obtained for the energy surplus. In order to maximise savings a day-ahead generation forecast is proposed to allow prosumers to schedule their flexible demands at the times of maximum generation. This forecast is made on accurate weather and solar radiation forecast databases that permit the hourly estimation of electricity generation for the day-ahead.

This complete set of functionalities for actual and potential prosumers enable eCREWers to optimise their participation in the community and boost the investments in self-generation facilities in the communities. The algorithms and calculation methodologies proposed in this document need to be integrated in the eCREW App (T3.3) and tested in the three LCs (WP4). Usage rate, number of new PV installations and surveyed user satisfaction rates will give hints for improvements in subsequent versions of the tools

6 References

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7 Appendix

7.1 Python code structure

This section presents the folder structure where the python code, which was developed to facilitate the integration of the proposed methodology in the app, is included. The folders include, on the one hand, the calculation algorithms of the different modules (CBA_module, demand_module, PV_module), and, on the other, the other necessary functionalities of the tool: management of the variables and default data and functions to paint the intermediate results obtained. In addition, the python file *main_payback_example.py* is included, where the modules involved in the different steps of the tool are run, so that it is possible to analyse the results provided by each of them:

- main_payback_example.py
- .\assement_module
    - __init__.py
    - adapt_dates.py
    - peak_power_optimizer.py
    - .\CBA_module
        - CBA_module.py
    - .\demand_module

        - Convert_monthly_profiles.py
        - Self.consumption_assessment.py
    - .\PV_module
        - adapt_solar_time.py
        - PV_module.py
        - PVGis_requests.py
- .\default_demand_data
    - demand.json
    - demand_profiles.csv
    - monthly_consumption.csv
- .\default_params_management
    - country_related_CBA_params.csv
    - country_related_CBA_params.json
    - default_params.json
    - set_default_params.py
- .\irradiance_data
    - Alginet.json
    - Bursa.json
    - HaBfurt.json
- .\print_figures
    - __init__.py
    - plot_figures.py
- .\tariff_params
    - adapt_year_tariff.py
    - generate_yearly_tariff.py
    - tariff_params.json