A free online tool for the simulation of collective self-consumption in Brussels

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ABSTRACT: In the past and until now, Belgium mainly had a mechanism in place that rewarded the PV energy production through feed-in tariffs that were attributed with a net annual balance counting. In Belgium, the mechanism of self-consumption for photovoltaic (PV) installations is projected to become mainstream. This change is going to have an important impact on the PV sector in Belgium. At the moment, there is a demand for a simple simulation tool that makes it possible to simulate the self-consumption ratio and the self-sufficiency ratio of a PV system or a group of PV systems in combination with one local consumption profile or a group of consumption profiles from the same neighborhood, in particular in the context of collective self-consumption. Indeed, combining different consumption profiles from the same neighborhood can significantly improve the self-consumption ratio to reduce the cost of a PV system for the users.
A free web application has been provided to the public for such simulation[1].
Keywords: Self-consumption, self-sufficiency, collective, Belgium, Brussels, simulation

1 INTRODUCTION

The self-consumption of the Photovoltaic (PV) systems is a strong driver in the revenue model.

Photovoltaic self-consumption is an economic model in which a PV system or a group of PV systems can be assessed to how much of PV power produced is consumed by a specific consumer or a group of consumers. In this model, the PV generated energy is consumed instantaneously as it is being produced and therefore uses on-site generated energy to cover the consumer electricity needs. It offers greater economic benefits and greater independence from the grid and future electricity rate variations. Since Belgium has had until now a mechanism in place that rewarded the PV energy production through feed in tariffs that were attributed with a net annual balance counting, the country is moving towards mechanisms of self-consumption for photovoltaic (PV) installations which are potentially projected to become mainstream. This change is going to have an important impact on the PV sector in the country.

A misalignment between PV energy generated and the local consumption whether it is for an individual prosumer or in a scenario of a collective of producers and consumers creates a lack of self-consumption, which can limit PV systems economic potential.

Assessing self-sufficiency is a parameter that combined with self-consumption form the basis of an energy community. Indeed, what individual self-consumption lacks to achieve energy independence can be provided by collective self-consumption, which can be achieved by having a community of energy producers sharing energy that they produce with a community of consumers (who also may be producers themselves and in that case called prosumers).

At the moment, there is a demand for a simple simulation tool that makes it possible to simulate the self-consumption ratio and the self-sufficiency ratio of a PV system or a group of PV systems in combination with one local consumption profile or a group of consumption profiles from the same local area, in particular in the context of collective self-consumption. Indeed, combining different consumption profiles from the same energy community can significantly improve the self-consumption ratio and thereby reduce the cost of the PV electricity generation for the users[2].

This free online tool, named Consolectiv (for CONsumption, SOLar, and collECTIVe) is the fruit of collaboration between the company Lucisun and Université Libre de Bruxelles (ULB) and can be used through a public web interface [1]. The tool is composed of an interface for calculating the self-consumption ratio, the self-sufficiency ratio and other results for the self-consumption of the energy produced by photovoltaic installations. It is aimed at the general public, policymakers, and the photovoltaic installation professionals. It has two main functionalities.

One is for the individual prosumers. It aims at helping people decide on the optimum design conditions for their photovoltaic installation, taking self-consumption into account, and the corresponding returns on investment.

Another one is for energy communities. It helps combining different types of building consumption profiles and photovoltaic producers to evaluate the global impact of these combinations on the self-consumption and self-sufficiency for a whole neighborhood of prosumers.

Therefore, both for the prosumer and for a whole energy community neighborhood, the Consolectiv tool contributes to help people make better informed decision.

2 METHODOLOGY

The tool takes inputs from the user and goes into a processing phase before generating the figures and numbers relative to the analysis of the defined systems.

Both the prosumer simulation section and the energy community simulation section take similar inputs to define the profile of energy consumer(s) and the profile of photovoltaic producer(s). The financial parameters of the PV system are opened to be modified in the prosumers section by the users. However, for the energy community, the financials parameters considered are fixed to the current context in the Brussels region area.

One of the main functionalities of the tool is to provide an energy consumption profile and the photovoltaic system generation profiles for different types of buildings that the user can select as a consumer and for different type of photovoltaic producer(s).

The self-consumption and self-sufficiency ratios of such a configured system is therefore calculated from the consumption and production profile as well as some financial metrics (only for the prosumers section) such as the payback time, and the net present value.

2.1 Energy consumption profiles

In order to have typical energy consumption profiles for different types of buildings, synthetic profiles in Typical Meteorological Year (TMY) format have been used corresponding to 17 different types of buildings, and therefore of consumption profiles. These profiles are obtained through a synthetic generation method developed by National Renewable Energy Laboratory in the USA [3] and takes into account the local climate and consumer preferences.

A set of data of commercial and residential hourly load profiles for different commercial building types and residential buildings has been used for the analyses.

The load profiles store a representative yearly consumption in an hourly format of consumed electricity, in kWh.

The tool therefore proposes a set of different profiles of consumers which when given as input a specific type of building, the electricity profile is defined. The hourly consumption data are for the different types of consumption profiles downsampled to 10 minutes granularity. This 10-min granularity is chosen to have the desired results respecting the usual time interval of metering by Distribution System Operators (DSO).

In the “prosumer” simulation section of the tool, there is a possibility to select and run an analysis with one consumption profile and in the “energy community” section different profiles can be combined.

2.2 PV generation profiles

For the photovoltaic generation part, the simulation tools use an internal simulation library from the company LuciSun which transpose the Global Horizontal Irradiance (GHI) data to the plane of array irradiance of the PV systems provided. The user can choose how the modules are mounted, by providing the system angle of inclination and orientation.

The Global horizontal irradiance data used is a Typical Meteorgical Year (TMY) dataset which is a set of meteorogical data values for every hour and representing a typical year for the region of Brussels.

The hourly irradiance data brought to the plane of array of the system(s) is downsampled to a 10-min granularity to simulate the flow of energy and the reference yield is derived from it. Considering the system peak power and an average system loss of 20% (Performance Ratio of 80%), the energy system yield of each PV system is calculated.

In the case of the prosumer simulation section, one single PV production profile is considered, and in the case of the energy community section, different profiles are combined.

2.3 Definition of self-consumption and other metrics

The 2 main principles of self-consumption and self-sufficiency will be defined below and are generally used in the world of local production. From them, ratios that allow different systems and operations can be derived and can be compared with each other to assess their efficiency and dependence on the public grid.

2.3.1 Self-consumption

Self-consumption (SC) can be defined as the share of self-consumed PV production, which is equal to the ratio of self-consumed energy from the photovoltaic system production (E_{lgc}) to the total photovoltaic energy production on the site (E_{gen}) [4] .

$$SC = E_{lgc}/E_{gen}$$

The concept brought to an energy community level consists of a local exchange between neighboring consumers of renewable electricity from one or more local producers. Collective self-consumption is therefore the application of self-consumption on a collective scale.

2.3.2 Self-sufficiency

Self-sufficiency ratio indicates how independent the user or a community of consumers will be from the grid.

It can be measured by the self-sufficiency ratio (SS), which is the ratio of self-consumed energy from production (E_{lgc}) to the overall consumption of the site (E_{load})[4].

$$SS = E_{lgc}/ E_{load}$$

The higher the SS ratio, the less energy is needed from the grid.

This exchange model therefore integrates the notion of self-consumption, which consists of the possibility of consuming locally self-produced energy. The same concept of self-sufficiency can also be brought at a community level, which allows for several actors to be brought together within the same energy community.

2.3.3 Pay-back time

In the prosumers section, the payback time is calculated and given as an output when a simulation is launched for a specific prosumer.

Th payback period refers to the amount of time it takes to recover the cost of an investment. It is the equivalent time that the PV investment requires to reach a break-even point. A shorter payback is what is usually seeked, representing a more attractive investment.

This metric is used as a way to calculate the financial return of the analyzed system. It can be calculated as the cost of the investment over the whole lifetime of the system divided by the annual cash flow[5].

In our context, for a prosumer, the payback time can be modelled and obtained by analyzing the cost of an investment for a specific system without considering a PV system installed in comparison with the analyzed system considering the consumption of the same scenario but with a PV installed system.

The payback time is the intersection of the two models representing the cost of the same system considering one with a defined PV installation and another without (as in example of simulation in Figure 7).

Such an analysis is interesting, but the main problem with payback calculation period is that it ignores the time value of money in this scope.

Therefore, the Net Present Value of the investment is also considered and presented in the following section.

2.3.4 Net Present Value

The Net Present Value (NPV) is considered in order to assess better the investment profitability considering a discount rate (opportunity cost) and also the Time Value of Money. The Time value of money allocates a value to this opportunity cost.

The Net Present Value (NPV) is the difference between the present value of cash coming in and the current value of cash going out over a period of time. It is used by looking at all the money expected to be made from the investment and translating it to today actual money. The calculation of this parameter is given by the sum of present value cash flows positive or negative for each year associated with the investment, discounted so that it is expressed in today's money[5] .
For a specific prosumer simulation, the NPV is calculated for a different range of peak power values. When the price of the energy surplus is too low, the NPV reaches a peak and then decreases so there is an optimum sizing of the PV system as a function of the energy consumption.

3 WEB INTERFACE

A free web application is available to the public in order to illustrate most of the concepts explained above. The web application allows the execution of a simulation considering a prosumer scenario and also in the context of an energy community. The website is interactive and the outputs are also dynamic and can allow the users to save their simulation scenarios and plots. Users can move from one simulation profile to another and provide their scenarios inputs.

3.1 Prosumers Simulation interface

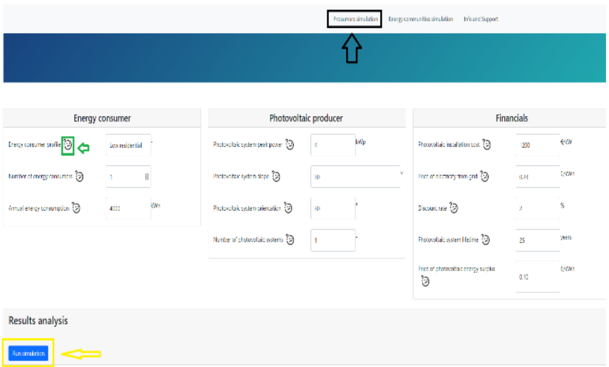

Figure 1: Web-based simple interface for prosumers self-consumption simulation.

The interface has for the different inputs provided a modal button next to the variables to be completed in the form by the users. This modal button provides information as a help element to the user when navigating the tool.
A prosumer is considered as a consumer and also a photovoltaic producer in this context. The two sections forms (energy consumer and photovoltaic producer in the "Prosumers simulation") can be therefore completed to define a prosumer type of system. There are automatic ranges of energy consumption values that are proposed as annual consumption in order to help the user get an order of magnitude of production value for such type of systems and be guided. It is actually encouraged to the user to modify the default values and test out different scenarios in order to launch a simulation. The modal buttons allow to bring some clarity when a concept is not clear and to clarify the different convention used.
Once all the inputs are included, a prosumer simulation is launched.

Figure 2 gives an example of the outputs obtained for the following input as a prosumer.

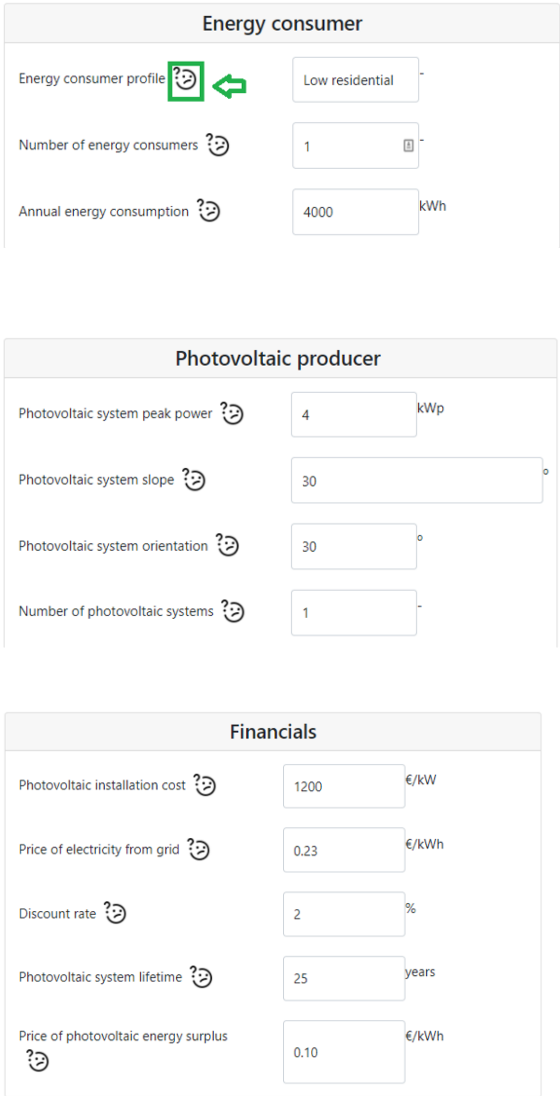

Figure 2: Prosumer analysis input example for a residential property in Brussels with a low type of consumption profile (green squared element highlighted in the first segment of the prosumers interface is an example of modal button helping the users to understand better the variables).

The outputs of the analysis provide a summary of the inputs given and other plots illustrating the analysis executed with the summary of different metrics explained in the next section where we give an example of outputs derived from the launch of simulation presented in Figure 2.
Below is an interpretation of the outputs from the simulation ran in Figure 2.
The different plots are interactive and the user can select the lines and elements they want to focus on or anlayze, hover over the curves and download the different plots.
In a first phase, the consumption profile of the system, the quantity of PV produced, the total electricity consummed , the quantity of power coming from the grid are illustrated and from these elements the PV power surplus is derived.

The illustration is provided on the highest production day and as well as on the day with the lowest PV production. For each of those two days, Consolectiv provides the profile of self consumption ratio and self sufficiency ratio.

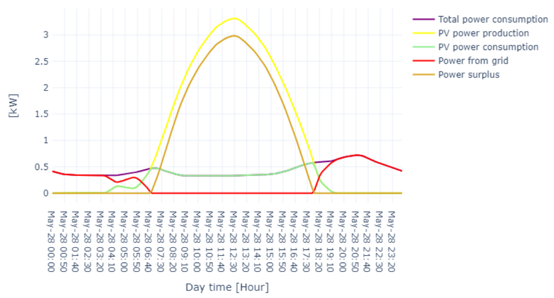

Figure 3: Electricity flow of the day with the highest PV production during the year

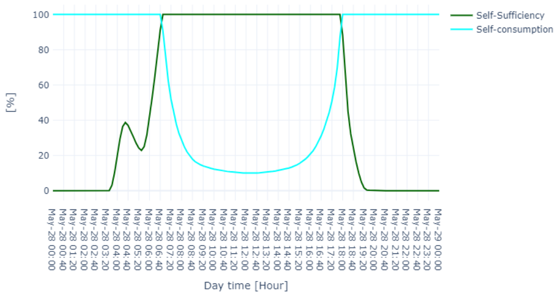

Figure 4: Time series view on self-consumption and self-sufficiency on the day with the highest PV production.

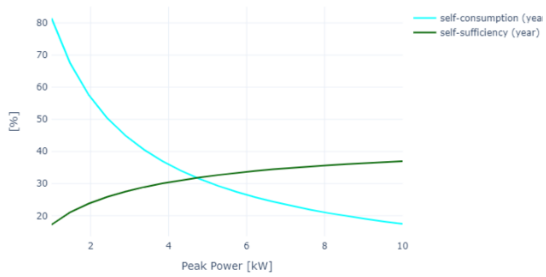

Figure 5: Yearly-integrated self-sufficiency and self-consumption vs peak power of PV installation.

Figure 5 highlights how the self-consumption and self-sufficiency ratio would evolve as a function of the PV system size. Increasing peak power with a defined consumption profile of prosumers decreases self-consumption ratio and since the peak power increases, the generated PV power of the system also tends to increase. With more increase of the peak power, the self-sufficiency ratio also does. A perfect annual balance between onsite generation and demand is the case where the self-consumption is equal to the self-sufficiency, as is shown in the intersection point in Figure 5.

Figure 6: Monthly-integrated self-consumption and self-sufficiency for a residential PV installation in Belgium.

Figure 6 shows the monthly evolution of self-consumption and self-sufficiency ratio. A higher production in summer in Brussels for such a system translates into a self-sufficiency rate that tends to be higher during summer period and lower during winter periods. We can see the self consumption having an opposite tendency in winter when all the PV power produced for this scenario is almost consumed.

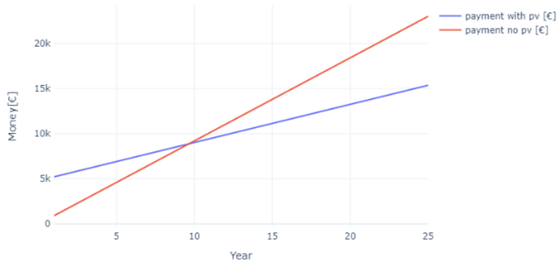

Figure 7: Illustration analysis of payback time during PV system lifetime

In the case of the prosumer simulation defined in Figure 2, and as explained in 2.3.3 , the payback time is estimated to be 10 years represented by the financial modelling for the same system with a PV system installed and another financial modelling without as seen in Figure 7.

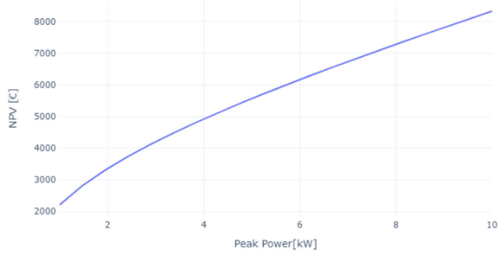

Figure 8: Evolution of Net Present Value vs peak power of PV installation.

Figure 8 shows the evolution for different ranges of

peak power values (even if the specific PV nominal power is given during the simulation) for such type of prosumer compared to the Net Present Value. The optimum peak power for such type of prosumer is considered where the NPV value is at its maximum value.
On a yearly basis, the output dashboard also provides a summary of the yearly self-consumption and self-sufficiency ratios and all the different financial metrics at the prosumer level.

Table 1: Final summary of simulation scenario presented in Figure 2.

self-consumption (year)	35.88%
self-sufficiency (year)	30.44%
Payback time	10 years
Net present value	4,915 €
Optimum peak power	10.0 kW

3.2 Energy communities simulation interface

The other interface allowing to execute a simulation mixing a community of consumers with a community of photovoltaic energy producers also provides some information on the total consumption profile and PV power produced for the community. For this section, only the self-consumption ratio and self-sufficiency ratio are provided.

Figure 9: Example of a community of consumers entered as input in ‘energy communities’ simulation section of Consolectiv.

Users may add different profiles of energy consumers. In the example illustrated in Figure 9, a unit complex of two low residential consumer profiles combined with another 3 units of base residential consumers and a rental office connected to the consumer unit are created as a community of consumers.

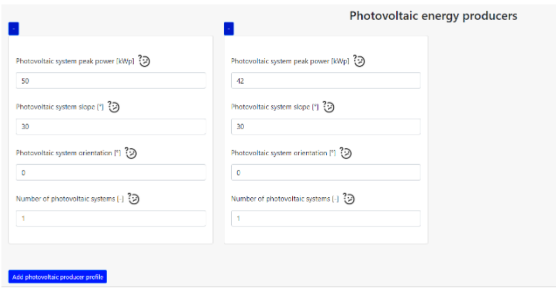

Figure 10: Selected inputs given as example for PV producers forming a community with consumers defined in Figure 9.

Below the consumers section on the interface, prior to launching a simulation, the user is invited to allocate to the community of consumers modelled in the first segment of the simulation a community of producers. An assessment of the overall scenario as a community is then exectued to provide the overall self consumption profile and self-sufficiency profile of the community.

As for the simulation for prosumers, an assesment of the highest production day profile of the overall community unit is carried out and the total consumption and PV power produced by the producers entity as well as an aggregation of the PV power coming from the grid is also provided. The same illustrations but here aggregated to the community level are given as in the prosumers section.

The self-consumption ratio and self-sufficiency ratio are derived on a 10-min basis for the whole year and also is illustrated on the user dashboard the profile for the highest production day of the year as well as the monthly aggregated form of self-consumption ratio and self-sufficiency ratio.

4 DISCUSSION

The first version of the tool has been released on the 7th of September 2021.

In future releases, some improvements to the user interface will be considered (in order to improve user experience on the application) as well as more documentation in order to help user navigate through it and also more automated suggestions will be added to it mainly for the energy community section.

A public changelog will therefore be considered in order to update the public on the changes that will be continuously done.

The next future releases will allow the possibility to consider in both types of simulation (prosumers and energy community) the possibility to integrate energy storage systems.
Also, through potential future collaborations, there may be the possibility to work with more accurate consumption profiles from Brussels if data is available, and as well replicate this tool for other regions of Belgium or in the world.

5 CONCLUSION

Consolectiv, as a tool, provides simple simulations aimed at the general public. There is an increased interest among end-users (real estate promoters, cities, regulators, etc.) and the scientific community.
Despite this interest, more research is still needed and further studies need to be done to compare the potential of the mix of different technologies. This available assessment tool may help fulfill that need to bring the concept to a broader audience.

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