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WEB TOOL FOR STIMULATING INVESTMENTS IN ROOFTOP PHOTOVOLTAIC SYSTEMS

BY

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Abstract. One of the most sustainable, inexhaustible and "clean" sources of electricity is photovoltaic solar energy that can be used for instant consumption while the surplus might be delivered in the power grid or stored in (local) batteries. In the study here presented, we analyze a usual, medium-sized household. The input data of the here developed application are the geolocation, the roof surface facing south, the geometric dimensions of the available individual solar panel, its installed power capacity and the (previous) electricity consumption for an entire calendar year. As output data the application will provide the total number of solar panels that can be placed and the total amount of energy produced in a year, for different values of conversion efficiency (solar energy-electricity, respectively DC power-AC power). Depending on these assessments, the user can decide whether is efficient to become a prosumer or opt for local storage of additional energy produced during solar peak irradiance hours.

Keywords: photovoltaic panels; solar irradiation; rooftop.

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1. Introduction

Over the last decade, due to significant technological advances, the price of photovoltaic systems has dropped considerably, so supporting larger affordability, simultaneously with the increasing of solar conversion efficiency. We can find applications of photovoltaic cells almost everywhere. They range from small garden lamps, to space flights, from simple street lighting to the most sophisticated surveillance and security systems. The professional marketing of this renewable and endless energy resource is mainly supported by the financial policy of most governments regarding investments in photovoltaic green energy, as well as by a multitude of private initiatives, making this challenge more and more affordable and attractive (Pehl *et al.* 2017).

A possible today investment in such "house-systems" recovers in about 5-6 years. The electricity bill decreases asymptotically to zero and the value of the residential building equipped with solar panels increases. It should be taken into consideration that most manufacturers offer a 10-year warranty, stating that the installed power of these panels decreases only by a maximum of 20% in 25 years of operation (*** Statista a, 2021).

The quantity of solar energy received by 1 sqm is defined by the term (solar) irradiation, being measured in kWh/m^2. A quasi-similar term used is insolation (acronym for "incident solar radiation"). It is the cumulated energy measured over a specified area (usually, 1 m^2) and for a distinct period of time (a day or even an entire calendar year), being calculated by integration. Not to be confused with solar irradiance, an instantaneous power, derivative concept, meaning the quantity of solar radiation instantly received per unit area, expressed in kW/m^2. A greater exposure of the solar panel to the sun means a higher amount of energy that might be converted to electricity. Location coordinates are essential in any such approach, both from the perspective of solar irradiation, but also from the perspective of infrastructure and economic environment (*** Statista b, 2021).

If we take into account, for instance, an area of 25 m^2 unshaded southern oriented roof, it will totally receive 35,000 kWh per year, (we have here considered the southern region of Romania, with an annual total (horizontal) irradiation of 1,400 kWh/m^2), (*** ANRE 2020). Moreover, we have to consider the tilt of these panels. If an adjustable system is available, the optimum inclination of the south-facing panels is 25° in summer and 53° in winter. In the case of a fixed system, a compromise of 34° is accepted. We have also to notice that modern photovoltaic panels currently have an efficiency of converting solar energy in electric DC energy between 13 and 21%.

To conclude our pinpointing estimations: with current technologies, a mini-photovoltaic system, with panels mounted on a (roof)surface of 25 m^2, can reach an installed power (capacity) of 5500 Wp (for instance, 11 panels with individual 500 Wp installed capacity). Considering a correct panel-orientation, (unshaded, to the south) and current technologies based on mono-Si (half)cell technology, a very good value for the conversion yield (from solar to electric DC energy) that could be reached is 20-21%. The specific yield of a photovoltaic system means the amount of kWh that is supplied over an entire year corresponding to a single kWp of the installed power (capacity) of the photovoltaic panels. For Iasi County, using very good equipment, this specific yield is around 900 kWh/kWp. So, the amount of energy that might be supplied annually in our county by a very good, up-to-date photovoltaic system with an installed power of 5.5 kWp is approximately 4950 kWh.

In the same vein, in May 2020, the IEA (International Energy Agency) issued an update report on renewable energy, publishing the analyze about the impact of Covid-19 on the developments of green energy in the last two years. The conclusion was that Covid-19 crisis is proving to be a threat, a serious difficulty, but it does not stop the global growth of renewable energy production, (*** International Energy Agency, 2020).

2. Case Study

We have developed an open application that can be used by accessing https://www.acoperisultausolar.com/. We have thought of this application as intended for a very wide audience, not necessarily made up of specialists in electric power, who want to estimate the efficiency of their own investment in roof mounted solar panels. At the same time, this application is intended to be a forum for education and debates aiming to promote and stimulate small private investments in the field of renewable energies. In the case study here presented we analyze a single-family household that had 2400 kWh as previous year consumption of electric energy, meaning an average of 200 kWh per month. Considering the per total tariff presently charged by the distribution company that has the most domestic clients in Iasi County, this would mean a value for the monthly bill of 140 lei. One of the most important input parameters for the web application is the reachable roof surface. The obtained value is 57 m^2. To fit the strongly recommended condition for southern orientation, only 25m^2 from the rooftop could be used. We have chosen a supplier that offers affordable, lightweight (essential for roof mounting) solar panels, each covering an area of 2.17 x 1.09 = 2.365 m^2, the associated installed power of a single panel being 500 Wp. These values are provided by the producer's data sheet. Thus, we will be able to place 11 such panels on the roof, (slightly exceeding the actual surface of the roof at the extremities) having the total installed power of 5.5 kWp. We have to calculate if the whole photo-voltaic system (panels, electronic converting circuitry and accumulators) is able to cover the annual consumption for the entire house and may be, to inject the surplus of energy in the power-grid, especially during longer and sunny summer days.

The application uses as input data the local coordinates and directly calculate the average daily and annual total solar irradiation associated to the location. In continuation, it calculates, starting from the solar panels (number and individual installed power), the local annual solar irradiation and the selected yield of the associated inverter circuitry, the electric energy that could be produced along the whole year. Our application also calculates the beneficial impact that the use of photovoltaic energy (instead of the equivalent produced by burning hydrocarbons) has on the environment.

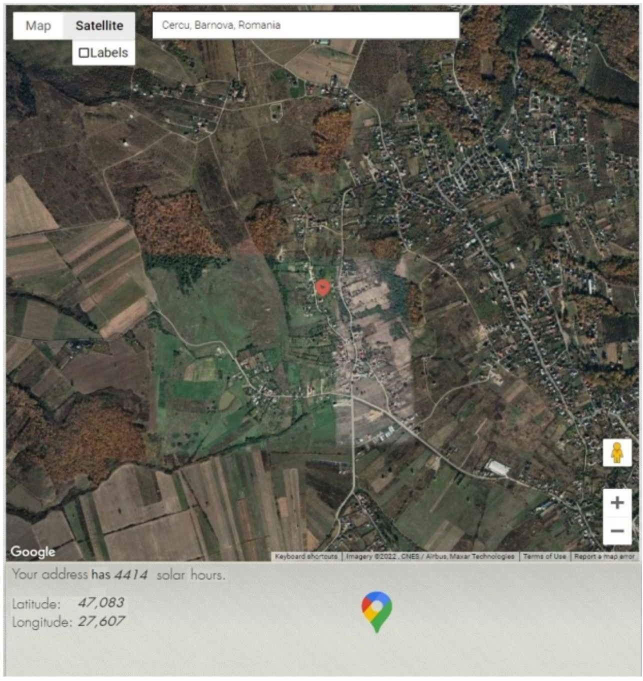

Fig. 1 – Our geolocation, input data for calculating annual total solar irradiation.

We will start from the geolocation of the building with the help of the Google Maps tool, Fig. 1. By simply entering the address, we obtain the latitude and longitude, which will serve as input parameters. The application will calculate the actual number of equivalent solar hours (having the reference solar irradiance 1000 W/m^2) and will display the average daily horizontal solar irradiation. In developing the web computing algorithm, we used "The Equation of Time", (Hughes, 1989). This algorithm calculates the equation of time for any calendar date and universal time at 3 seconds over 30 centuries starting from August 21st, 1989, when the article has been published. We have improved the calculation by going through each day starting with the first day of last year and returning the amount obtained as a rounded number to the nearest whole number.

Data validation of solar hours was done by using Global Monitoring

Laboratory file. The spreadsheets provided by NOAA (National Oceanic and Atmospheric Administration) can be used to calculate solar data for a day or year at a specified location. The file is available in Microsoft Excel and Open Office format being valid only for data between 1901 and 2099, due to an approximation used in the calculation of Julian Day. The web computer does not use this approximation and can report values between -2000 and +3000. The NOAA East / West and Solar Position Calculator deliverables are based on the equations of astronomical algorithms developed by Jean Meeus, (*** Global Monitoring Laboratory, 2021).

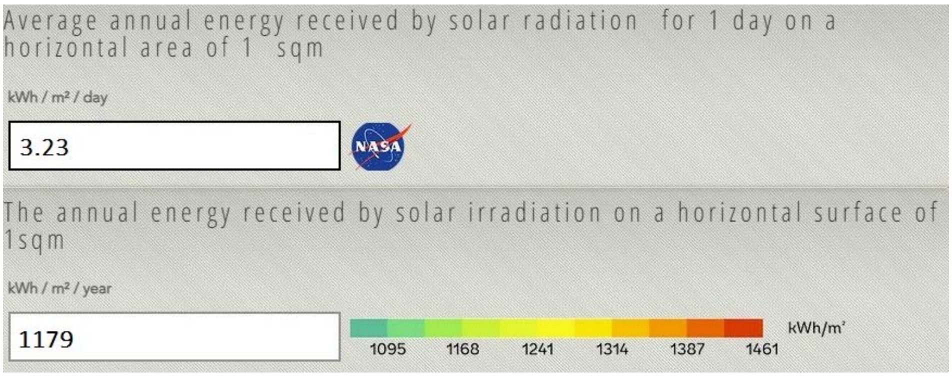

Fig. 2 – Daily average and annual (total) solar irradiation for our specified location.

The daily average (reported for an entire calendar year) of solar irradiation on a horizontal surface and the total annual solar energy received for our latitude and longitude, acquired by directly accessing NOAA spreadsheets are displayed in Fig. 2. This data has been indexed in our own database using an excel spreadsheet provided by "POWER Data Access Viewer" application developed by NASA.

The study conducted by NASA covers a period of 22 years (July 1983 - June 2005) and the monthly average values were calculated as arithmetic mean, (*** NASA Prediction of Worldwide Energy Resources, 2021).

Concluding, for our location, the average daily solar irradiation (on a horizontal surface, provided by the previous mentioned application) is 3.23 (kWh/m^2)/day. By multiplying with 365 days, the web tool calculates 1,179 kWh/m^2, representing the annual average irradiation (shadings not considered).

The next step supported by our web-tool is to calculate the effective number of panels that might be placed on the southern part of the roof and the associated installed power.

To generate the number of solar panels, the application will perform the following calculation: the roof area (here, 25 m^2) is divided by the area of a single panel (here, 2.17 x 1.09 = 2.365 m^2), (*** Photovoltaic-software, 2020).

The value obtained by division could be rounded up, as it is technically sustainable that the total area of the panels might slightly exceed the surface of the roof. Next, the deduction of the total deliverable (installed) power is performed by multiplying the power provided by a single panel with their total number, (*** Energy Education, 2021).

Fig. 3 illustrates the specific inputs of our case.

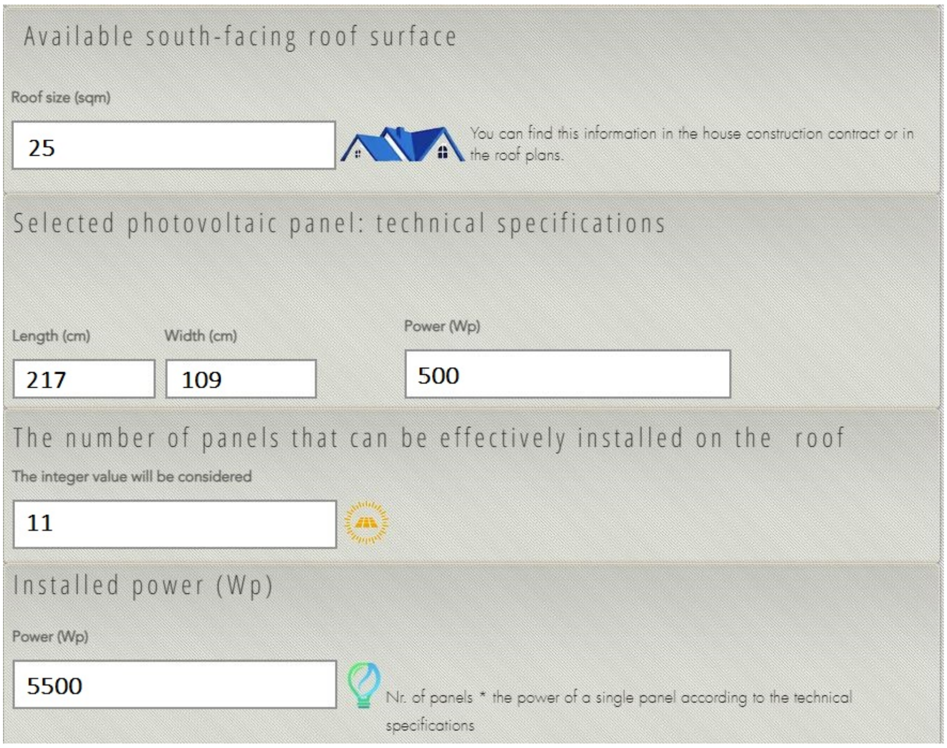

Fig. 3 – Available roof area and solar panel specifications.

Concluding, the electrical energy produced in a year by a photovoltaic system can be calculated by multiplying total solar panels area (A), solar panel yield (r), annual average solar radiation (H) and performance ratio (PR), (coefficient for electrical losses mainly produced in the inverter and wires), (*** Wikipedia, 2021).

$$E = A * r * H * PR \tag{1}$$

Our photovoltaic system having 2.17 x 1.09 x 11 = 26.02 m^2 entire solar panel area can yearly produce a total output energy of 4831 kWh, as we can see in Fig. 4, considering 21% efficiency of solar panel and 0.75 second yield, from the solar panel output to the effective consumer.

There is a good correspondence between the total surface of the panels (26.02 m^2), the efficiency of the conversion of solar energy to DC electric energy (21%, an up-to-date, very good yield) and the total value of the installed power of the 11 panels (11 x 0.5 = 5.5 kWp).

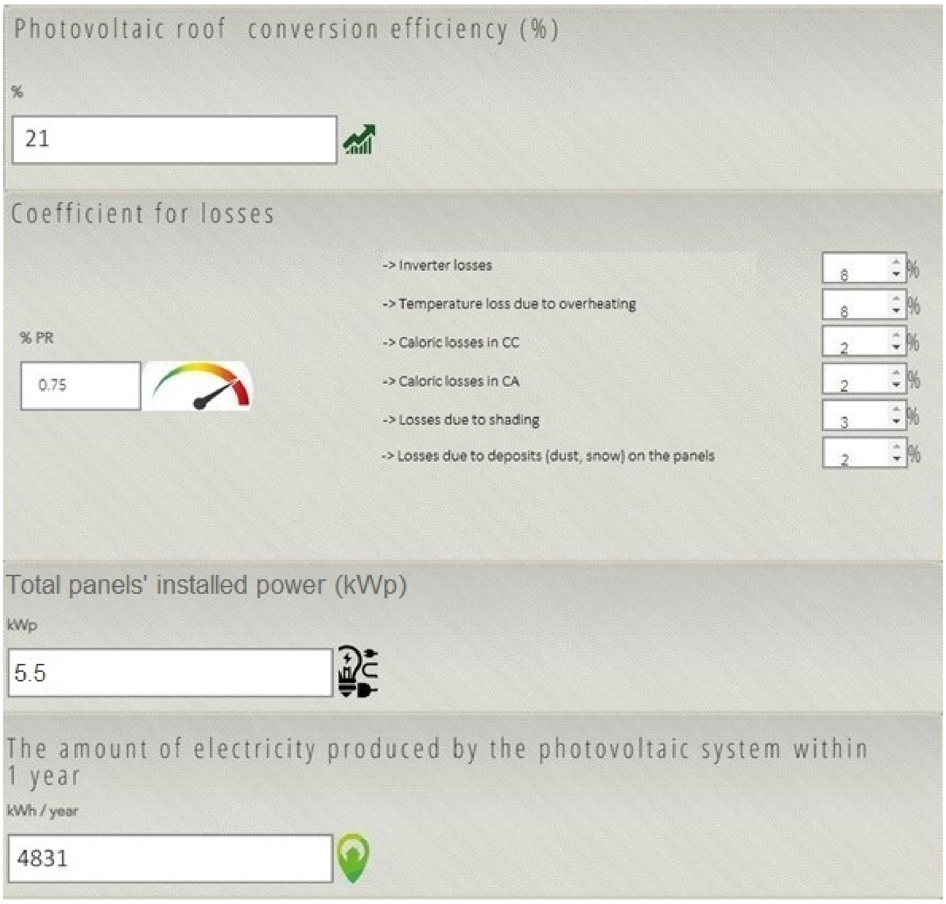

Fig. 4 – Performance ratio and annual energy potential of our simulated PV System.

The second step is to determine the energy consumption of the residential house over an entire year, expressed in kWh. This information must be calculated by any user. Basically, the value of electricity bills is added for 12 consecutive months. It is essential because there are significant differences between winter and summer consumption, depending mainly on the energy certificate of the building, heating and/or cooling sources used. This consumption also depends on the habits of the residents and the required degree of comfort.

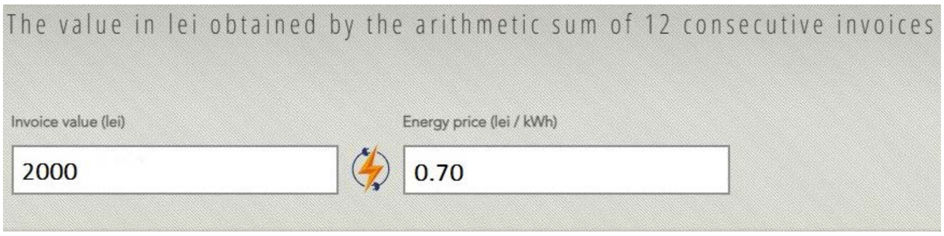

Fig. 5 – Actual household energy consumption and price.

Our tool supplies, by dividing this total annual amount, expressed in RON at the total price per kWh provided by the distribution company with which the user has contract, Fig. 5, the annual energy consumption expressed in kWh. For our simulation, this is 2857 kWh. The user can modify the input representing the composite price per kWh, depending on the oscillating prices set by the electricity market. In the here presented example we have used 0.70 lei per kWh, an average actual price established after the liberalization of the energy market in 2021 and expected price increases, (*** Global solar atlas, 2021). This includes the energy intrinsic price, the value of the fixed component, regulated tariffs for services (transport, system service and distribution service), contribution for cogeneration and green certificates, excise for commercial and non-commercial purposes and VAT.

This returned value is compared with the energy that could be effectively produced by the PV roof-plant. In this manner it is determined whether the "solar roof" of the building can provide the energy needs of the household. Even if the result does not totally satisfy your needs, because it does not reach the entire household consumption, a considerable saving of electricity (and money) can still be achieved. And there is another considerable advantage. While using the solar energy produced by our own system, we reduce the consumption of conventional energy, the production of which being associated with the generation of a significant quantity of CO_2. Specifically, at the level of the entire electricity production in Romania for the year 2020, an averaged quantity of 213 g of CO_2 has been released in atmosphere for every kWh of delivered electricity (*** TopSolar, 2021). This means that at the level of a whole year (considering an average power output of 7900 MW), about $69\text{x}10^9$ kWh are produced, being associated with the generation of 14.69 Mega tons of CO_2, (Cîrstea *et al.*, 2018).

As already mentioned, our application is intended to be a psychological stimulus in self-assuming a decision with a favorable impact on the environment. Considering that the photovoltaic energy produced replaces an energy that would have been generated by burning hydrocarbons (emission of about 450 g CO_2 per kWh), the application also displays the equivalent number of mature trees thus "planted".

For the concrete case here discussed, a quasi-little PV system that holds 11 roof-mounted solar panels produce 4,831 kWh per year, thus also avoiding the release into the atmosphere of 2,173,950 g of CO_2. Considering that an adult tree consumes through photosynthesis approximately 16 kg of CO_2 in a whole year, we can conclude that our photovoltaic system yearly "plants" 136 trees, Fig. 6.

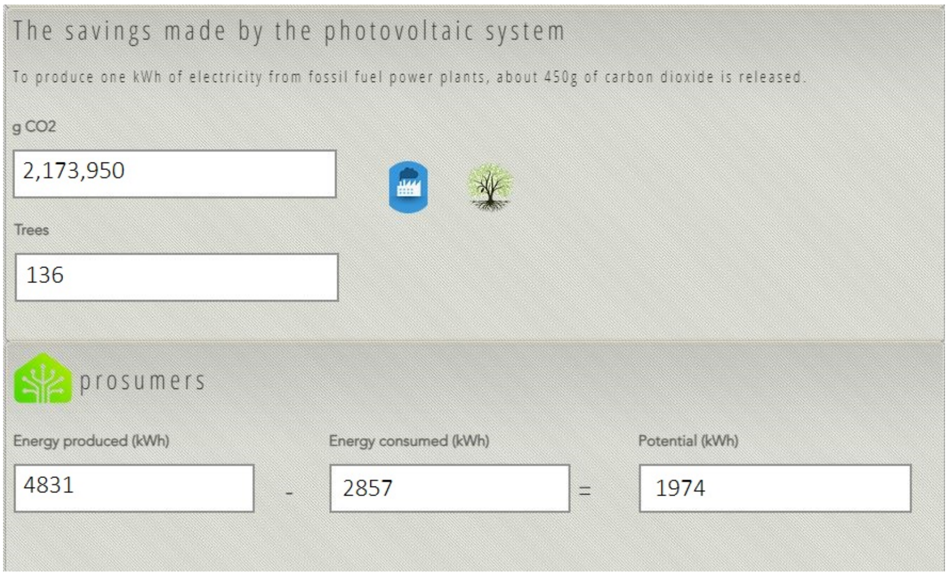

Fig. 6 – Solar system “savings”.

This is in addition to the main purpose of fully ensuring the energy needs of the household, additionally including the production of a surplus of 1974 kWh that should straighten out the possibility of becoming a prosumer.

3. Conclusions

The share of renewable sources in the total electricity production in Romania is a bit above 45%, (*** European Environment Agency, 2021). This percentage should also be increased by the contribution of photovoltaic power plants, which currently represents only 2.69% of the total.

Starting from the symbolic 41 MWp installed capacity in 2012, the value of 1400 MWp installed capacity of photovoltaic energy has now been reached in Romania, allowing an annual production of around 1900 GWh. This correspondence between installed peak power and the energy actually produced allows the calculation of a specific yield of 1350 kWh/kWp, representing a very good value for the locations around parallel 45, an objective argument for the very good quality of the equipment used.

The here promoted opportunity of “solar roofs” is an available but underexploited resource. More precisely, there are 7,470,000 houses in Romania, of which 3,360,000 might be suitable for the installation of roof photovoltaic systems, (Statista b, 2021).

All studies show that rooftop photovoltaic systems are a cheap, clean and perfectly accessible source of energy for (small) private investors who take on the challenge of becoming prosumers. Investing in photovoltaic systems is a "must do", especially in the context of expected increases of energy price, (*** ArcGIS Online, 2021).

In addition, aiming to stimulate government and local policies, accurate and accessible information is needed, including the non-specialists, with simple and user-friendly methods to calculate the investment and benefits of such an approach. This is exactly what our web tool assumes: information and support for those who want to invest in the energy "integrated in their residential roof".

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APLICAȚIE WEB PENTRU STIMULAREA INVESTIȚIILOR ÎN SISTEME FOTOVOLTAICE DE ACOPERIȘ

(Rezumat)

Una dintre cele mai sustenabile, inepuizabile și “curate” surse de electricitate este energia solară fotovoltaică, care poate fi folosită pentru consum direct, imediat, în timp ce un eventual surplus ar putea fi livrat în rețea sau stocat în baterii (locale). În studiul prezentat în lucrare analizăm o locuință de dimensiuni medii. Datele de intrare ale aplicației dezvoltate sunt coordonatele geografice, suprafața acoperișului orientată către sud, dimensiunile panoului fotovoltaic disponibil, capacitatea instalată și consumul anual anterior al gospodăriei. Ca date de ieșire aplicația calculează numărul total de panouri ce pot fi efectiv montate și cantitatea de energie electrică livrată într-un an calendaristic, pentru diferite valori ale randamentului conversiei (energie solară-energie electrică, respectiv energie c.c.-energie c.a.). În funcție de aceste evaluări, utilizatorul poate decide dacă este eficient să devină prosumator sau doar optează pentru stocarea locală a energiei suplimentar produse în timpul orelor de vârf ale radiației solare.