Deliverable Proof – Reports resulting from the finalisation of a project task, work package, project stage, project as a whole - EIT-BP2018

Name of KIC project the report results from that contributed to/ resulted in the deliverable	ProSumE: Enabling Prosumers Services
Name of report	DELIVERABLE 2. FINAL REPORT.
Summary/brief description of report	Report describing the analysis of the technical potential for prosumer production and first economic and environmental analysis.
Date of report	28 September 2018

Supporting Documents: attach in pdf format

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ProSumE: Enabling Energy Prosumers Services

DELIVERABLE 2. FINAL REPORT.

September 2018

Leading institution:

FUNDACIÓN LAS NAVES. AYUNTAMIENTO DE VALENCIA

Presented by:

Instituto Universitario de Investigación de Ingeniería Energética

Universitat Politècnica de València

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EXECUTIVE SUMMARY.

This report presents the main findings of the working package 2 (WP2): *Screening of prosumer energy production potential*, of the project *ProSumE: Enabling Energy Prosumers Services*.

Our first task was to estimate the potential of electricity production based on photovoltaic (PV) generation from sun radiation in the city of Valencia. For estimating the energy production potential at the city scale, we have conducted two parallel calculations, each one following the methods of different research teams in similar studies, as explained in the main text. Based on the results, only taking into account the rooftops, in Valencia there is enough potential of PV electricity to power between the 85.1% (838 GWh/year) and the 91.5% (901 GWh/y) of all the domestic electricity consumption nowadays (985 GWh/y, based on a mixture of data of years 2016 and 2017). If the electricity consumption of the all sectors was added: commercial, industrial, public sector, etc. then, the generation of PV electricity could cover up to 33% of the total electricity consumption of Valencia.

This electricity would be generated with the approximately 536 MW peak of PV panels that would be installed in the almost 4 million of square meters of rooftops devoted to PV power. The overall investment would be of around 876 M€, but the investment, the savings and the payback would be very different for each case study: residential buildings of more or less floors, commercial buildings, public buildings, etc.

Based on the study of Azigrene[1] for the *Plan de Acción para el Clima y laEnergía Sostenible de la Ciudad de Valencia* (PACES), in 2016 approximately 40% of all the GHG emissions of the city of Valencia were released by the set of buildings. Of the buildings emissions, around 80% were indirect GHG emissions of the electricity consumption, the other 20% direct emissions of gas consumption. If the full potential of PV power generation was used, 27% of the buildings GHG emissions could be saved, that is to say, 10,9% of the total GHG emissions of the city.

In the WP2 we have also identified the so called “hot spots” of the city with the biggest potential for energy production. Those hotspots were:

- Single family houses
- Single family houses off-grid
- Multi storey residential buildings
- Standalone commercial and industrial buildings, privately owned.
- Standalone buildings, publicly owned.

In order to highlight the business opportunity we have estimated how much power it could be installed and generated, and we have made an economic simulation. As there are many variables that condition the economic performance of each installation, on the one hand we set all the variables to the best value possible in terms of economic performance. We call it “Best case” scenario. On the other hand, we have set all the variables to the worst value possible in a “Worst case scenario”. The following table give the main values of the economic simulation.

[1] http://www.azigrene.es/

Model	Case	Cost of investment (€/kWp)	Power installed (kWp/unit)	Pay back (years)	Savings/unit[2] (€/year)
Residential. Single family	BEST	1,101	9.5	3.5	3,011
	WORST	3,374	4.7	31.2	513
Residential. Single family off grid	BEST	1,300	9.0	14.6	967
	WORST	3,059	9.0	28.5	967
Residential ≥ 2 floors	UNIQUE	1,694	12.7[3]	5.5	339
Commercial/Industrial building	BEST	968	22.7	3.1	7,204
	WORST	1,452	17.0	8.1	2,702
Public buildings	BEST	968	28.4	3.1	9,020
	WORST	1,452	14.2	9.0	2,300

As can be seen, the differences are very important for single-family houses and PV systems can be from very profitable to not profitable at all. However, for larger PV systems like those of the other hotspots, the profitability of the installation would be almost guaranteed. In particular, for standalone buildings commercial and public there are no relevant economic or technical barriers, and the obstacles to such projects seem to be only administrative and cultural. In such projects, the investment would be paid back in a few years (between 3 and 9 years) and together they represent more than 25% of all the PV generation. Multi storey buildings are a very different case as, to use the full potential for power generation they would need an agreement of all the owners of the involved households, and practice shows that can get to be really difficult. Those cases amount to more than 60% of the total PV generation.

Finally, we have assessed the environmental benefits of producing and consuming PV electricity. Assuming the electricity of Valencia to have the following environmental aspects per kWh: release to atmosphere of 285 gCO_2e, 0.62 g of SO_2e and 0.42 g of NOxe, the following table shows how the electricity savings of the previous table would be reflected in avoided air emissions.

Model	Case	Saved electricity (GWh/year)	GHG saved (kg/year)	SO_2 (kg/year)	NOx (kg/year)
Residential. Single family	BEST	103.73	29,561,913	64,310	43,565
	WORST	17.68	5,038,048	10,960	7,424
Residential. Single family off grid	BEST	14.39	4,102,512	8,925	6,046
	WORST	14.39	4,102,512	8,925	6,046
Residential ≥ 2 floors	UNIQUE	514.52	146,638,200	319,002	216,098
Commercial/Industrial building	BEST	165.68	47,218,632	102,721	69,585
	WORST	62.13	17,707,050	38,521	26,095
Public buildings	BEST	54.07	15,411,085	33,526	22,711
	WORST	13.79	3,929,827	8,549	5,791

[2] “Savings” are an average for all the units: household, shop, public office, etc. Therefore, they may vary considerably from one case to another.

[3] In this case, “unit” is building, not household like in the last column.

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As can be seen, the use of the full potential for PV electricity generation could get to save up to 243,000 tonnes of GHG, 528 tonnes of SO_2e and 358 tonnes of NOxe

1. INTRODUCTION.

In the project proposal it is said the Working Package 2 (WP2 hereinafter) consist of: *Screening of prosumer energy production potential at the city scale. Providing a first technical assessment of the potential to supply the local electric demand through solar photovoltaic energy and a zoom on identified production "hot spots" of the city with the biggest potential for energy production to highlight business opportunity (A2.1). As well a first assessment of economic and climatic benefit of the energy "prosumption" in selected cases (A2.2)*.

2. ESTIMATION OF THE OVERALL PROSUMER ENERGY PRODUCTION POTENTIAL AT THE CITY SCALE.

2.1. Potential of electricity generation from solar photovoltaic energy.

In this first section we follow the study by Marta Victoria[4] in which she estimates the overall potential electricity generation from solar photovoltaic energy (PV hereinafter). However, we follow a modified method based on other similar research found in the literature.

2.1.1. Design of the methodology.

Based on Singh and Banerjee (2015)[5] for Mumbai, and Byrne et al. (2015)[6] for Seoul, we have designed the following methodology for the first project goal (see figure 1):

1. Estimation of overall rooftop area
    1.1. All rooftop area
    1.2. Available area
    1.3. Characteristics of the roofs: Use, pitched, orientation, other uses, etc.
2. Insolation estimation
    2.1. Direct, Diffuse, others
    2.2. Temperature corrections
3. Technical parameters of generation
    3.1. Panel efficiency
    3.2. Shadows
    3.3. Panels tilt

[4] *Potencial de la energía solar fotovoltaica y termosolar integrada en edificios de viviendas en la Comunidad de Madrid*. http://observatoriocriticodelaenergia.org/

[5] Rhythm Singh, Rangan Banerjee. *Estimation of rooftop solar photovoltaic potential of a city Solar.* Energy 115 (2015) 589–602

[6] John Byrne, Job Taminiau, Lado Kurdgelashvili, Kyung Nam Kim. *A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul*. Renewable and Sustainable Energy Reviews 41 (2015) 830–844

3.4. Orientation

3.5. Other components' performance

4. Consumption curves and requirements

4.1. Demand curves

4.2. Other technical requirements

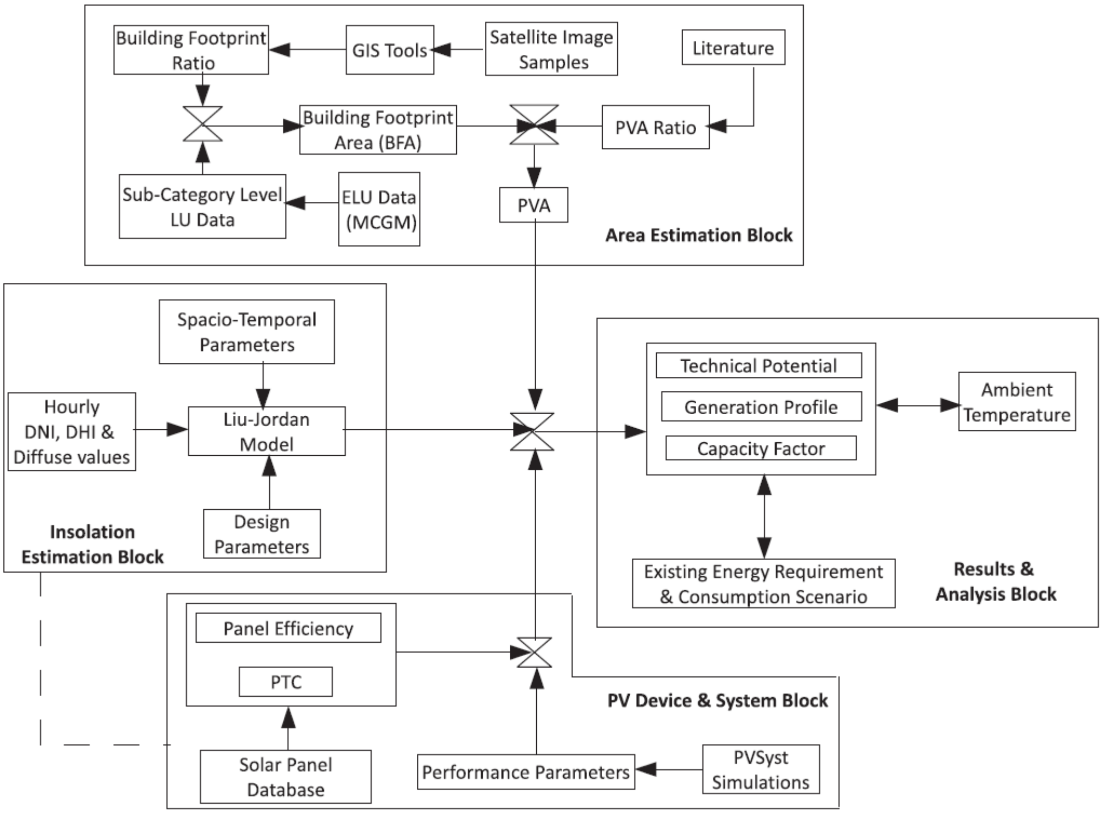


Figure 1. Methodology in blocks (based on Singh and Banerjee, 2015).

2.1.2. Estimation of overall rooftop area.

Unfortunately, neither are there complete statistics of rooftop surface, nor GIS data about the available rooftop area in Valencia. Therefore, we had to calculate it based on the information of table 1.

Table 1. Data, estimations and calculations for the total rooftop surface

Concept	Data	Source
Number of buildings	35.840	City's statistics[7]
Number of households	419.930	City's statistics
Households total surface in m^2	29.953.255	City's statistics
Number of floors per building, average	4,92	City's statistics & calculation

[7] Statistical yearbook of the town hall. Year 2017, data of 2016. https://www.valencia.es/ayuntamiento/estadistica.nsf

Concept	Data	Source
Number of households per building	11,72	Calculation
Number of households per floor	2,38	Calculation
Rooftop surface per building in m^2	228	Calculation
Rooftop residential buildings in m^2	8.157.978	Calculation
Surface municipal buildings in m^2	694.943	City's statistics & calcul.
Private schools in m^2	342.245	City's statistics & calcul.
Hotels in m^2	23.217	City's statistics & calcul.
Total rooftop Surface in m^2	**9.218.384**	**Calculation**

2.1.3. Insolation estimation and technical parameters of generation

Based on the following assumptions, data and calculations, the electricity generation from PV power plants in the rooftops could cover up to 90% of the domestic electricity demand, and up to 33% of all the electricity demand in Valencia (see table 2).

Table 2. Data, estimations and calculations for the total electricity generation.

Concept	Data	Source
Total surface (m^2)	9.218.384	Calculation
Available surface (m^2), 50% assumed for other uses of the roofs or for unusable roofs	4.148.273	Calculation
Reduction Factor Roof shape	1	Included in the 50% reduction
R.F. Roof orientation (azimuth angles) of pitched roofs[8]	1	Included in the 50% reduction
R.F. Shading	1	Included in the 50% reduction
R.F. Roof's tilt	1	Included in the 50% reduction
R.F. Gaps for access and maintenance	90%	Estimation based on experience
Panel efficiency	15%	Estimation based on experience
Losses for transport, temperature, maintenance, etc.	80%	Based on literature

[8] Best option, facing South

Concept	Data	Source
Irradiation on the horizontal plane (Wh/m²·day)	4.960	PVGIS at 0º. Average for Valencia[9]
Generation at 0º with all available surface (GWh/y)	**901,20**	**Calculation**
Domestic Electricity demand (GWh/y)	985,01	Statistics. Datum for 2016
% of the Domestic Electricity demand covered by PV	**91,5%**	**Calculation**
Total private Electricity demand (GWh/y)	2.506,39	Statistics. Datum for 2016
% of the private electricity demand covered by PV	36,0%	Calculation
Total Electricity demand of Valencia (GWh/y)	2.617,8	Statistics. Datum for 2016
% of the total electricity demand of Valencia covered by PV	**34,43%**	**Calculation**

In conclusion, there is a high potential for electricity generation form photovoltaic systems installed in the rooftops of the buildings at the city of Valencia. Nevertheless, those are gross estimations that need to be confirmed with a more detailed calculation based on case studies. This more detailed calculation is carried out in a later section of this report.

2.2. Characterization of the Buildings.

Based on similar studies, the local statistics and the analysis of the city map, we can identify the types of buildings of the table 3:

Table 3. Classification of buildings and facilities.

Land use type	Permissible categories	Relevant features
Residential	Individual households	Some with pitched roofs Other uses for roofs
	Multi-storey	Other uses for roofs
Municipal	Offices	Other uses for roofs
	Education	Some with pitched roofs
	Law, Order, Security	Some protected Some with pitched roofs
	Health	Some with pitched roofs Other uses for roofs
	Cemeteries	Low covered surface
	Social centres	Some with pitched roofs
	Sport Halls	Main activity at dusk and night

[9] For solar radiation calculations, besides PVGIS there are other sources of information. Among them, we will analyse mainly: http://www.huellasolar.com/?lang=es

Land use type	Permissible categories	Relevant features
	Transport facilities	Some with pitched roofs Some with structural problems
	Public markets	Some protected Some with pitched roofs
	Libraries, art galleries, museums…	Some protected Some with pitched roofs
Commercial	Hotels	Other uses for roofs
	Malls	Other uses for roofs
	Disco, restaurants, theatres, cinema, etc.	Roofs shared with households
	Shops	Roofs shared with households
Industry	Industry	Some with pitched roofs Some with structural problems

All the above listed cases are buildings with an eligible rooftop, although not always the roof will be suitable for PV electricity generation. In the following section we analyse the buildings identifying which types could be hotspots for PV generation.

3. IDENTIFICATION AND ANALYSIS OF HOTSPOTS.

3.1. Identification of Hotspots.

We group the more than 15 possible case studies we have identified 5 into types of opportunities for PV electricity generation. Those types or models are:

1. Standalone building of 1 household (single family house)
2. Standalone building of 1 household that wants to go off grid
3. Buildings of several households in different floors (multi storey building)
4. Commercial standalone buildings
5. Public standalone buildings

3.2. Assessment of the economic, environmental and technical features of the models.

For the assessment of the models, the software HOMER® has been used. HOMER has been developed by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL)[10]. HOMER examines all possible combinations of energy system types in a single run, and then sorts the systems according to the optimization variable of choice: Net present cost, levelized cost of energy, fraction of renewable energy resources, avoided emissions, etc.

[10] https://www.homerenergy.com/index.html

In order to build the models in Homer, several assumptions, estimations and calculations were needed. The main ones are listed below:

- In the first place only Photovoltaic solar (PV) panels have been considered, not thermal solar panels or any other combination of renewable sources of energy. Thus, all the available surface on the roofs has been devoted to PV panels and, when needed, the batteries and other equipment.
- The goal for the simulations has been to maximize the economic profit and, in second place, to maximize the energetic and environmental benefits. Studies have had a lifespan of 25 years to consider equipment replacement and other situations of the life cycle of the installations.
- The price of electricity has been considered as[11]: 20.85 c€/kWh including both the fixed and the variable part.
- For equipment costs the maximum costs of the IVACE[12] have been taken as prices. Those prices are an overestimation of the real prices and, hence, results obtained will remain on the conservative side. The interest rate for the present costs has been set at 1%. Finally, panels are estimated to last 25 years, converters 25 years, batteries 20 years, and all the rest of the installation: wires, meters, actuators, etc. need not be replaced in the lifetime of the installation.
- The peak power that can be installed will be based on the ratio 7 m^2/kWp used in their simulations[13] by the Asociación de Agencias Españolas de Gestión de la Energía (EnerAgen). All panels have been installed horizontally, tilt angle = 0º.
- Solar Radiation will be that provided by the database of PVGIS[14]. However, for selecting the buildings with more solar radiation we have used the maps for Valencia of Huellasolar (http://www.huellasolar.com/?lang=es).
- As there are no statistics about the "representative" demand curve for electricity, in most of the cases the one provided by the Spanish Electric Grid[15] (REE) has been selected. In particular, the one for contracts under the tariff 2.0A – 2.1A (installed power < 15kW) for households.

[11] www.autoconsumoaldetalle.es

[12] Reference costs according to the Resolución del 3 de mayo de 2018. DOGV 8299 del 21/05/2018

[13] www.autoconsumoaldetalle.es

[14] http://re.jrc.ec.europa.eu/pvgis/

[15] BOE 2017.12.28. Resolución de 26 de diciembre de 2017, de la Dirección General de Política Energética y Minas, por la que se aprueba para el año 2018, el perfil de consumo y el método de cálculo a efectos de liquidación de energía, aplicables para aquellos consumidores tipo 4 y tipo 5 que no dispongan de registro horario de consumo, según el Real Decreto 1110/2007, de 24 de agosto, por el que se aprueba el reglamento unificado de puntos de medida del sistema eléctrico.

For larger buildings, the tariff 3.0 (installed power < 450kW) and a demand curve like the one of Open Energy Information[16].

Furthermore, some other considerations apply as explained in the specific sections later.

- For the avoided emissions, as every household may have a different supply company, an average conversion factor (CF) has been selected. The CF is the one given by REE for year 2017[17]: 285 gCO_2e/kWh.
- The models for a Net Billing have considered one month of inputs and outputs of electricity before paying or being paid. As purchasing and sale prices are different, the first being higher than the second, the longer the period for the balance the better for the Prosumer. However, as the Net Billing is a demand rather than a reality, if it ever gets admitted, it seems distribution companies will demand to adjust to the billing period, and this is normally one or two months. Therefore, one month remains on the conservative side.
- For electricity sale prices and other costs of being connected to the grid, those suggested in the simulations by the EnerAgen have been selected. Particularly, electricity sale price: 5.00 c€/kWh. Costs of connexion to the grid: 0 c€/kWh
- The case studies selected do not have shadows or barriers to solar radiation other than random cloudy days. Those cloudy days were simulated by Homer based on PVGIS statistic data.

Finally, we identify the hotspots within those models as those examples particularly suitable for the PV generation. That is to say, following we simulate a hotspot for every model: standalone single family house, standalone commercial building, etc. Later we will calculate how many buildings similar to the hotspot there are and what their PV generation could be.

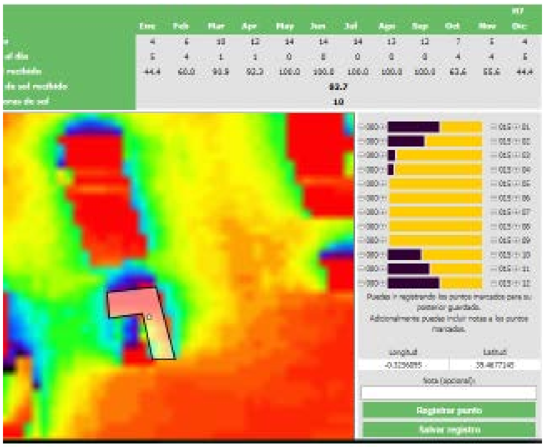
3.3. Simulations of an independent residential building with one household.

As an example, in this case the household of the following picture is modelled as a hotspot.

[16] https://openei.org/wiki/Main_Page.

[17] https://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/series-estadisticas/series-estadisticas-nacionales

Example of the case study



Insolation based on ®Huellasolar

Plan view of the building, from ®Google Maps

Figure 2. Case study 1. Independent household.

3.3.1. Model 1.1. Only self consumption without storage or sale to the grid.

For this case, the demand curve of REE was considered, as explained before, in particular the one for contracts under the tariff 2.0A – 2.1A (installed power < 15kW) for households. The total power per year is 4,500 kWh/year (see figure 3).

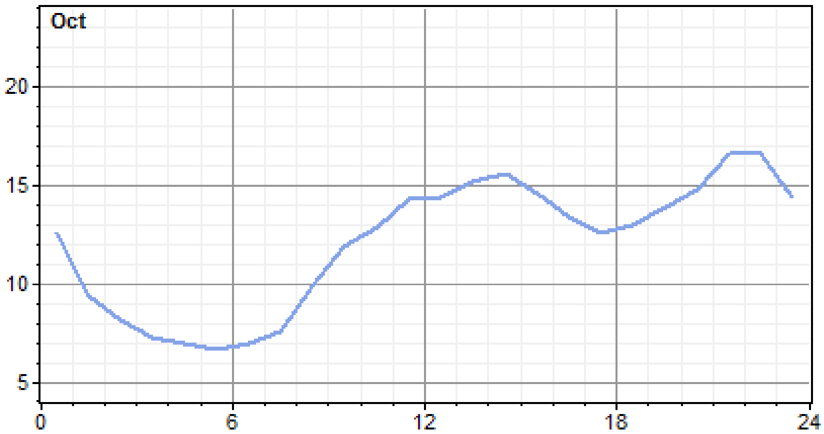


Figure 3. REE's demand curve for contracts under the tariff 2.0A – 2.1A (installed power < 15kW). Example for an average day of October.

For the representative building selected, based on the available rooftop surface, the maximum power that could be installed was 4.5 kWp. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 1.5 kWp installed (Technical characteristics by default in Homer, for this and all the following similar choices)
- Converter: 2.5 kW (Technical characteristics by default in Homer, for this and all the following similar choices)
- Total investment: 5,061€
- Total electricity consumption: 4,636 kWh/year (note that the figure is slightly greater than the 4,500 kWh/year introduced before. This is due to the random small variations HOMER introduce to the given demand curve in order to simulate the normal variations of a real situation)
- Electricity from the grid: 2,881 kWh/year
- Electricity from the PV installation: 2,461 kWh/year
- Electricity surplus (not sold, not deducted from purchases in a Net Billing): 460 kWh/year
- Renewables Fraction: 47.78%
- Levelized Cost Of Energy (LCOE): 22.14 c€/kWh
- Net Present Cost in 25 years (total costs of investment, replacement, operation and maintenance, electricity purchases, etc.): 22,582 €
- Payback: 29.60 years
- Greenhouse Gas Emissions avoided: 532 kg/year, 11.704 kg in 25 years (in this first simulation we focus only on Global Warming but in a later section we do a more complete environmental assessment)

Based on the results, it can be concluded that the PV installation without electricity sale or storage is not profitable for an independent single family house. This is due mainly to the high prices of equipment in the *Resolución del 3 de mayo de 2018*. But even with prices based on the market, the levelized cost of electricity (LCOE) is higher for short periods of time (10 or 15 years for example) than the LCOE of the grid. However, the amount of renewable energy generation and emissions avoided is significant.

Furthermore, based on the multiple HOMER's tested configurations, the one which maximized profits does not take advantage of all the rooftop surface available. It sets the power to 1.5 kWp when up to 4.5 kWp was possible.

3.3.2. Model 1.2. Only self consumption with storage but without sale to the grid.

This model is like the model 1.1. adding the best combination of batteries based on HOMER's simulations. However, there is no combination with accumulation that obtains a lower LCOE or Payback. The best combination is always the one that makes batteries zero and, hence, in the end this option has been discarded.

3.3.3. Model 1.3. Self-consumption with electricity sale to the grid.

This model is like the model 1.1. but it adds the possibility to sell to the grid the occasional surplus of energy at a price of 0,05 €/kWh.

- PV installation characteristics: 2 kWp installed
- Converter: 2.5 kW
- Total investment: 5,829 €
- Total electricity consumption: 4,636 kWh/year (the same than in the previous section because we have used the same model of electricity consumption in all the simulations)
- Electricity from the grid: 2,685 kWh/year
- Electricity from the PV installation: 3,282 kWh/year
- Electricity sold to the grid: 1,003 kWh/year
- Renewables Fraction: 63.72%
- Levelized Cost Of Energy (LCOE): 21.48 c€/kWh
- Net Present Cost in 25 years: 21,934 €
- Payback: 24.70 years
- Greenhouse Gas Emissions avoided: 709 kg/year, 15,598 kg in 25 years

The same configuration was tried with storage and sale and the outcomes were clearly less profitable, therefore, batteries were discarded.

Based on these results, the PV installation is more profitable if the occasional surplus of electricity can be sold. Also the environmental benefits are higher. In fact, the power installed for the optimum profits would be 33% greater. Again, the total availability of roof was not used in the best combination and, with the high prices of equipment in the *Resolución del 3 de mayo de 2018*, the LCOE is higher than that of the electricity in the grid for short periods of time.

3.3.4. Model 1.4. Self-consumption with electricity sale to the grid in a program of Net Billing.

This model is like the model 1.3. adding the possibility to make a Net Billing every month and, then, to buy the resulting amount of overall electricity consumption, or to sell the resulting overall electricity production.

- PV installation characteristics: 4.5 kWp installed
- Converter: 5 kW
- Total investment: 10,345 €
- Total electricity consumption: 4,636 kWh/year
- Electricity from the grid: 2,351 kWh/year

- Electricity from the PV installation: 7,384 kWh/year
- Electricity sold to the grid: 4,361 kWh/year
- Renewables Fraction: 143.36%
- Levelized Cost Of Energy (LCOE): 19.56 c€/kWh
- Net Present Cost in 25 years: 19,982 €
- Payback: 19.56 years
- Greenhouse Gas Emissions avoided: 1,595 kg/year, 35,090 kg in 25 years

The same configuration was tried with storage and sale with Net Billing and the outcomes were clearly less positive, again batteries were discarded.

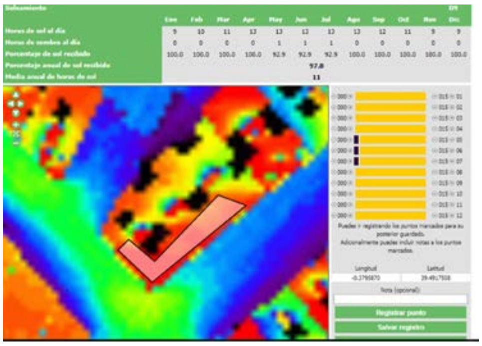
Based on these results, the PV installation is somehow profitable if the occasional surplus electricity can be sold in a Net Billing system. That is to say, the LCOE is smaller than the prize of electricity, 19.56 vs 20.85 c€/kWh). In addition, the environmental benefits are higher. In fact, the power installed for the optimum would be the maximum possible with the available rooftop surface.

Moreover, with prices more similar to the market's the LCOE would be clearly lower than the LCOE of consuming electricity from the grid.

3.4. Simulations of a residential building with several households in several floors.

In this case the building of the following chart is modelled as a hotspot.

Example of the case study



Insolation based on ®Huellasolar

Plan view of the building, from ®Google Maps

Figure 4. Case study 2. Building of several households.

3.4.1. Model 2.1. Only self-consumption without sale to the grid.

For this case the demand curve of REE is considered, as explained before, with a total power per year of 4,500 kWh/year for all the households. The building is 5 floors high, with the premises of the ground floor devoted to shops and not considered in this study. There are 3 households per floor with a total number of 12 households. For the representative building selected, based on the available rooftop surface, the maximum power that could be installed is 20 kWp. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 20 kWp installed. All households participate in the installation, equipment is unique for all the installations but there are individual meters to monitor and manage individual consumptions.
- Converter: 20 kW
- Total investment: 32,466 €
- Total electricity consumption: 55,480 kWh/year
- Electricity from the grid: 33,535 kWh/year
- Electricity from the PV installation: 32,816 kWh/year
- Electricity surplus (not sold, not deducted from purchases in a Net Billing): 7,589 kWh/year
- Renewables Fraction: 53.23%
- Levelized Cost Of Energy (LCOE): 19.26 c€/kWh
- Net Present Cost in 25 years: 235,372 €
- Payback: 13.76 years
- Greenhouse Gas Emissions avoided: 6,227 kg/year, 155,675 kg in 25 years

It can be concluded that the PV installation without electricity sale or storage is profitable for a community of households of similar characteristics. Even with the high prices of equipment in the *Resolución del 3 de mayo de 2018*, the LCOE is slightly lower than that of the electricity in the grid for periods of 15 years. Besides, the amount of renewable energy generation and emissions avoided is very important.

In fact, different from what happened with the previous case study, the model takes full advantage of the rooftop. The power is set to 20 kWp out of the possible 20 kWp. Besides, it was not considered the effect of aggregating different consumption curves, they were all considered equal. Actually, the aggregated demand will show instants of high demand peaks, covered by the electric grid, and longer periods of smoother, flatter, curves and, then, the contribution of the PV system can be larger.

If the building was one floor higher, it would have three more households and the model shows again all the available rooftop would be used for PV generation. However, that would not be enough to cover all the consumption and thus, more PV electricity is consumed substituting electricity from the grid.

In conclusion, the model with 15 households gives a LCOE and a payback better than the model with 12 households. In fact, the taller the building, the more households to aggregate, the more profitable the PV power system; up to a point where all the available surface for generation is used, and all the generated PV electricity is consumed, substituting electricity from the grid. From that point onwards, aggregating more households only makes the "per household" savings smaller, but the other overall economic features remain the same.

3.4.2. Model 2.2. Only self-consumption with accumulation, without sale to the grid.

This model is like the model 2.1. adding the best combination of batteries based on HOMER's simulations. However, there is no combination with accumulators that obtains a lower LCOE or Payback. The best combination is always the one that makes batteries zero and, hence, in the end this option has been discarded.

3.4.3. Model 2.3. Self-consumption with sale to the grid.

This model is like the model 2.1. but adding the possibility to sell the occasional surplus of energy to the grid.

- PV installation characteristics: 20 kWp installed under the same conditions as the previous case.
- Converter: 15 kW
- Total investment: 31,726 €
- Total electricity consumption: 55,480 kWh/year
- Electricity from the grid: 33,535 kWh/year
- Electricity from the PV installation: 32,816 kWh/year
- Electricity sold to the grid: 7,448 kWh/year
- Renewables Fraction: 53.23%
- Levelized Cost Of Energy (LCOE): 18,50 c€/kWh
- Net Present Cost in 25 years: 225,548 €
- Payback: 11.45 years
- Greenhouse Gas Emissions avoided: 6,261 kg/year, 156,525 kg in 25 years

It can be concluded that the PV installation with electricity sale is more profitable for a community of households of similar characteristics. Even with the high prices of equipment in the *Resolución del 3 de mayo de 2018,* the LCOE is lower than that of the electricity in the grid for short periods of time. Besides, the amount of renewable energy generation and emissions avoided is very important. In this case, the more PV that can be installed the better for the community, up to cover the full amount of electricity consumption during daylight. And, as happened with case study 1, batteries never help to decrease costs or payback.

3.4.4. Model 2.4. Self consumption with sale to the grid in a Net Billing program.

This model is like the model 2.3. adding the possibility to make a Net Billing every month and, then, to buy the resulting amount of overall electricity consumption, or to trade the resulting overall electricity production.

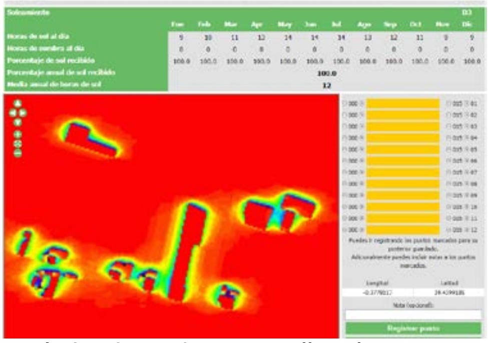
- PV installation characteristics: 20 kWp installed under the same conditions as the previous case.
- Converter: 15 kW
- Total investment: 31,726 €
- Total electricity consumption: 55,480 kWh/year
- Electricity from the grid: 33,535 kWh/year
- Electricity from the PV installation: 32,816 kWh/year
- Electricity sold to the grid: 7,448 kWh/year
- Renewables Fraction: 53.23%
- Levelized Cost Of Energy (LCOE): 17.20 c€/kWh
- Net Present Cost in 25 years: 210,425 €
- Payback: 9.17 years
- Greenhouse Gas Emissions avoided: 6,261 kg/year, 156,525 kg in 25 years

Based on these results, the PV installation is clearly more profitable if the occasional surplus electricity can be sold in a Net Billing system. Also, the environmental benefits are higher. In fact, the power installed for the optimum would be the maximum possible with the available rooftop surface. The same configuration was tried with storage and sale with Net Billing and the outcomes were clearly less positive, hence batteries must be excluded. Again, even with the high prices of equipment in the *Resolución del 3 de mayo de 2018,* the LCOE is clearly lower than that of the electricity in the grid for short periods of time.

3.5. Simulations of case 3: standalone one-household building, going off grid

This case is different from the first in the sense that the house has no access to the grid, or does not want to be connected to the grid. For this case study the household of the following chart is modelled as a hotspot.

Example of the case study



Insolation based on ®Huellasolar

Plan view of the building, from ®Google Maps

Figure 5. Case study 3. Off grid building

3.5.1. Model 3.1. Self-consumption with batteries.

For this case the demand curve of REE is considered, as explained before, with a total power per year of 4,500 kWh/year as the house is considered to be energy efficient. The building is a standalone house, what locals call an "Alquería", that decides to go off grid. For the representative building selected, based on the available rooftop surface, the maximum power that could be installed is 15 kWp. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 9 kWp installed.
- Converter: 8 kW
- Batteries HOPPECKE Power VL 2-1150, 12 V, of 1500Ah in C100: 16 units
- Total investment: 27,533 €
- Total electricity consumption: 4,636 kWh/year
- Electricity from the grid: 0 kWh/year
- Electricity from the PV installation: 14,767 kWh/year
- Electricity surplus (not sold, not deducted from purchases in a Net Billing): 10,131 kWh/year
- Renewables Fraction: 100%
- Levelized Cost Of Energy (LCOE): 38.12 c€/kWh
- Net Present Cost in 25 years: 38,905 €
- Payback: 61.05 years

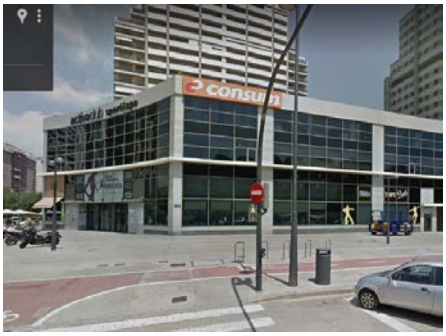
- Greenhouse Gas Emissions avoided: 1,113 kg/year, 27,825 kg in 25 years

It can be concluded that if the house wants to go off grid the PV installation with storage provides the demanded electricity without power cuts. However, the LCOE would be clearly more expensive than a combination of PV panels and a connection to the grid. Although more PV could be installed, the economic optimum was set at 9 kWp. One problem of this option is that approximately 10,100 kWh/year of renewable clean electricity is generated and wasted, almost double the amount consumed. If connected to the grid, this previously wasted electricity now would further avoid 55,200 kg CO_2 in 25 years.

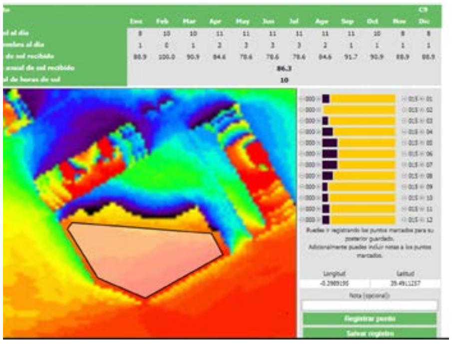
The option without batteries is not feasible due to the differences between the demand curve and the solar radiation curve. As there are no other renewable resources available such as wind, hydro, biomass, etc. a power system fuelled with diesel was tried. But, although the investment would be almost half, the LCOE would be 3.4 times higher (diesel was modelled to cost 1.2 €/litre). Besides, the emissions balance would be negative. The latter means the power system would emit about 5 times more CO_2 than if consuming from the grid. Adding storage, simulations are better, but still worse than the configuration of PV+accumulation, or PV+grid. In fact, the best combination is the one that does not use the engine, that is to say, the more the diesel engine is turned on the more consumption of diesel and the more expensive the electricity generation is, even considering the investment and operation costs of the batteries.

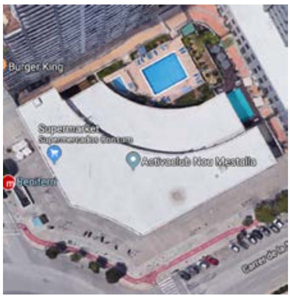
3.6. Simulations of case 4. Prosumer is a privately owned organization operating in a standalone building.

This case is different from the first in the sense that the owner of the building is an organization that has a main source of incomes different form energy production and sale. Besides, the building is normally large with a high potential for electricity generation form PV. For this case study the building of the following chart is modelled as a hotspot.



Example of the case study


Insolation based on ®Huellasolar



Plan view of the building, from ®Google Maps

Figure 6. Case study 4. Standalone building of a private organization

3.6.1. Model 4.1. Self-consumption without storage or sale to the grid.

For this case the demand curve has been obtained combining the one by REE for tariff 3.0 and consumption lower than 450 kW, the consumption curve a of a similar Supermarket in Barcelona (see picture 7), and the demand curves of some examples of the website: https://openei.org/wiki/Main_Page.

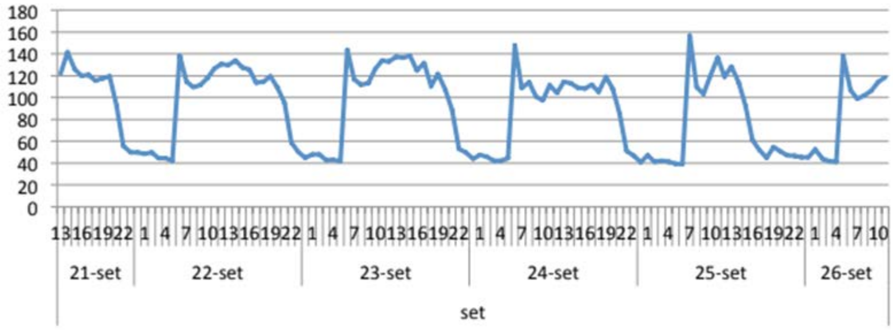


Figure 7. Power demanded during several days in a supermarket similar to the case study

The representative building is a supermarket with 1,700 m^2 in plant. The rooftop has 1,600 m^2 and could hold up to 200 kWp of PV modules. In this first model, only self-consumption is considered. Overall, the supermarket is set to consume around 510.000 kWh/year[18]. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 150 kWp installed.
- Converter: 150 kW
- Total investment: 169,690 €
- Total electricity consumption: 509,902 kWh/year
- Electricity from the grid: 319,683 kWh/year
- Electricity from the PV installation: 246,119 kWh/year
- Electricity surplus (not sold, not deducted from purchases in a Net Billing): 34,761 kWh/year
- Renewables Fraction: 37%
- Levelized Cost Of Energy (LCOE): 8.95 c€/kWh
- Net Present Cost in 25 years: 1,004,217 €
- Payback: 12.55 years
- Greenhouse Gas Emissions avoided: 45,653 kg/year, 1,141,325 kg in 25 years

[18] 300 kWh/year·m^2 has been considered. This estimation is consistent with data from the EU-funded project “SuperSmart - Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel”. In its second report they use a case that consumes 326 kWh/year·m^2 in SPAIN. Besides, there is an energy audit done on a supermarket in Barcelona where a consumption of 251 kWh/year·m^2 was obtained.

As a first conclusion, this is the best model up to now in economic terms. However, a great amount of electricity is lost, the equivalent of approximately 8 households. Although more PV could installed, the economic optimum was set at 150 kWp. The option with batteries is not feasible because the solar radiation curve and the supermarket consumption curve almost match. Hence, there is almost no electricity to be stored, and the accumulators are an extra cost of investment and operation, with little electricity savings from the grid.

3.6.2. Model 4.2. Self-consumption with sale to the grid.

This model is like the previous one but adding the possibility of selling to the electric grid. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 200 kWp installed.
- Converter: 160 kW
- Total investment: 216,536 €
- Total electricity consumption: 509,902 kWh/year
- Electricity from the grid: 293,185 kWh/year
- Electricity from the PV installation: 328,158 kWh/year
- Electricity sold to the grid: 78,298 kWh/year
- Renewables Fraction: 58%
- Levelized Cost Of Energy (LCOE): 8.4 c€/kWh
- Net Present Cost in 25 years: 942,906 €
- Payback: 11,75 years
- Greenhouse Gas Emissions avoided: 51,573 kg/year, 1,289,325 kg in 25 years

This model is even better than the previous one as the possibility of selling to the grid allows to take advantage of the surplus of electricity generated in the middle hours of the day. In fact, the optimum is set at the installation of all the kWp allowed by the surface.

3.6.3. Model 4.3. Self-consumption with sale to the grid in a Net Billing program.

This model is like the previous one but now electricity is compensated in a monthly Net Billing program. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 200 kWp installed.
- Converter: 160 kW
- Total investment: 216,536 €
- Total electricity consumption: 509,902 kWh/year
- Electricity from the grid: 293,185 kWh/year

- Electricity from the PV installation: 328,158 kWh/year
- Electricity sold to the grid: 78,298 kWh/year
- Renewables Fraction: 58%
- Levelized Cost Of Energy (LCOE): 8.2 c€/kWh
- Net Present Cost in 25 years: 915,576 €
- Payback: 11,00 years
- Greenhouse Gas Emissions avoided: 51,573 kg/year, 1,289,325 kg in 25 years

This model is again better than the previous one, and LCOE are the lowest of all models while the payback is the shortest. All that, even although the somewhat high costs of the IVACE have been considered.

3.7. Simulations of case 5. Prosumer is a public organization operating in a standalone building.

In this case again the building is large, and also the organization has a main source of incomes which is different from energy production and sale. For this case study the building of the following chart is modelled as a hotspot.

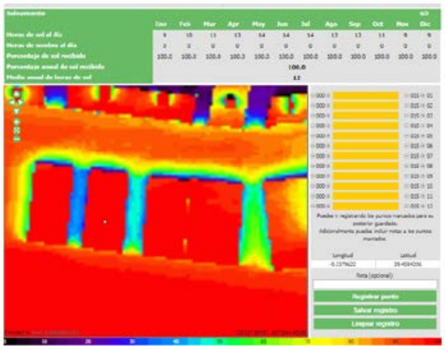



Figure 8. Case study 5. Standalone building of a public organization.

3.7.1. Model 5.1. Self-consumption without storage or sale to the grid.

The demand curve has been obtained from Las Naves foundation directly, and the data belong to the buildings where Las Naves have their offices and halls. Picture 5 includes the average daily power demand.

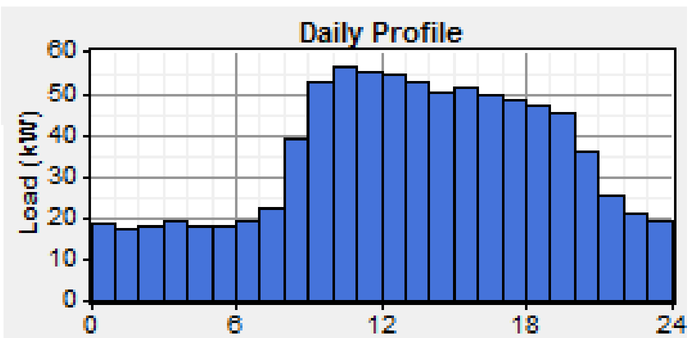


Figure 9. Power demanded during several days in the case study

The three buildings add up to 2,400 m^2, but not all the surface can be used and the maximum to be installed would be up to 200 kWp. The roof is pitched with a slope of 25º. The axis of the rooftop has a North-South direction, leaving one side of the roof facing East and the other facing west. Solar panels have been placed parallel to the roof surface, i.e. tilted at 25º.

With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 100 kWp installed.
- Converter: 80 kW
- Total investment: 113,261 €
- Total electricity consumption: 310,990 kWh/year
- Electricity from the grid: 200,414 kWh/year
- Electricity from the PV installation: 144,718 kWh/year
- Electricity surplus (not sold, not deducted from purchases in a Net Billing): 21,866 kWh/year
- Renewables Fraction: 35.6%
- Levelized Cost Of Energy (LCOE): 10.92 c€/kWh
- Net Present Cost in 25 years: 747,155 €
- Payback: 13.60 years
- Greenhouse Gas Emissions avoided: 26,536 kg/year, 663,400 kg in 25 years

As can be seen, the model is profitable. The LCOE, payback, etc. are better than getting the electricity only from the grid. However, the economic optimum is at a power amount of 100 kWp, well below the maximum power peak that could be installed.

3.7.2. Model 5.2. Self-consumption with storage.

This model is like the previous one but adding the possibility of storing the surplus of electricity to be used later. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 110 kWp installed.
- Converter: 70 kW
- Batteriess HOPPECKE Power VL 2-1150 de 1500Ah in C100 (HOPPECKE 10 OPzS 1000 12V 1500Ah in C100): 24 units
- Total investment: 761,593 €
- Total electricity consumption: 310,990 kWh/year
- Electricity from the grid: 193,458 kWh/year
- Electricity from the PV installation: 159,189 kWh/year
- Electricity surplus (not sold, not deducted from purchases in a Net Billing): 28,609 kWh/year

- Renewables Fraction: 38%
- Levelized Cost Of Energy (LCOE): 11.13 c€/kWh
- Net Present Cost in 25 years: 761,593 €
- Payback: 15.6 years
- Greenhouse Gas Emissions avoided: 28,205 kg/year, 705.125 kg in 25 years

This model is better than the previous one in terms of fraction of renewable energy or avoided emissions, but slightly worse in economic terms.

3.7.3. Model 5.3. Self-consumption with sale to the grid.

This model is like the previous one but changing the possibility of storing energy by the possibility of selling it to the electric grid. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 200 kWp installed.
- Converter: 120 kW
- Total investment: 210,148 €
- Total electricity consumption: 310,990 kWh/year
- Electricity from the grid: 152,560 kWh/year
- Electricity from the PV installation: 298,435 kWh/year
- Electricity sold to the grid: 97,567 kWh/year
- Renewables Fraction: 82.32%
- Levelized Cost Of Energy (LCOE): 10.14 c€/kWh
- Net Present Cost in 25 years: 696,603 €
- Payback: 13.8 years
- Greenhouse Gas Emissions avoided: 61,436 kg/year, 1,535,900 kg in 25 years

This model is better than the previous ones, the possibility of selling to the grid allows taking advantage of the surplus of electricity generated in the middle of the day. In fact, the optimum is set at the installation of all the kWp allowed by the surface. Adding batteries does not make sense as it adds investment and operation costs. Although it saves the consumption of some electricity, that does not compensate the extra costs.

3.7.4. Model 5.4. Self-consumption with sale to the grid in a Net Billing program.

This model is like the previous one but now electricity is compensated in a monthly Net Billing program. With these assumptions and all estimations and calculations previously commented, the results for this model are:

- PV installation characteristics: 200 kWp installed.
- Converter: 120 kW

- Total investment: 210,148 €
- Total electricity consumption: 310,990 kWh/year
- Electricity from the grid: 152,560 kWh/year
- Electricity from the PV installation: 298,435 kWh/year
- Electricity sold to the grid: 97,567 kWh/year
- Renewables Fraction: 82.32%
- Levelized Cost Of Energy (LCOE): 9.5 c€/kWh
- Net Present Cost in 25 years: 647,407 €
- Payback: 12.32 years
- Greenhouse Gas Emissions avoided: 61,436 kg/year, 1,535,900 kg in 25 years

This model is again the best one, and LCOE are the lowest of all models for public buildings while the payback is the shortest.

4. DETAILED CALCULATION OF THE OVERALL POTENTIAL OF ELECTRICITY GENERATION IN VALENCIA.

In this section we retake the estimations and calculations of the first section, but we take advantage of the simulations of the five types of buildings. Hence, we try to answer the question of how many of the different case studies there are in Valencia, i.e. how many single family houses there are, how many houses of more than a floor and more than a household there are, how many standalone commercial buildings, etc.

4.1. Design of the analysis.

For that, we have considered two sources of information, on the one hand secondary information obtained in the city's and national statistics, and the National cadastre[19]. On the other hand, we have conducted a research similar to other studies of the literature[20], already mentioned in the first section.

[19] https://www1.sedecatastro.gob.es/

[20] Rhythm Singh, Rangan Banerjee. Estimation of rooftop solar photovoltaic potential of a city Solar. Energy 115 (2015) 589–602.

Jibran Khan, Mudassar Hassan Arsalan. Estimation of rooftop solar photovoltaic potential using geo-spatial techniques: A perspective from planned neighborhood of Karachi – Pakistan. Renewable Energy 90 (2016) 188-203

John Byrne, Job Taminiau, Lado Kurdgelashvili, Kyung Nam Kim. A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renewable and Sustainable Energy Reviews 41 (2015) 830–844

L.K. Wiginton, H.T. Nguyen, J.M. Pearce. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. Computers, Environment and Urban Systems 34 (2010) 345–357

Luca Bergamasco, Pietro Asinari. Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: Further improvements by ortho-image analysis and application to Turin (Italy). Solar Energy 85 (2011) 2741–2756

Based on the proposals of the papers found, we have divided most of the city map in 28 x 40 = 1,120 squares of 250 x 250 m^2 each. Therefore, each square contains 62.500 m^2 (see figure 10).

Figure 10. Division of most of the city of Valencia.

However, we did not cover the full municipal term, as can be seen in the following picture where the red square in the picture shows the area covered by the study.

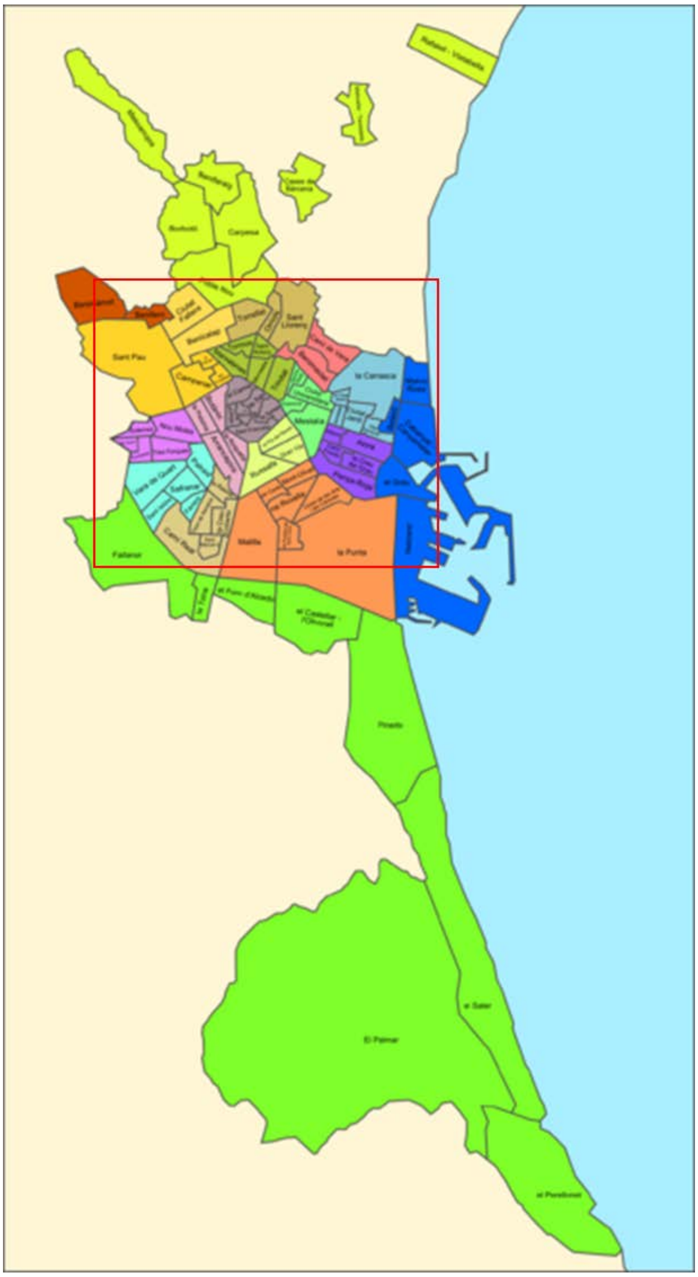
Assuming the scattering of buildings in Valencia follows a Normal distribution for all the variables, the following formula can be applied to estimate the size of the sample for a given error "e":

$$n = \frac{Z_\alpha^2 Npq}{e^2(N-1) + Z_\alpha^2 pq}$$

We set the error to be 10% (e=0.1), "p" to 0.5 as it is usually done when the percentage of the study phenomena in population are not known[21], and "q" is the probably of the contrary (q = 1 – p). Besides, we set the uncertainty to 15% (which means that Z_a = 1.44). Calculating, the sample must include approximately 50 squares, as can be seen below:

$$\frac{1.44^2 \cdot 1{,}120 \cdot 0.5 \cdot 0.5}{0.1^2 \cdot (1{,}120 - 1) + 1.44^2 \cdot 0.5 \cdot 0.5} = 49.59$$

[21] In this case the phenomena are the number of different houses in the city, and their features.



By means of the function “random” of the Excel sheet a series of 50 squares were selected off the grid in the previous picture. The first random series of number covering from 1 to 40 for the horizontal axis, and from 1 to 28 for the vertical axis.

Then, square by square, with the help of pictures in 2D and 3D obtained from Google maps®, the samples were taken. Each one with a label showing where it is in the map. For example, in the following picture: sample 18-23.

Following, we counted all the buildings, noting their characteristics: type and use, surface in plant, height, type of roof, orientation, etc. For that, we also used the information from the cadastre.

The following pictures show the type of samples we have worked with. In the sample of Figure 12 there are 42 buildings with 2 duplex/ building. They have pitched roofs of about 20º slope.

They are oriented North-East (North is the top of the picture) with little shadowing (this observation was confirmed with the radiation obtained in (Huellasolar®). They are privately owned residential buildings, although some hold a commercial activity (child care, restaurants, hairdresser & beauty, etc.), with approximately 150 m^2 in plant.

Figure 11. Full municipal term and studied area.

There are 19 buildings of 5 floors, with diverse surfaces in plant, and of an average of 160 m^2 with two flats per floor. They have horizontal rooftops oriented East or South-East with almost no shades. All of them are residential households but hold commercial activities in the premises of the ground floor (shops, bars, etc.).

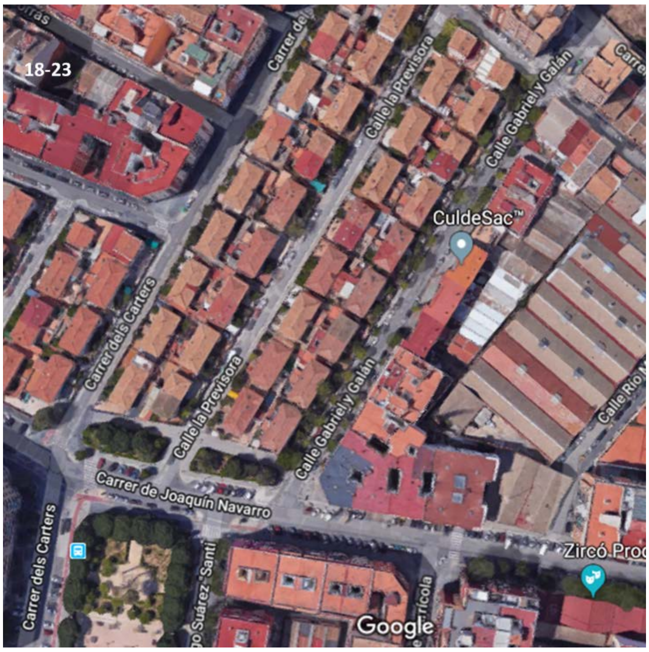


Figure 12. Enlargement of the section 18-23 and 3-D view of the same section

There are 7 buildings of 7 floors of the same characteristics of the previous ones. Just the surface in plant is approximately 200 m^2 on average and there are 2 to 3 flats per floor.

Finally, there are 7 industrial buildings of one floor, pitched roof of 25º, and around 500 m^2 on average. They are oriented South-East with certain shadows. They hold light industrial activities, car parking or similar. There also are 5 smaller industrial buildings of similar characteristics but approximately 150 m^2 on average.

After performing the same analysis with all the samples, we get to the aggregates results we show in the following section.

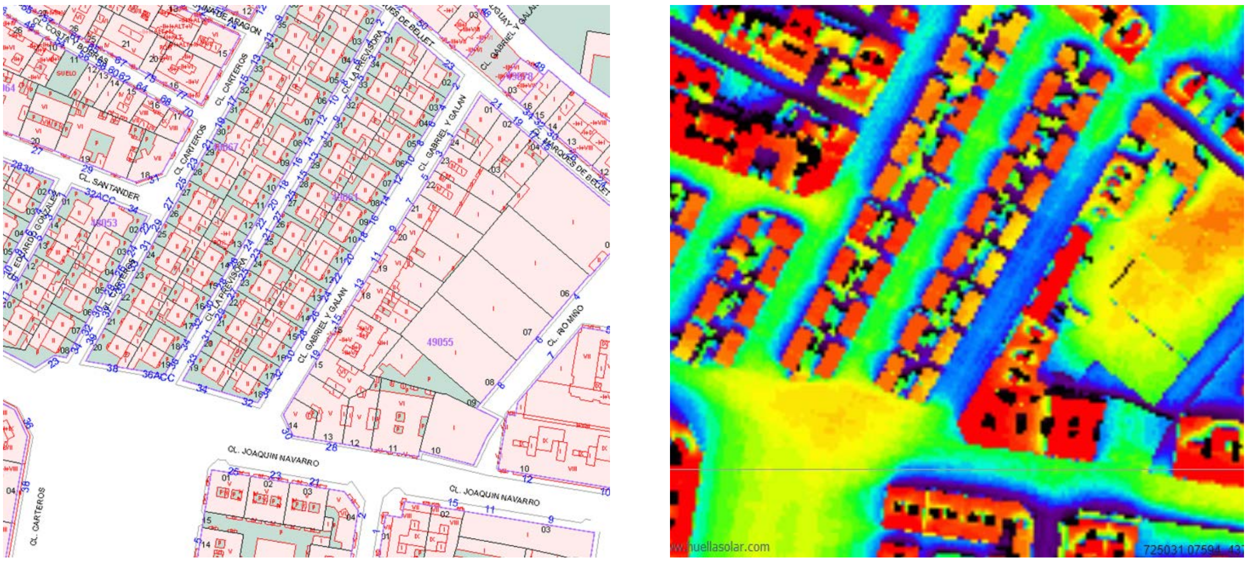


Figure 13. Cadastre's information of section 18-23 and solar radiation of the same section based on Huellasolar®.

4.2. Total power generation for the case studies.

We have carried out the same accounting as explained above with the 50 squares of the sample. We have combined the measures with the data included in the cadastre of Valencia and, mainly, the statistical yearbook of the municipality of Valencia. The mistake can get to be 10% and a further uncertainty of 15% must be added. Therefore, all the figures that will follow can be up to a 25% higher or lower. The results are:

- There are 5,456 residential buildings with only 1 floor, of which:
  - 4,085 are single family homes
  - 1,371 have other uses
- There are 6,986 houses with 2 floors, of which:
  - 3,098 are duplex households
  - 3,887 have two households
- There are 13,072 buildings for residential purposes with 3 to 6 floors.
  - They have 111,530 households
- There are 10,326 buildings for residential purposes with 7 or more floors.
  - They have 205,264 households

Therefore, for around two thirds of the households in Valencia, 205,000 out of 329,000, the electricity demand cannot be covered with their own photovoltaic power generation. Provided they could install PV panels in their roofs, the amount of clean electricity per household would be very small. Nevertheless, the LCOE would be very low because the installation would be optimised for the available space. Besides the aggregation of demand curves would match better the generation curve.

4.2.1. Case study 1 standalone residential buildings of 1 or 2 floors.

On average, the 1 floor houses have 120 m^2 of roof. The 2 floor houses 150 m^2. Taking 50% of it as available due to inconvenient orientation, other uses of the roof, pitched roofs, etc. That gives, for houses of only one household:

4,085 x 120 x 0.5 +3,098 x 150 x 0.5 = 477,450 m^2 available surface.

That would allow to install up to 68,207 kWp of PV (we take 7 m^2/kWp as explained in section 3). But based on the model for case study 1, at IVACE's prices, to install all the possible PV power is only economically worth it in a Net Billing system. If delivering the exceeding electricity to the grid was possible and also the Net Billing, then

4,636 kWh/house·year (see section 3.1.), then: (4,085 + 3,098) x 4,636 = 33,30 GWh/year.

4,960 Wh/m^2·day[22] x 15%[23] x 80%[24] = 595.2 Wh/m^2·day. Or 217.25 kWh/m^2·year

217.25 kWh/m^2·year x 477,450 m^2 = 103.73 GWh/year could be generated.

As can be seen, PV systems in the roofs can generate three times more electricity than it is demanded in the single family houses that would host them. Besides, the investment is not really profitable for those houses. Hence, it is the perfect situation to promote sharing the PV installations with other users that can not cover their electricity consumption with PV electricity. It would be a kind of virtual market with producers and consumers.

4.2.2. Case study 2 residential buildings of 2 floors or more.

Similar calculations could be done for case study 2. On average, the 3,887 buildings of two floors and two households have a surface in plant of 100 m^2. Hence the available surface is:

3,887 x 100 = 388,700 m^2.

Now, all the available surface would be used if the surplus of electricity was sold to the grid, even without a Net Billing System. Hence, if 50% of that rooftop surface could be dedicated to PV, taking into account other uses of the roofs, and an extra 50% was discounted to take into account shades, the calculation would give: 13,882 kWp (7 m^2/kWp). And that installed power could generate up to:

217.25 kWh/m^2·year x 50% x 50% x 388,700 m^2= 21.111 GWh/year.

The buildings of 3 to 6 floors have 1,5 households per floor and a surface in plant of 150 m^2. Hence the available surface is:

13,072 x 150 = 1,960,800 m^2.

Again, all the available surface would be used if the surplus of electricity was sold to the grid, even without a Net Billing System. Hence, if 50% of that rooftop surface could be dedicated to PV, taking into account other uses of the roofs, shadows, etc. the calculation would give: 140,057 kWp (7 m^2/kWp). And that installed power could generate up to:

217.25 kWh/m^2·year x 50% x 1,960,800 m^2= 212.99 GWh/year.

The rest of the buildings are 10.326 units, of 250 m^2 on average of surface in plant. Assuming 50% available it can be produced:

10,326 x 250 x 0.5 = 1,290,750 m^2.

That is to say, 184,393 kWp PV installed, generating up to:

217.25 kWh/m^2·year x 1,290,750 m^2 = 280.42 GWh/year.

---

[22] PVGIS at 0º. Average for Valencia. Not all the rooftops have this angle, some will have it better and other will have it worse. Horizontal panels is a good estimation for the average of all of them.

[23] Panel efficiency

[24] After losses for distribution, temperature, maintenance, etc.

But always provided the owners can be convinced to install the PV systems. We are talking about large neighbourhood communities difficult to lead to an agreement, particularly when there is so little to win for each household (see section 5.4.).

4.2.3. Case study 3 residential buildings off grid.

For case study 3, there are approximately 3,105 houses (included in the number of single family houses previously mentioned) in the 14,635 rural plots. However, their potential contribution to the electricity generation has been accounted for in section 4.2.1.

However, if those houses wanted to go off grid, the exceeding electricity calculated in the previous section would not be delivered to the grid. Some of it would be stored in batteries, and some of it would not be generated because the PV system would not be as large as possible (see section 3.4.1.). Based on the simulation of section 3.4.1. actually, the off grid house would cease to send to the grid more PV electricity than conventional electricity it would save. In an ideal situation, none of the houses would go off-grid and they would find other consumers to whom send the surplus electricity. That way, the PV power system would be as big as it could be, and the installations would be clearly more profitable.

4.2.4. Case study 4. Standalone commercial buildings.

Again, we counted the standalone commercial buildings in the 50 squares of the sample. We have combined the measures with the data included in the cadastre of Valencia and the statistical yearbook of the municipality of Valencia, and the results are those given below. Due to the uncertainty of the study, all the figures that will follow can be up to a 25% higher or lower. The results are:

- 58,192 commercial activities in the sector of shops, catering and reparations. This number is based on the electricity contracts, however, they could be up to 79,389 based on statistics of tax payers. Nevertheless, the first figure matches better our findings in the samples, and we are more interested in those activities that are consuming energy. Most of the shops, bars, repair shops, etc. are settled in premises on the ground floor of residential buildings. However a good number of them are in the floors of the multi storey buildings.

  The majority of those shops could benefit of shared PV installations on the rooftops of the buildings they are in. But that would influence the account of who consumes the electricity, not the account of who produces it, already accounted for in the section of residential buildings.

- However, based on the samples, up to 1,472 standalone buildings have a pure commercial use currently, including: offices, supermarkets, cinemas, department stores, big shops (furniture, household appliances, gardening, pets, etc.), malls, some banks, gyms, car dealers, restaurants, healthcare, warehouses, etc. Hence:
  - o We have calculated 405 m^2 of plant surface on average, we keep the overall estimation of 50% of available roof surface. Furthermore, we add an extra 50% reduction because the majority of those buildings are low and have problems of shade.

    Thus: 1,472 x 400 x 0.5 x 0.5 = 149,040 m^2

- 2,997 industrial buildings. Normally standalone buildings, but many of them surrounded by shadows: other buildings, trees, commercial panels, etc.
    - We have calculated 711 m^2 of plant surface on average, we keep the overall estimation of 50% of available roof surface. We add an extra 50% reduction because of shade.

      Thus: 2,997 x 711 x 0.5 x 0.5 = 532,717 m^2
- 244 private schools and educational centres, of which 82 have an agreement with the public administration. Normally standalone buildings, but many of them with some kind of protection against changes or reforms. The great majority of them without problems of shade.
    - We have calculated 1,062 m^2 of plant surface on average, we keep the overall estimation of 50% of available roof surface. We add an extra 50% reduction to discard the protected buildings.

      Thus: 244 x 1,062 x 0.5 x 0.5 = 64,782 m^2
- 82 hotels. Normally standalone buildings, but some of them with some kind of protection. Almost no shade. There are also 20 hostels and 43 boarding houses, although they normally belong to a larger residential building of which we have already accounted its rooftop in the previous section.
    - We have calculated 523 m^2 of plant surface on average, we keep the overall estimation of 50% of available roof surface. We add an extra 25% reduction to discard the protected buildings.

      Thus: 82 x 523 x 0.5 x 0.75 = 16,082 m^2

Altogether they amount to 762,621 m^2 of available roof surface. This would allow installing 108,946 kWp of PV power. And based on the case study 4.2 of section 3.5.2., if the surplus of electricity can be sold to the grid, the PV power plants could generate up to 217.25 x 762,621 = 165,679,412 kWh/year of electricity.

4.2.5. Case study 5. Public buildings.

We have counted the standalone public buildings in the 50 squares of the sample. We have combined the measures with the data included in the cadastre of Valencia and the statistical yearbook of the municipality of Valencia, and the results are those given below. Due to the uncertainty of the study, all the figures that will follow can be up to a 25% higher or lower. The results are:

- 102 public education centres. Most of them are standalone buildings with almost no shade.
    - We have estimated 273,120 m^2 of plant surface based on their own statistics. If 50% of it could be used, it would allow installing up to 19,509 kWp of PV power that would generate 29,667,660 kWh/year if surplus electricity could be sold.
- 456 open space playgrounds for children
    - We have calculated 1,122 m^2 of plant surface on average. If 10% could be covered with PV panels. This would allow installing 16.03 kWp/playground that would generate up to 11,115,205 kWh/year if surplus electricity could be sold.

456 x 1,122 x 217.25 x 0.1 = 11,115,205 kWh/year

However, those installations would be very vulnerable, more expensive than other models and the use for the electricity would be uncertain.

- 148 buildings for healthcare, only some of them standalone buildings, normally with problems of shade.
    - We have calculated 767 m^2 of plant surface on average. If 25% could be covered with PV panels because there are several problems with the roof usage: thermic solar power wherever there are beds, shadows, protected buildings, or roofs, etc. that would allow installing 4,054 kWp that would generate up to 6,165,338 kWh/year if surplus electricity could be sold.

      148 x 767 x 217.25 x 0.25 = 6,165,338 kWh/year

- 16 public markets, standalone buildings. Some of them protected, some of them with important shadows.
    - We have calculated 28,404 m^2 of overall available roof surface (based on their own statistics). If 25% could be covered with PV panels because there are several problems with the roof usage: shade, not suitable buildings, or roofs, etc. that would allow installing 1,014 kWp that would generate up to:

      28,404 x 217.25 x 0.25 = 1,542,692 kWh/year
      if surplus electricity could be sold

- 240 public buildings for offices, halls, courts, car parks, stores, headquarters, etc.
    - We have calculated 714,252 m^2 overall based on their own statistics. The buildings have 3 floors on average:

      714,252 m^2 / 3 floors per building = 238,084 m^2 of available roof surface. If 10% could be covered with PV panels because there are several problems with the roof usage: thermic solar power needed, shadows, not suitable buildings, or roofs, etc. that would allow installing 3.401 kWp that would generate up to:

      238,084 x 217.25 x 0.10 = 5,172,375 kWh/year
      if surplus electricity could be sold

- 288 residential buildings with offices, libraries, stores, etc.
    - We have calculated 75,701 m^2 overall based on their own statistics. These buildings have 4 floors on average:

      75,701 m^2 / 4 floors per building = 18,925 m^2 of available roof surface. If 10% could be covered with PV panels because there are several problems with the roof usage: thermic solar power needed, shadows, not suitable buildings, or roofs, etc. that would allow installing 270 kWp that would generate up to:

      18,925 x 217.25 x 0.10 = 411,151 kWh/year
      if surplus electricity could be sold

Altogether, they amount to 54,073,981 kWh/year of electricity.

4.3. Summary of the total potential for electricity generation in Valencia.

The following table summarizes the calculations of this chapter:

Table 4. Summary of the potential for electricity generation in PV systems in the rooftops of Valencia.

	Energy generation	Installed capacity
	GWh/year	MWp
Single family buildings	103.73	68.2
Buildings of 2 to 6 floors	234.10	140.1
Buildings of more than 6 floors	280.42	184.4
Standalone commercial and industrial buildings	165.7	108.9
Public buildings	54.07	35.5
TOTAL	**838.02**	**536.4**

As can be seen. The total amount is slightly smaller than the overall energy generation estimated in section 2.1.3.: 901.20 GWh/year. That is to say, a more detailed calculation gives a total amount of potential PV electricity generation of around 93% of the first estimation, double checking both figures.

5. ECONOMIC ANALYSIS.

5.1. Necessary investment.

The costs of the PV power installations can vary much depending on the size, the quality of the equipment, appropriateness of the rooftops, number of users and complexity of the distributions, existence or not of smart meters, etc. Therefore, all the following estimations and calculations are subject to a great uncertainty. To tackle the uncertainty we will design a "best case" and a "worst case" scenarios and calculate the investments. Logically, the real values that could be obtained will belong to the interval encompassed by the upper and lower values obtained in the scenarios.

To use equipment prices different from those of the IVACE, we have reviewed the prices given by Eneragen and the International Energy Agency[22]. Thus, we have found Spanish owners paid between € 1.4 and € 1.5 (VAT excluded) per installed peak watt for a PV power system in 2016[25] in a residential building (see the following table). PV systems in commercial and industrial buildings paid even less: 0.8 - 1.33 €/Wp. Furthermore, in those provinces or communities where incentives or subsidies are in force, that cost is reduced by around 35%[26]. Finally, off-grid PV systems costed between 2 and 2,8 €/Wp for installations larger than 1 kW.

[25] www.iea-pvps.org

[26] http://www.eneragen.org/es/

Table 5. Indicative installed costs for PV systems in 2016 (prices without VAT).

	OFF-GRID (LOCAL CURRENCY OR USD PER W)				GRID-CONNECTED (LOCAL CURRENCY OR USD PER W)							
	<1 kW		>1 kW		RESIDENTIAL		COMMERCIAL		INDUSTRIAL		GROUND-MOUNTED	
COUNTRY	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W
AUSTRALIA	5,5 - 11	4,08 - 8,17	5,5 - 11,0	4,08 - 8,17	2,42	1,80	1,79	1,33	1,82	1,35	2,76	2,05
AUSTRIA	5,00	5,50	5,00	5,50	1,65	1,80	1,39	1,40	NA	-	NA	-
BELGIUM	NA	-	NA	-	1,5 - 1,9	1,66 - 2,11	1,2 - 1,5	1,33 - 1,66	1,20 - 1,40	1,33 - 1,55	NA	-
CANADA	NA	-	NA	-	3,00 - 3,5	2,26 - 2,64	2,5 - 3,00	1,88 - 2,26	2,00 - 2,5	1,5 - 1,88	2,00	1,51
CHINA	22,00	3,31	18,00	2,71	7 - 10	1,053 - 1,5	7 - 8	1,05 - 1,20	7 - 7,5	1,05 - 1,12	7 - 7,2	1,05 - 1,08
DENMARK	10,0 - 25,0	1,4 - 3,71	20,0 - 35,0	3,0 - 5,19	8 - 15,0	1,18 - 2,2	6,0 - 13,0	0,891 - 1,9	6,0 - 14,0	0,891 - 2,0	4,0 - 7,0	0,59 - 1,3
FINLAND	5,00	5,53	3,50	3,87	1,3 - 2	1,47 - 2,2	1,05 - 1,35	1,16 - 1,49	0,95 - 1,3	1,05 - 1,43	1 - 1,2	1,1 - 1,32
FRANCE	NA	-	NA	-	2,2 - 2,9	2,4 - 3,2	1,20	1,33	1,20	1,32	0,90 - 1,10	0,99 - 1,21
GERMANY	NA	-	NA	-	1,3 - 1,7	1,43 - 1,88	1,0 - 1,7	1,1 - 1,88	NA	NA	0,60	0,66
ITALY	NA	-	NA	-	1,34-1,73	1,43 - 1,88	1,20-1,48	1,326-1,635	1,08-1,26	1,19 - 1,39	0,76-0,98	1,10 -1,08
JAPAN	NA	-	NA	-	324,00	2,98	245,00	2,25	245,00	2,25	236,00	2,17
KOREA	NA	-	NA	-	1 500 - 2 000	1,29 - 1,72	2 200 - 2 300	1,89 - 1,98	NA	NA	NA	-
MALAYSIA	NA	-	NA	-	7,83	1,89	7,10	1,71	6,94	1,67	NA	-
NORWAY	30 - 150	3,57 - 17,85	45 - 150	5,35 - 17,84	15,00	2,23	14,00	1,67	12,00	1,43	NA	-
PORTUGAL	3,00	3,32	2,70	2,99	2,20	2,43	1,40	1,55	1,00	1,11	0,7 - 0,8	0,78 - 0,89
SPAIN	2,5 - 3	2,7 - 3,3	2 - 2,8	2,2 - 3,09	1,4 - 1,5	1,54 - 1,65	0,8 - 1,2	0,88 - 1,33	0,8 - 1,2	0,88 - 1,32	0,70	0,77
SWEDEN	25,00	2,92	20,40	2,38	15,00	1,75	12,30	1,44	11,60	1,35	9,20	1,07
SWITZERLAND	5,0 - 12,0	5,07 - 12,17	4,0 - 12,0	4,05 - 12,17	2,5 - 3,5	2,53 - 3,55	1,5 - 2,5	1,52 - 2,53	1,25 - 1,70	1,26 - 1,72	NA	-
USA	NA	-	NA	-	2,93	2,93	2,13	2,13	2,03	2,03	1,49	1,49

NOTE: DATA REPORTED IN THIS TABLE DO NOT INCLUDE VAT.

5.2. Scenarios of investment. One household residential buildings.

5.2.1. Best case scenario. One single family residential buildings in a Net billing system and selling electricity directly to other consumers.

In this scenario, it is a grid-connected residential building. If instead of the maximum costs of the IVACE[27], prices are based on the PVPS data (Table 5), the economic analysis is as follows.

- Net billing system:
  - 68,207 kWp of installed capacity.

    4,085 + 3,098 = 7,183 single family houses

    4,636 kWh/year·house of electricity consumption (see section 3.2.)

    4,636 x 7,183 = 33,300,388 kWh/year of electricity demand

    103,726,012 kWh/year of maximum electricity generation (see section 4.2.1.). As this amount is three times as big as the total electricity consumption of the houses, it is assumed the exceeding electricity will be delivered to other consumers instead of selling it to the grid. Hence, each kWh of electricity will either save[28] 20.85 c€ to the owner of the PV system, reducing the consumption from the grid; or will be sold to another consumer

[27] Reference costs according to the Resolución del 3 de mayo de 2018. DOGV 8299 del 21/05/2018

[28] www.autoconsumoaldetalle.es

that will pay that cost and will be an income of 20.85 c€/kWh for the owner of the PV system.

68,207 kWp x 1,400 €/kW x 1.21 (VAT) = € 115,542,900 of investment without subsidies

€ 115,542,900 x (1 - 35%) = € 75,103, 885 investment with subsidies[29]

103.73 GWh/year will be saved from consumption or delivered to consumers at a price of 20.85 c€/kWh, and thus:

103,726,012 kWh/year x 0.2085 €/kWh = 21,626,874 €/year.

75,103,885 € / 21,626,874 €/year = 3.47 years (no operational costs included, although they will be small taking into account no batteries are needed and the short payback time).

As can be seen, the savings for single family buildings would be overall more than 20 M€/year. Furthermore, in less than 4 years the installation is paid back.

If the total amount is divided among all the possible houses, on average each house would save (and earn): 21,626,874 / 7,183 = 3,011 €/year·house

Anyhow, this best case scenario is very difficult and will be achieved in a few specific situations.

5.2.2. Worst case scenario. One single family residential buildings. Only self-consumption.

In this scenario the exceeding electricity neither can be delivered to the grid nor can it be delivered to other consumers, nor are there subsidies. Therefore, the economic analysis is as follows.

68,207 kWp of maximum installed capacity, but only 50% of it is installed because bigger PV plants are not profitable (see section 3.2.). We take the high prices of IVACE like in 3.2. to account for those difficult installations that would increase the average cost per installed peak Watt.

As the total electricity consumed/saved from the PV system would be 2,461 kWh/year·house (see section 3.2.1.), then:

- Only self-consumption:
    - 68,207 kWp x 50% x 3,374 €/kW = € 115,065,209 of investment without subsidies

      2,461 x 7.183 = 17,677,363 kWh/year saved

      17,677,363 kWh/year x 0.2085 €/kWh = 3,685,730 €/year saved

      3,685,730 €/year / 7,183 houses = 513 €/year·house saved

      115,065,209 € / 3,685,730 €/year = 31.22 years

      As can be seen, the savings for single family buildings would be overall more than 3.5 M€/year. But, per house it would only be 513 €/year

[29] Note that at the time of writing this report, in the Comunidad Valenciana, there are subsidies of the IVACE in the form of fiscal deductions in the income tax on persons (IRPF in Spanish) for self-consumption and renewable energies. Also for the financing of projects of electric self-consumption in companies and entities. However, they do not reach the 35% of the installation investment except for isolated cases (www.ivace.es).

On the other hand, it would take more than 31 years to pay back the investment, and in this case operational costs are relevant and must be taken into account.

This situation is not probable as with such figures only very sensitized consumers will invest on a PV system.

5.3. Scenarios of investment. One household residential buildings off grid.

5.3.1. Best case scenario. One single family residential building off grid.

In this scenario, a single family house wants to go off grid. Taking prices based on the PVPS data (Table 4), and based on the results of section 3.4., the economic analysis is as follows.

- One single family house off grid:
  - o 9 kWp installed.

    4,636 kWh/year of electricity consumption.

    9 kWp x 2,000 €/kW x 1.21 (VAT) = € 21,780 of investment without subsidies

    21,780 x (1-35%) = € 14,157 with subsidies

    4,636 kWh/year x 0.2085 €/kWh = 967 €/year

    14,157 € / 967 €/year = 14.65 year (without operational costs)

    As can be seen, the savings for single family buildings off grid would be in the range of €1,000. However, the investment would take almost 15 years to be paid back.

5.3.2. Worst case scenario. One single family residential building off grid.

In this scenario we take the prices of IVACE like in 3.4. Therefore, the economic analysis is as follows.

- One single family house off grid:
  - o 9 kWp installed.

    4,636 kWh/year of electricity consumption.

    9 kWp x 3,059 €/kW = € 27,533 of investment

    4,636 kWh/year x 0.2085 €/kWh = 967 €/year

    27,533 € / 967 €/year = 28.48 year (without operational costs)

    As can be seen, the savings for single family buildings off grid would be in the range of €1,000. However, the investment would take almost 30 years to be paid back.

5.4. Scenarios of investment. Residential buildings connected to grid of two floors or more.

5.4.1. Scenarios.

In this case, the prices of the PVPS data (Table 4) are higher than the maximum prices taken from IVACE. But they are very similar: 1,694 €/kWp the former and 1,623 €/kWp the latter). Besides, in all cases (only self-consumption, sales to the grid or Net billing system) the maximum available surface would be occupied by the PV system (see section 3.3). Therefore, only one case will be studied.

- Residential Buildings of more than 2 floors and more than 3 households per building:
  - 140,057 + 184,393 + 13,882 = 345,332 kWp installed.

    4,636 kWh/household·year x 316,794 households = 1,469 GWh/year of electricity consumption. This is an overestimation, larger than the 985.01 GWh/year based on the city hall statistics. The overestimation is because not all the households consume such a quantity of electricity per year.

    212.99 + 21.11 + 280.42 = 514.52 GWh/year of electricity generation, less than the demanded electricity consumption. Hence, all the electricity generated would be subtracted from the consumption from the grid at a cost of 0.2085 c€/kWh

    331,450 kW x 1,400 €/kW x 1.21 (VAT) = € 584,992,408 of investment without subsidies[30]

    514.52 GWh/year x 208,500 €/GWh = 107,277,420 €/year of savings

    584,992,408 € / 107,277,420 €/year = 5.45 year (without operational costs)

    As can be seen, the savings for multi storey buildings would be overall more than 100 M€/year. Furthermore, in less than 6 years overall the installations are paid back.

    If the total amount is divided among all the possible houses, on average each house would save: 107,277,420 / 316,794 = 339 €/year. The investment would be, on average: 584,992,408 / 316,794 = 1,847 €/house. That is to say, although the investment is profitable overall, per household it may not be worth the resources needed: investment, time, works, procedures...

5.5. Scenarios of investment. Standalone commercial and industrial buildings connected to grid.

5.5.1. Best case scenario.

This scenario is about standalone grid-connected buildings, there is a net billing system and the exceeding electricity, if any, can be delivered to the grid at the price of 20.85 c€/kWh. If investment prices are based on the PVPS data (Table 4), the economic analysis is as follows.

- Net billing system:
  - 108,946 kWp of installed capacity.

    4,795 buildings

    165,679,412 kWh/year of maximum electricity generation (see section 4.2.4.).

    108,946 kWp x 800 €/kW x 1.21 (VAT) = € 105,459,728 of investment without subsidies[31]

    165.68 GWh/year will be saved from consumption at a price of 20.85 c€/kWh, and thus: 165,679,412 kWh/year x 0.2085 €/kWh = 34,544,157 €/year.

    105,459,728 € / 34,544,157 €/year = 3.05 years (no operational costs).

[30] As we will see the economic analysis is so profitable that subsidies are not expected for these projects.
[31] Again, the economic analysis is so profitable that subsidies are not expected for these projects, and they will not be taken into account even in the best case scenario.

As can be seen, the savings for commercial and industrial buildings, on average, would be more than 34 M€/year. Furthermore, in around 3 years the installation is paid back.

If the total amount is divided among all the possible commercial and industrial buildings, on average each one would save: 34,544,157 / 4,795 = 7,204 €/year. Although this average is not very relevant because the differences among cases are very important.

5.5.2. Worst case scenario. Only self-consumption.

In this scenario the exceeding electricity neither can be delivered to the grid nor can it be delivered to other consumers, nor are there subsidies. The investment prices are those of table 4 because they are greater than the IVACE's. Therefore, the economic analysis is as follows.

- Only self-consumption:
  - The possible 108,946 kWp of installed capacity are reduced to 81,709 (75% of the maximum) because larger PV systems would not be profitable (see section 3.5.1.).

    4,795 buildings

    The maximum savings of electricity consumed from the grid would be around 50% of the electricity generation (see section 3.5.1.). Hence, the electricity savings would be: 165,679,412 kWh/year x 75% x 50% = 62,129,779 kWh/year (see section 4.2.4.).

    81,709 kWp x 1,200 €/kW x 1.21 (VAT) = € 105,459,728 of investment without subsidies

    62.13 GWh/year will be saved from consumption at a price of 20.85 c€/kWh, and thus: 62,129,779 kWh/year x 0.2085 €/kWh = 12,954,059 €/year.

    105,459,728 € / 12,954,059 €/year = 8.14 years (no operational costs).

    As can be seen, the savings for commercial and industrial buildings, on average, would be almost 13 M€/year. Furthermore, in around 8 years the installation is paid back.

    If the total amount is divided among all the possible buildings, on average each one would save: 12,954,059 / 4,795 = 2,702 €/year. Although this average is not very relevant because the differences among cases are very important.

5.6. Scenarios of investment. Standalone public buildings connected to grid.

5.6.1. Best case scenario.

In this scenario there is a net billing system and the exceeding electricity, if any, can be delivered to the grid at the price of 20.85 c€/kWh. Investment prices are based on the PVPS data (Table 4) and the economic analysis is as follows.

- Net billing system:
  - 35,536 kWp of installed capacity.

    1,250 buildings

    54,073,981 kWh/year of maximum electricity generation (see section 4.2.5.).

35,536 kWp x 800 €/kW x 1.21 (VAT) = € 34,398,848 of investment without subsidies. Subsidies will not be considered in this scenario as the public sector would be the donor of the funds.

54.07 GWh/year will be saved from consumption at a price of 20.85 c€/kWh, and thus: 54,073,981 kWh/year x 0.2085 €/kWh = 11,274,425 €/year.

34,398,848 € / 11,274,425 €/year = 3.05 years (no operational costs).

As can be seen, the savings for public buildings, on average, would be more than 11 M€/year. Furthermore, in around 3 years the installation is paid back.

If the total amount is divided among all the possible buildings, on average each one would save: 11,274,425 / 1,250 = 9,020 €/year. Although this average is not very relevant because the differences among cases are very important.

5.6.2. Worst case scenario. Only self-consumption.

In this scenario the exceeding electricity neither can be delivered to the grid nor can it be delivered to other consumers, nor are there subsidies. The investment prices are those of table 4 because they are greater than the IVACE's. Therefore, the economic analysis is as follows.

- Only self-consumption:
    - The possible 35,536 kWp of installed capacity are reduced to 17,768 (50% of the maximum) because larger PV systems would not be profitable (see section 3.6.1.).

      1,250 buildings

      The maximum savings of electricity consumed from the grid would be around 51% of the electricity generation (see section 3.6.1.). Hence, the electricity savings would be: 54,073,981 kWh/year x 50% x 51% = 13,788,865 kWh/year (see section 4.2.5.).

      17,768 kWp x 1,200 €/kW x 1.21 (VAT) = € 25,799,136 of investment without subsidies

      13.79 GWh/year will be saved from consumption at a price of 20.85 c€/kWh, and thus: 13,788,865 kWh/year x 0.2085 €/kWh = 2,874,978 €/year.

      25,799,136 € / 2,874,978 €/year = 8.97 years (no operational costs).

      As can be seen, the savings for commercial and industrial buildings, on average, would be near 3 M€/year. However, around 9 years would be necessary to pay back the installation.

      If the total amount is divided among all the possible buildings, on average each one would save: 2,874,978 / 1,250 = 2,300 €/year. Although this average is not very relevant because the differences among cases are very important.

5.7. Summary of the economic analysis.

The following table summarizes the results of the economic analysis.

Table 6. Summary of the economic analysis.

Model	Case	Cost of investment (€/kWp)	Power installed (kWp/unit)	Pay back (years)	Savings/unit[32] (€/year)
Residential. Single family	BEST	1,101	9.5	3.5	3,011
	WORST	3,374	4.7	31.2	513
Residential. Single family off grid	BEST	1,300	9.0	14.6	967
	WORST	3,059	9.0	28.5	967
Residential ≥ 2 floors	UNIQUE	1,694	12.7[33]	5.5	339
Commercial/Industrial building	BEST	968	22.7	3.1	7,204
	WORST	1,452	17.0	8.1	2,702
Public buildings	BEST	968	28.4	3.1	9,020
	WORST	1,452	14.2	9.0	2,300

6. ENVIRONMENTAL ANALYSIS.

6.1. Environmental aspects of the Spanish electricity.

As explained in section 3.2. to characterize the environmental aspects of the electricity, as every household may have a different supply company, an average emission factor (EF) has been selected. The EF is the one given by REE for year 2017[34]: 285 gCO_2e/kWh. CO_2e is the reference unit of the Greenhouse Gases (GHG) that produce Global Warming.

Besides, the observatory[35] of the European Environmental Agency (EEA) adds that, per kWh generated, the electric power mix of Spain releases: 0.62 g of SO_2 and 0.42 g of NOx. While Sulphur Dioxide contributes directly to Acid Rain and indirectly to Smog, Nitrogen Oxides also directly produce Acid Rain, plus Smog and damage to human health like respiratory infections and asthma.

If the savings of electricity are turned into savings of air emissions, we have the figures of table 7. As can be seen, the yearly indirect savings of air emissions would be very important if all the potential for PV electricity generation could be realized, that electricity substituted electricity delivered by the grid, and the environmental aspects of that grid's electricity remained the same.

[32] "Savings" are an average for all the units: household, shop, public office, etc. Therefore, they may vary considerably from one case to another.

[33] In this case, "unit" is building, not household like in the last column.

[34] https://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/series-estadisticas/series-estadisticas-nacionales

[35] https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-1/assessment

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Table 7. Savings of air emissions.

Model	Case	Saved electricity (GWh/year)	GHG saved (kg/year)	SO_2 (kg/year)	NOx (kg/year)
Residential. Single family	BEST	103.73	29,561,913	64,310	43,565
	WORST	17.68	5,038,048	10,960	7,424
Residential. Single family off grid	BEST	14.39	4,102,512	8,925	6,046
	WORST	14.39	4,102,512	8,925	6,046
Residential ≥ 2 floors	UNIQUE	514.52	146,638,200	319,002	216,098
Commercial/Industrial building	BEST	165.68	47,218,632	102,721	69,585
	WORST	62.13	17,707,050	38,521	26,095
Public buildings	BEST	54.07	15,411,085	33,526	22,711
	WORST	13.79	3,929,827	8,549	5,791

7. CONCLUSIONS.

Based on the calculations and estimations explained in this report, our conclusion is that the rooftops of the buildings of Valencia present the potential to generate up to 80% to 90% of the electricity demanded by the residential sector by means of PV power systems. Thus, with a general electricity saving program that accomplished a 10% of overall reduction, the total electric power could be supplied. Compared with the total electricity consumption of the city, the generation could cover between the 30% and 33%

The majority of the PV systems simulated are profitable today, particularly the larger ones in tall residential buildings, standalone commercial and industrial buildings and standalone public buildings.

Other PV systems would be profitable if just the exceeding electricity could be sold to the grid at a reasonable price of 0.05 €/kWh and the connection was not too expensive. Finally, the rest of PV systems will be profitable if a monthly Net Billing systems allows making a balance of electricity input and output before calculating the bill.

The single family houses, besides, should be able to sell their surplus of electricity in order to install as much PV power as the full potential of their roofs allows. That sale would be all the more profitable if it could be done at the market price (in this study 20.85 c€/kWh including the fixed and variable part). For that, consumer and producers could meet together in virtual markets where they would deal directly with each others, or by means of a trading company and a scheme of Guarantee of Origin (GO or GoO).

Finally, the environmental benefits of the total realization of the PV potential for electricity generation in the rooftops would indirectly save an enormous amount of air emissions that contribute to Global warming, Acid rain and Smog, among others.

Based on these conclusions, our recommendations for the promotion of the use of the PV energy in Valencia would be:

- Platform on line for self design of PV-Grid electric systems.
- Help for the adaptation of rooftops

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- Energetic rehabilitation of buildings
- Development of virtual electric markets for Prosumers with virtual power plants (VPP).
- Start pilot projects that serve as a claim for prosumers. For example, the installation of visible PV cells in public buildings or public events