Economic benefits of small PV "prosumers" in south European countries

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ABSTRACT

Within various renewable energy technologies, Photovoltaic (PV), long known as one of the most expensive, is today becoming cost competitive with wind, hydro and other conventional thermal technologies in countries with a considerable number of hours of sun exposition. The development of the PV sector in the last decade has been fuelled by the implementation of various supporting strategies aimed to reduce the gap between PV energy cost and the price of energy from conventional generation. Many countries have had policies which directly subsidise small-scale PV systems for domestic applications but these have stopped in 2014/15 not only as a response to economic crisis but mainly because solar PV has become able to compete without subsidies.

This paper presents a comparative assessment of the expected economic benefits of grid-connected residential and small business PV systems. Case studies from Portugal, Spain, Italy, France and Greece are taken as examples, as they have similar levels of the solar resource and customers demand but some differences in electricity prices and financial support mechanisms.

The levelized costs of energy (LCOE) from PV systems have already, crossed the increasing cost of electricity for low voltage consumers. Italy, Spain and Portugal have higher electricity prices than France and Greece and for those, self-consumption and net-metering have become the most profitable solution even considering that the energy injected into the grid is paid at less than the average spot-electricity price (or even zero as the case of Spain). Under these conditions, a 50% to 80% of self-consumption is needed to attain any benefit from a PV investment, depending on, other also important factors, such as location and PV systems costs. The best case studies maximized NPV for 95% of self-consumption, which indicated for residential customers a low PV power installed and only 30% of self-sufficiency while for commercial consumers, as the majority of consumption coincides with PV generation, it is possible to install more PV power and attain almost 50% of self-sufficiency. With further increase of retail electricity prices and decrease of PV costs, PV self-consumption becomes the logical way to decrease energy costs with environment benefits (renewable energy) and increase energy efficiency (energy is generated locally).

KEYWORDS: Photovoltaic System, *prosumer*, Grid connected PV, LCOE

1. INTRODUCTION

Solar photovoltaic (PV) technology, which converts sunlight directly into electricity, is one of the fastest growing Renewable Energy Technologies in the world (IEA, 2014). PV, a clean, sustainable, renewable energy conversion technology is thus becoming a visible source in helping to meet the world's growing electricity demand. It draws upon the planet's most abundant and widely distributed renewable energy resource - the sun. The technology is inherently elegant - the direct conversion of sunlight to electricity without any moving parts or environmental emissions during operation. In the last ten years, cumulative installed capacity has grown at an average rate of 49% per year, and can, at present, be considered as a mature technology which in about two or three decades would probably move to the terawatt scale, of global cumulative installed power (Martínez-Duart JM, 2013, Hernández-Moro J., 2015). In Europe, from 2000 to 2013, solar PV deployment has increased at an annual average rate of 31% (40% between 2010 and 2012) and passed the 80GW in 2013 (Fig.1).

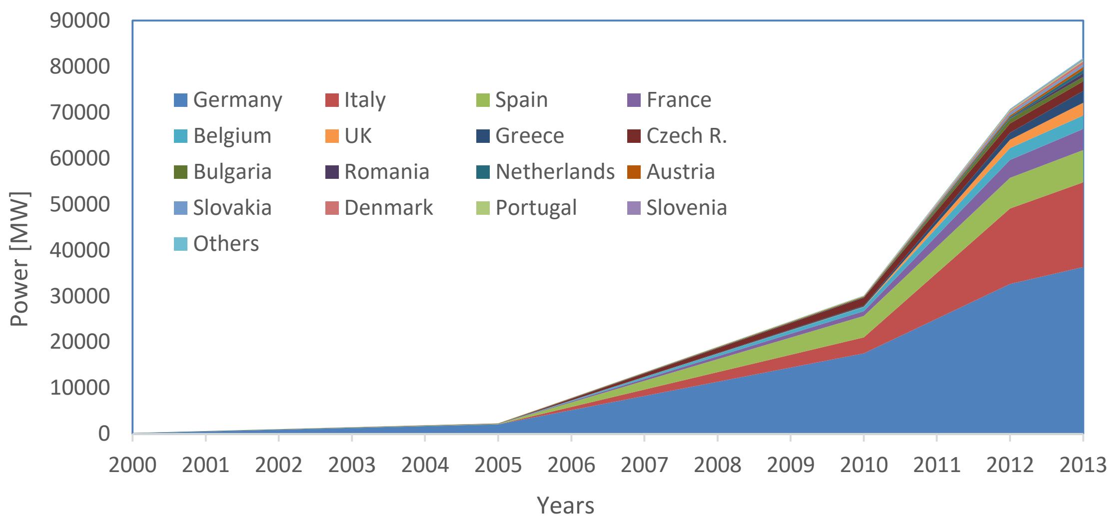

Fig. 1 – Evolution of solar capacity installed in Europe (EU energy, 2015)

Although Germany was the country with more capacity installed by the end of 2013, with almost 50% of all European capacity, Italy was the country with the highest percentage (7.4%) of PV generation within the country's total electricity production (Fig. 2).

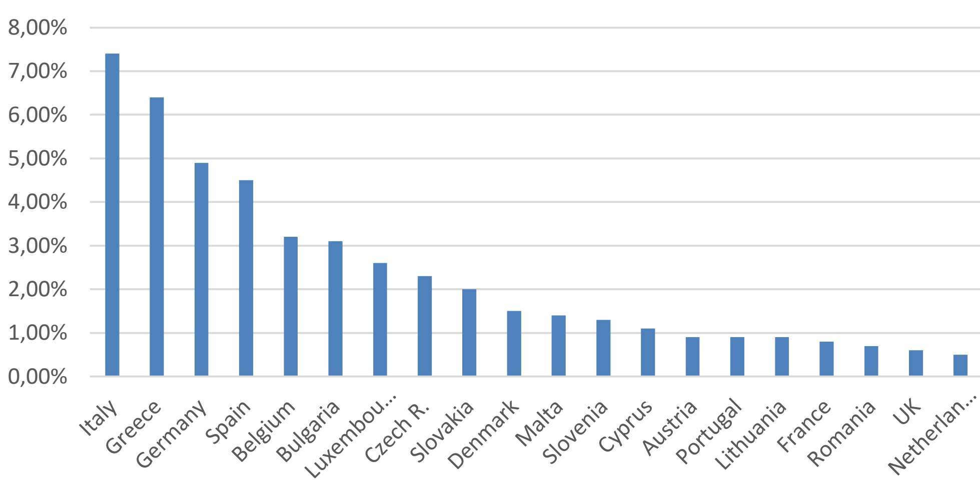

Fig. 2 – Percentage of PV generation within total electricity production in 2013 (EU energy, 2015)

In fact PV penetration at the end of 2013 was below 5% in all the European countries except in Italy and Greece (countries with both high sun exposition and considerable amount of PV capacity installed.

From 2004 to 2008, the price of PV modules remained approximately flat at €3.20 - €3.70/W, despite manufacturers making continuous improvements in technology and scale to reduce their costs. Much of this could be attributed to the fact that the German, and then the Portuguese and Spanish, tariff incentives allowed project developers to buy the technology at this price, coupled with a shortage of poly-silicon that constrained production and prevented effective pricing competition (Morgan Brazilian et al., 2013). From 2008 onwards PV systems prices have decreased (Fig. 3 – adapted from IEA-PVPS 2006 till IEA PVPS 2015).

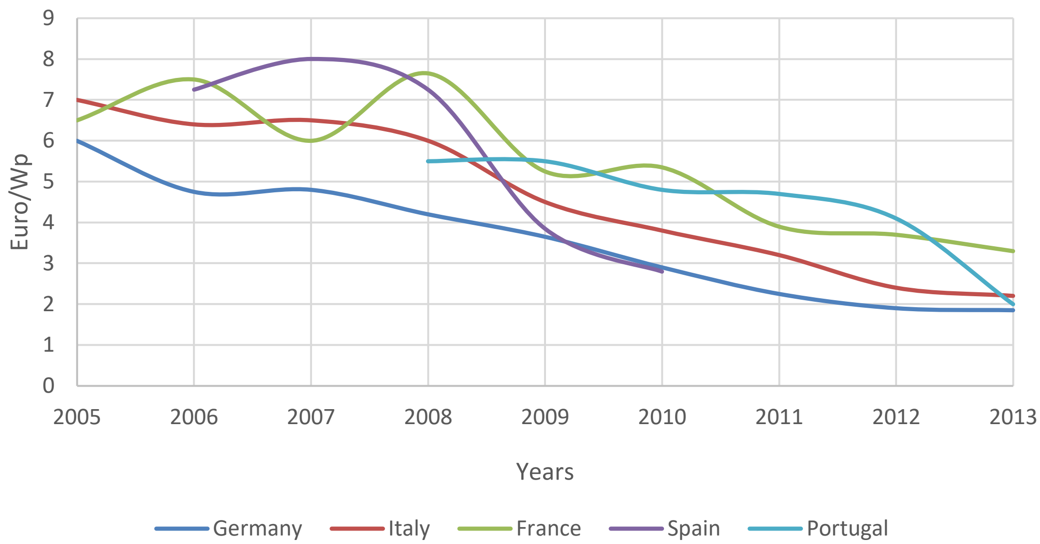

Fig. 3 – Evolution of PV systems prices in selected European countries

A growing important part of the PV market has been formed by Rooftop or Building Integrated PV (BIPV). This segment is important for deployment of PV because of two reasons: no additional space is required because the panels are mounted on existing or newly build structures and the energy is consumed locally reducing distributional losses and the need for network upgrades. The idea that PV producers could be considered as *prosumers* – both producers and consumers of energy – has been evolving rapidly and policies have been adapted accordingly in several countries. Net-metering policies have been considered in some countries such as, Denmark, Netherlands, Portugal, Sweden and Belgium and many countries are introducing a variant through self-consumption (IEA-PVPS 2015).

This paper presents a comparative assessment of the expected economic benefits of grid-connected residential and small business PV systems. Case studies from Portugal, Spain, Italy, France and Greece are taken as examples, as these counties have similar levels of the solar resource and customers demand but some differences in electricity prices and financial support mechanisms.

2. SUPPORTING STRATEGIES FOR PV SYSTEMS

The development of the PV sector in the last decade has been fuelled by the implementation of various supporting strategies, reducing the gap between the PV energy cost and the cost of energy for conventional generation. Different forms of financing have been put into force for PV systems in the last decade: capital subsidies, VAT reduction, tax credits, net-metering, feed-in tariffs (FiTs), etc.

2.1. PV supporting policies

PV is by nature a technology with limited maintenance costs, no fuel costs but a high upfront investment need in the earlier years. This has led some countries to put in place policies that reduce that up-front investment in order to incentivize PV. Capital subsidies, VAT reductions and tax credits are part of the government expenditures and are limited by their capacity to free enough money.

FiTs have been the most widespread support mechanism adopted all over the world. A FiT's value represents the full price received by an independent producer for any kWh of electric energy produced and injected into the grid by a RES-based system under a long-term contract between RES producers and the electric utility company, based on the generation cost of each technology. Under a FiT, utilities are obliged to purchase the energy produced from RES, paying a tariff established by public authorities and guaranteed for a fixed period. The FiT rate is determined by each country based on investment and maintenance costs. FiT is a very simple instrument to develop PV technology, but it needs to be fine-tuned on a regular basis in order to avoid uncontrolled market development. The subsidy component costs of FITs are normally spread among tax payers and/or electricity users; economic efficiency is thus central to their design (IEA-PVPS 2013).

2.2. Electricity Compensation Schemes

Various schemes exist that allow compensating electricity consumption and the PV electricity production, some compensate real energy flows, while others are compensating financial flows.

Traditional self-consumption systems assume that the electricity produced by a PV system should be consumed immediately or within a 15 minutes timeframe in order to be compensated. The PV electricity not self-consumed is injected into the grid. Several ways to value this excess electricity exist today (IEA PVPS 2015):

- The lowest remuneration is 0: excess PV electricity is not paid while injected;
- Excess electricity gets the electricity market price, with or without a bonus (Germany);
- A FiT remunerates the excess electricity (Germany, Italy) at a pre-defined price. Depending on the country, this tariff can be lower or higher than the retail price of electricity.
- Price of retail electricity (net-metering), sometimes with additional incentives or additional taxes (Belgium, USA).

A net-metering system allows energy compensation to occur during a longer period of time, ranging from one month to several years, sometimes with the ability to transfer the surplus of consumption or production to the next month(s).

2.3. PV markets evolution

The incentives towards micro-generation started strongly in 2008/9. Table 1 shows details of the initial purchased conditions for PV electricity in some European countries (L.M. Ayompe n, A.Duffy, 2013). Thanks to the declining cost of PV technology, several countries are starting to put in place rules allowing local consumption of the RES electricity produced. In 2014, the cost of producing electricity from PV (LCOE) continued to drop to levels that are, in some countries, below the retail price of electricity.

Table 1 – Micro-generation FiTs in years 2008/09 in some south European countries

Country	Guarantee period years	Year of implement.	PV Capacity kWp	Feed In Tariffs cents/kWh		
				Rooftop	Ground-based	Build integrated
Italy	20	2008	1-3/3-20	44/42	40/38	49/46
Spain	25	2009	≤ 10	34	32	
Greece	10	2008	<100	45.3		
Portugal	15	2008	≤ 3.7	65		

The Spanish government has suspended all incentives for PV systems in response to the current financial situation, PV generators up to 10kW have to pay for the net assess and receive nothing for the exported electricity (RD 900/2015).

In Portugal, in the end of 2014 a new legal framework was set to incentivize self-consumption and the electricity exported to the grid should be paid to the PV generator at a 90% of the monthly average Iberian Electricity Market (IEM) price and no net assess fees are charged until 3% of total power is achieved (DL 153/2014). In Italy and in Greece installations bellow 20kW pay no charges and receive the pool price for the exported electricity (Hellenic Association of Photovoltaic Companies, 2015). In France, in the end of 2014, the PV roof top tariffs were 0.0736 €/kWh for installations less than 12 MW (EPEXSPOT).

3. METHODOLOGY

In this section, self-consumption and related economic metrics are formally defined as well as input data and PV system modelling.

3.1.PV energy generation modelling and simulation

The amount of energy produced by the PV modules is determined by developing a mathematical model of the PV array allowing the determination of the extracted electrical energy as a function of the solar radiation and the ambient air temperature.

PV modules are commonly characterized by their *Wp* (Watt-peak) equivalent, being a measure of the nominal power of the PV module by determining the current and voltage while varying the resistance under defined laboratory illumination, at 1 kW/m² and 25°C. This peak power value serves a reference and is given per m² area of the PV module. A PV module characteristics is made under STC, the standard temperature and radiation conditions (radiation of 1000 W/m^2, and cell temperature of 25ºC). Short circuit current, I^r_{sc}, maximum power current I^r_{mp}, open circuit voltage V^r_{oc} and maximum power voltage V^r_{mp} are standard values available in manufacturer's catalogues. The annual total of global irradiation, *G*, that hits the module, is specific for each location.

The model starts to compute the constant parameters:

Thermal voltage, V_T under STC

$$V_T = \frac{KT}{q} \qquad (V) \tag{1}$$

Where K is the Boltzman's constant (1.38 x 10^{-23} J/K), T, the cell absolute temperature in Kelvin (0 ºC = 273.16 K) and q, the electron charge (1.6 x 10^{-19} C).
The cell's ideality factor, m (ideal cell m=1, real cell m>1)

$$m = \frac{V_{mp}^r - V_{oc}^r}{V_T^r \, ln\left(1 - \frac{I_{mp}^r}{I_{sc}^r}\right)} \tag{2}$$

The maximum inverse saturation current under STC,

$$I_0^r = \frac{I_{sc}^r}{\left(e^{\frac{V_{oc}^r}{mV_T^r}} - 1\right)} \qquad (A) \tag{3}$$

The short circuit current, considering a linear function of radiation

$$I_{sc} = I_{sc}^r \frac{G}{G^r} \qquad (A) \tag{4}$$

The parameters that depend on the cell temperature

$$I_0 = I_0^r \left(\frac{T}{T^r}\right)^3 e^{\frac{\varepsilon}{m'}\left(\frac{1}{V_T^r} - \frac{1}{V_T}\right)} \qquad (A) \tag{5}$$

Where ε is the silicon energy gap (ε*=1.12 eV*) and m', the equivalent ideality factor.
The cell temperature T must be computed in each condition of radiation and air temperature

$$T = \theta_c + 273.16 \qquad (K) \tag{6}$$

$$\theta_c = \theta_a + \frac{G(NOCT - 20)}{800} \quad {}^\circ C \tag{7}$$

where θ_a is the ambient temperature (^oC); G the solar radiation (W/m^2); *NOCT* the normal operation cell temperature ($NOCT = 45^\circ C \pm 2^\circ$), it represents the temperature of a cell at $G=800\ W/m^2$ of $\theta_a = 20^\circ C$ ambient temperature.

There is a non-linear relationship between the voltage (V) and the current (I) at the terminals of the PV array,

$$I = I_{sc} - I_0\left(e^{\frac{V}{mV_T}} - 1\right) \qquad (A) \tag{8}$$

The power generated in DC can be computed by

$$P = V \times I = V\left[I_{sc} - I_0\left(e^{\frac{V}{mV_T}} - 1\right)\right] \qquad (W) \tag{9}$$

The relation between voltage and power is also non-linear and a maximum power point can be detected. This maximum power point voltage can be analytically computed by *dP/dV=0* and solved by implicit equation 10.

$$I_{sc} - I_0\left(e^{\frac{V_{mp}}{mV_T}} - 1\right) - \frac{V_{mp}I_0}{mV_T}e^{\frac{V_{mp}}{mV_T}} = 0 \quad (10)$$

Current at maximum power point using equation 8, with $V=V_{mp}$ and $I=I_{mp}$
Maximum DC power

$$P_{mp} = V_{mp} \times I_{mp} \qquad (W) \quad (11)$$

The AC output power is computed considering the inverter and MPPT (Maximum Power Point Tracker) performances

$$P_{ac} = P_{mp} \times \eta_{inv+MPPT} \qquad (W) \quad (12)$$

3.2. Solar regional data base and location selection

In this research PVGIS climate-SAF was used as reference solar database for the selected countries. (PVGIS). The main parameters influencing the PV system energy output in a specific location are the irradiation and air temperature. The annual Direct Normal Irradiation (DNI) for a fixed orientation of 35º for the PV modules in each of the selected places varies from 1350kWh/m^2 in the north of France to 2180kWh/m^2 in the south of Spain. In each country, 3 different sites were chosen (north centre and south) and aggregated information was computed for a 1kW of PV modules installed and is described in table 2.

Table 2 – Annual DNI at 35% inclination and full load hours in the selected location

Country	City	Latitude	DNI (35%) kWh/m2	Annual full load hours
France	Paris	48°51'23" N	1370	1030
	Lyon	45°45'50" N	1540	1160
	Marseille	43°17'47" N	1940	1470
Italy	Milan	45°27'55" N	1680	1270
	Rome	41°54'10" N	1930	1440
	Sicilia	37°35'59" N	2060	1550
Greece	Salonica	40°38'24" N	1940	1460
	Athens	37°59'2" N	2090	1570
	Heraklion	35°20'19" N	2100	1570
Spain	Bilbau	43°15'45" N	1490	1130
	Madrid	40°25'0" N	2070	1560
	Sevilla	37°23'20" N	2180	1600
Portugal	Oporto	41°9'28" N	2000	1490
	Lisbon	38°43'20" N	2020	1500
	Beja	38°0'55" N	2150	1580

For self-consumption computation the hourly DNI data in each site is used in conjunction with local hourly temperature to hourly PV energy generation simulation.

3.3. *Prosumers* annual PV generation and energy balance

Fig. 4 shows a schematic outline of the power profiles of on-site PV generation and power consumption. The area A+B is the total energy demand and the area B+C is the total PV energy generated. Self-consumption is thus the self-consumed part relative to total production.

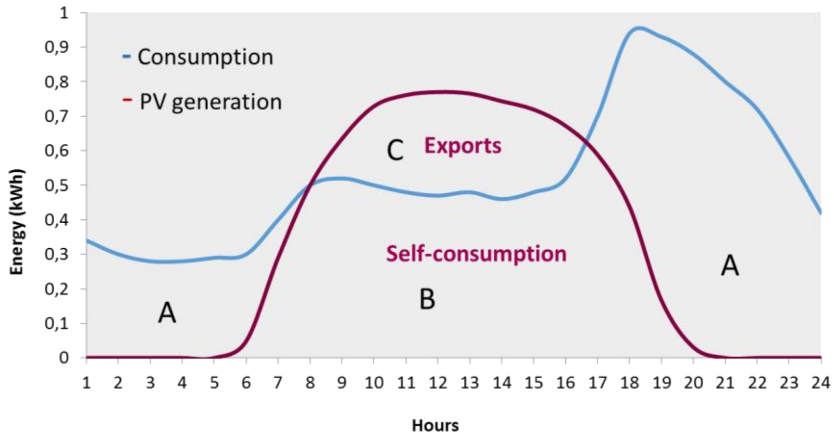

Fig. 4 – Schematic outline of a daily energy balance of a residential PV *prosumer*

$$self - consumption = \frac{B}{B+C} \tag{13}$$

The self-consumed part relative to total load is also a computed metric named self-sufficiency.

$$self - sufficiency = \frac{B}{A+B} \tag{14}$$

More formally, let *L(t)* the instantaneous building power consumption, *P(t)* the instantaneous PV power generation. The power generation used on site is

$$M(t) = min\{L(t), P(t)\} \tag{15}$$

Self-consumption and self-sufficiency are defined as

$$\varphi_{SC} = \frac{\int_{t=t1}^{t2} M(t)dt}{\int_{t=t1}^{t2} P(t)dt} \tag{16}$$

$$\varphi_{SS} = \frac{\int_{t=t1}^{t2} M(t)dt}{\int_{t=t1}^{t2} L(t)dt} \tag{17}$$

3.4. Economic Assessment

For a PV *prosumer* there are two kinds of benefits: The energy savings due to self-consumption and the revenues due to the surplus energy produced and exported to the grid. The costs associated are mainly investment costs in the PV system, although in some cases it could be considered annual operation and maintenance costs and costs associated with the use of the electric networks that depend on the PV power installed. The generation costs of any electricity plant are computed using the *LCOE* (Levelized Cost of Electricity). The *LCOE* is defined as the cost assigned to every unit of energy produced by the system over the lifetime period,

$$LCOE = \frac{I_a + o\&m}{E_a} \tag{18}$$

where I_a is the annualized capital cost of the plant, *o&m*, are the annual operating and maintenance costs and E_a the expected annual energy generated.

$$I_a = \frac{I}{k_a} \quad (18)$$

where *I* is the total initial investment and k_a the annuity factor.

$$k_a = \frac{1}{r} - \frac{1}{r(1+r)^n} \tag{19}$$

where *r* is the discount factor (assumed to be constant) and *n* is the economic life of the plant.

If the *prosumer* was paid at the same retailer price of the electricity he/she consumes, the *prosumer* profits could be easily computed by the difference between retailer electricity price (*RP*) and *LCOE* and the *NPV* as equation 20

$$NPV = (RP - LCOE) \cdot E_a \cdot k_a \tag{20}$$

Under different values of *RP* and PV sales price (*SP*), and considering the percentage of self-consumption, φ_{SC}, the *NPV* should be computed as in equation 21

$$NPV = \left(RP - \frac{LCOE}{\varphi_{SC}}\right) \cdot E_a \cdot \varphi_{SC} \cdot k_a + SP \cdot E_a(1 - \varphi_{SC}) \cdot k_a \tag{21}$$

The first term represents the savings along the system life cycle due to self-consumption and the second term represents the revenues due to the surplus energy sold to the grid.

4. RESULTS AND DISCUSSION

Location has a great effect on PV energy production, but the cost of PV systems, retail electricity prices, export electricity tariff and the percentage of self-consumption define in conjunction with PV generation, the level of economic benefits of PV *prosumers*. Table 3 summarises the main results of each of the selected countries. For Italy, due to high retailer electricity prices and low investment costs on PV systems, with less than 50% self-consumption the project's NPV becomes positive, while on the other side, France with low retailer prices and high PV investment costs, the LCOE for PV is higher than retailer prices (PV investments should be less than 2200€/kW in the south and at least 90% of self-consumption).

Table 3 – Summary of expected results for minimum self-consumption level

Country	France	Italy	Greece	Spain	Portugal
Project life time (n)	25				
Discount rate % (r)	6				
Capital Cost (€/kW)	3000	1750	2000	2200	2500
Annual O&M costs (€/Wh)	a)				
Electricity price (€/kWh) b)	0,1384	0,2227	0,1564	0,1908	0,1856
Export tariff (€/kWh) c) – f)	0,048	0,0558	0,0523	0	0,0432
PV generation (kWh/kW)	1030	1270	1460	1130	1490
	1470	1550	1570	1600	1580
LCOE (€/kWh)	0,228	0,108	0,107	0,152	0,131
	0,160	0,088	0,100	0,108	0,124
Min Self-consumption (%)	-	48	69	80	75
	-	40	64	57	68

a) O&M costs were neglected in this analysis b) (Eurostat 2015) c) (OMIE 2015) d) (GME 2015) e) (PV-tech) f) (Hellenic operator of electricity market, 2015)

Residential consumption usually peaks at 8am and 8pm while PV production is at its highest between 10 am and 3 pm, and under these conditions it is difficult to attain a high level of self-consumption so the majority of the energy produced will be exported to the grid instead of self-consumed unless the PV power installed is very low. Fig. 5 shows how NPV and IRR with self-consumption and self-sufficiency evolve with the PV power installed.

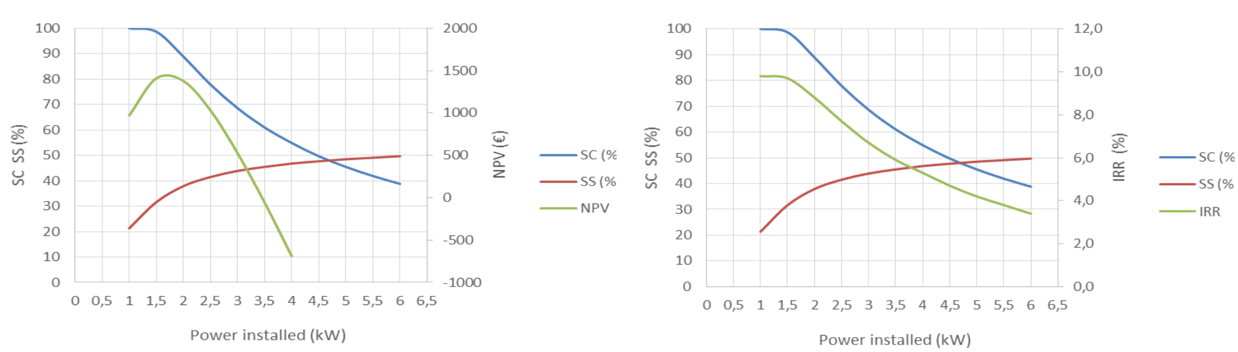

Fig. 5 – Evolution of NPV, IRR, SC and SS with PV power installed regarding a typical load profile of a *prosumer* in the south of Portugal

In this case, NPV is maximum at 95% of self-consumption which is attained at 1.75kW of power installed.

Several simulations were made in different sites and with different consumer types. Fig 6 represents an example of the typical load diagrams for a residential and a commercial *prosumer* considering the power installed for the NPV maximization. The optimal power installed for a commercial customer is much higher than for a residential. In this case self-sufficiency is 48% for a commercial client and for a residential only 31%.

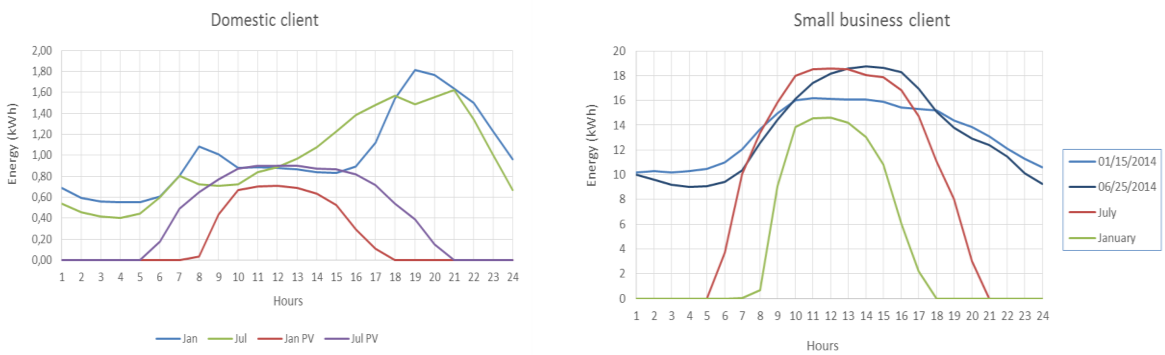

Fig. 6 – Typical winter and summer load and production profiles for domestic and commercial customers

The coincidence between consumption and PV generation is thus one of the major factors that make the PV investment the best economic and environmental solution. Load shifting measures could help in increasing self-consumption level for residential customers allowing more PV power installation.

5. CONCLUSIONS

The expected economic gains for a PV *prosumer* depend on many factors: location, PV system prices, retailer electricity prices, national policies and load/production adequacy. A location with high radiation, cheap PV systems, high retailer electricity costs and governmental policies that do not penalise PV producers with net access costs is the best combination for maximizing *prosumers* NPV especially if the consumer power follows the PV generation increasing PV power and self-sufficiency. A residential customer installing a grid-connected PV system, is paid for the exported electricity less than 5 c€/kWh (or nothing) by the electricity provider while charging about 18c€/kWh for the same kWh. At this exchange rate it is obviously more economical to consume than to export. In fact NPV maximizes at a 95% of self-consumption in the best case studies which usually is attained with small percentage of self-sufficiency and low power installed. With further increase of retail electricity prices and decrease of PV costs the business case for storage may become economically interesting for residential customers with the advantage of increasing self-sufficiency and decreasing even more electricity demand for the centralized power systems.

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