ASSESSMENT OF THE PV SELF-CONSUMPTION IMPACT ON THE PORTUGUESE SCENARIO WITHIN THE EUROPEAN ENERGY LEGISLATIVE SCHEME

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Abstract

Founded on the emerging new energy paradigm, which places decentralized renewable energy (RE) production as the core and engine of the XXIst century energy revolution, the purview of this work is to delve into how RE decentralization in Portugal would evolve by means of self-consumption (SC). For this study, it has been taken into account current legislative progress, assuming solar photovoltaics (PV) as the most convenient and plausible technology to be applied. Thus, it has been evaluated the adequacy and impact of real demand profiles of residential, retail, hotel and industrial sectors to simulated solar PV production profiles of different locations, orientations and inclinations. In order to assess the optimum *prosumer* (producer and consumer) profile, which would impact subsequently on the SC rate of adoption, a techno-economic performance analysis using payback time and interest rate of investment as reference metrics, has been realized. Furthermore, solar technology has been appraised and the European market and the legislative energy strategies evolution has been revised in order to provide a comprehensive framework for the study.

Keywords: Self-consumption, Electricity Demand, Solar Photovoltaics, Renewable Energy Sources

1. Introduction

Consumer's side is being the core of energy systems transition and development, in order to increase energy efficiency and security of supply, with the use of endogenous resources. With that in mind, using renewable resources for self-consumption is spreading all over Europe, supported by different national policies, either on small or large scale generation. In this is way the consumer is no longer a passive agent, becoming a *prosumer*: an active consumer and producer [1], [2].

However, besides self-consumption brings economic benefits for the end user (prosumer), the implications of large deployment of self-consumption technologies are yet to be deepen.

Most of energy balances analysis are taken with synthetized profiles or average demand profiles, not representing effectively the natural demand dynamics of a single consumer, either residential or industrial. In this way there is still a lack of knowledge on the real balance between production and demand at the consumer's level and its impact, either economic (for the consumer) or energetic (for the grid). While normally optimal tilt and azimuths are considered, in many cases the implementation of these systems are dependent on available area, orientation and angle of roofs. This fact may lead to a different profile of solar production for self-consumption systems. Also the optimum sizing of self-consumption systems can differ according to the energy excess policy or consumer's family typology.

Therefore, the scientific contribution of this study, framed into a technological and legislative review, deepens the knowledge on:

- Adequacy of real demand profiles with self-consumption policies.
- Impact of different orientations and inclinations on the balance of prosumers.

The study is organized as follows: Section 2 provides a frame for this study, Section 3 explains the methodology of the study, Section 4 presents the results and discussion, while in Section 5 are made the final statements and possible future work.

2. Literature review framework

2.1 European energy legislation introduction

Since 1990 and maybe even before, Europe has intended to quickly rise the proportion of native energy employing zero-carbon resources, stablishing new industries, banking on clean technologies and confronting the energy framework with a more distributed energy model [3].

This leading movement has been guided by concerns over climate change, as revealed in the Earth Summit in Rio of 1992 and the negotiation of the United Nations Framework Convention on Climate Change (UNFCCC), but also by the indelible memories of the 1970's oil price crisis, which affected many EU economies by cause of their large dependence on fossil fuel (FF) imports. The main milestones for Climate change fight in Europe were the compliance of these events:

- The Kyoto Protocol, where Europe committed to cut emissions from 2008-2012 to at least 5.2% below 1990 levels (overachieved, 18% [4],[5])

The European Union 2020 climate and energy package made three objectives compulsory and pooled for all Member States to be reached by 2020:

- Lowering greenhouse gases (GHGs) emissions in a share of 20% compared to 1990.
- Reduction in primary energy consumption in a share of 20%.
- 20% of RE in final energetic gross consumption.

The fundamental pillars for EU's willingness to decarbonize its economy through climate legislation are the EU Emissions Trading System (EU ETS) and Effort Sharing Decisions (ESD).

- EU ETS is architected to cap emissions from large installations in the power and industrial sectors, rights to emit GHGs, and market for trading allowances.
- ESD sets emissions reductions targets for the sectors not covered by the EU ETS.

Besides, there is an ample diversity of bonus for distributed renewable generation:

- Feed-in Tariff is a remuneration mechanism that consists in selling the electricity produced at a higher rate than the electricity market.
- Feed-in Premiums (FIP) provide bonus payment on top of the electricity market price.
- Quota obligation establish the amount or proportion of renewable electricity that must be produced, consumed or supplied in a given year.

However, now that distributed renewable production has a more than a decade, its incentives are decreasing and competing in market-based auctions, like conventional energy sources, is the new tendency for RE to reach grid parity and to assure a cost-effective future for the electricity market [6]. In fact, this mechanism will be adopted after 2017 by the whole EU, endeavoring a wide harmonization by the use of competitive market tools for dissimilar programs.

Electricity Directive 2009/72/EC undertakes several grid-related regulations. Associate states have to guarantee that national Transmission System Operators (TSO[1]s) and distribution system operators (DSOs) ensure transmission and distribution of RES-E. The directive specifies several technical actions to be applied in the grid [8]:

- With Priority connection, Member states are required to grant preference communication to REs generators.
- Priority dispatch means that before dispatching electricity from other plants, electricity from REs has to be expedited.
- Through Priority access, RE installations can sell and transmit their generated energy whenever the source is available in accordance with the connection procedures.
- The assurance that the maximum amount of electricity from REs sold will obtain access to the grid, is pledged to guarantee access.

In order to ensure security of supply whilst energy transition, capacity markets were created. These are based on fixed payments to electricity generators to deliver (or being ready to deliver) a certain power when needed in order to assure backup for intermittent low carbon sources. There is a wide menu of mechanisms within capacity markets.

- Capacity payments are permanent or variable wages given to all or part of the qualified capacity declared or available.

[1] "Natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity"[7].

- The capacity obligation regime is characterized by the fact that each supplier contracts an advanced load of his customer´s portfolio and a predesignated security margin.
- In the strategic reserve mechanism, an autonomous agent (normally the TSO) tenders or contracts peak load.
- UK is pioneering the auction model for 2018-19 capacity production to backup capacity.

2.2 PV deployment

In 2013, Solar Photovoltaic energy represented 0.87% of the global electricity generation worldwide in 2013, sustaining a compound annual growth rate in cumulative installed capacity of 43% since 2000 [9]. Between 2000 and 2014, global grid-connected PV capacity grew from 1.3 to 139 GWp. In fact, it is expected to play a major role in the global energy system by mid-century. In one of the most plausible energy scenarios drew by the International Energy Agency (IEA) [10], global demand of electricity rises by 79% between 2011 and 2050, being in 2050, 27% of it assured by solar. Within this scenario, 16% of global electricity is projected to be generated by PV and 11% by concentrated solar power (CSP)[11, p. 21].

The singularities that confer PV an added value are its capacity to operate at ambient temperature, with no moving parts and its modularity. This last characteristic grants that its electric power conversion efficiency is not influenced by scale, albeit cost per unit of generating capacity is lower for utility-scale installations than for residential systems as a result of balance-of-system (BOS) costs, contrary to other generation pathways such as thermal generator or wind turbines [10].

2.3 Self-Consumption in Portugal

Prosumer figure sprung forth the Decree-law 68/2002, underpinning a local and decentralized archetype of energy generation. From this point, an assortment of regulated regimes succeed one another from microgeneration and minigeneration to SC, mainly promoted through incentive programs based and PV specific legislation.

During 2014, national on FITs Renewable energy subsidies for micro and mini generation were rectified and unified into a sole category called small production units (UPP) regulated by the Decree Law 153/2014. UPP facilitates the installation of renewable utilities with a capacity up to 250 kW, and an annual cap limit of 20 MW for grid-connected installations supplanting the remuneration regime heretofore applicable to micro and mini units.

Decree Law 153/2014 also defines the Self-consumption Units (UPAC), where the opportunity of self-consuming and trading the spare energy to the public electricity grid is finally legally conceived [12].

The essential variation has been the change of paradigm to a more rational maximization of local produced energy, with a more direct and subsidy-free market structure. Besides, the decree safeguards the electric system by a compensation provision once the penetration of SC reaches the 1% of the installed capacity.

The SC program sets up a limit of installed capacity according to the contracted power. Therefore an accurate plant scaling is required to size the system to the yearly demand. The surplus is allocated to the provider of last resort (POLR) and the price is tabulated to the 90% of the value of the simple arithmetic mean of the Iberian spot market operator (OMIE) on monthly basis. The reason why 10% is retained, is to compensate for the energy trading costs and the guarantee purchase. The new remuneration mechanism is founded on a bidding model where each generator proposes discounts to a benchmark tariff, which is arranged annually by the authorities depending on the technology utilized. Nevertheless, the former FITs would remain valid for the existing systems during the statutory period [12]. SC was *de facto* promulgate in March 2015.

3. Methodology

3.1 Demand

One of the key defiance SC presents is the level of complementarity or synchronization of the production and demand profiles. This fact is a challenge for SC valorization, since the way the excess energy is counted and remunerated will limit its economic viability.

To define representative demand profiles, four categories have been created corresponding to the main sectors: residential (Demand1, Demand2 and Demand3), which held the 27% share of the electric national consumption in 2014, tertiary sector of economy encompassing retail profiles (Retail1, Retail2, Retail3, Retail4), accommodation service profiles (Hotel1, Hotel2, Hotel3) and industrial profiles (Industry1, Industry2, Industry3, Industry4). The demand profiles were accessed from an ongoing Project OTGEN [13].

For the residential sector, three specific and individualized profiles, extracted from an every-15minutes data during two years of consumption, are representative of a relevant diversity of economic and power purchase types of clients. Given tertiary and industrial sector profiles are the result of a clustering based on the approximate maximum hourly daily average demand (KWh) and the similarities on the hourly average daily pattern obtained from the annual profile data.

These real profiles are representative of a relevant diversity of economic, demand-routine and power purchase types of clients as portrayed in Figure 1, Figure 2, Figure 3 and Figure 4.

At the retail profiles, it could be anticipated that the SC synchronicity would be better than for the residential case, since the loads are better fit to the solar generation, where there is a constant demand during the working days with night and weekends absence.

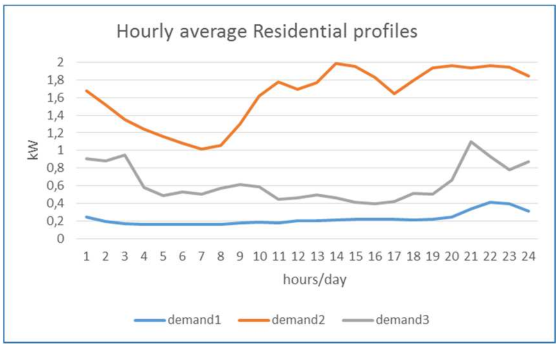

Figure 1. Hourly average Residential profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

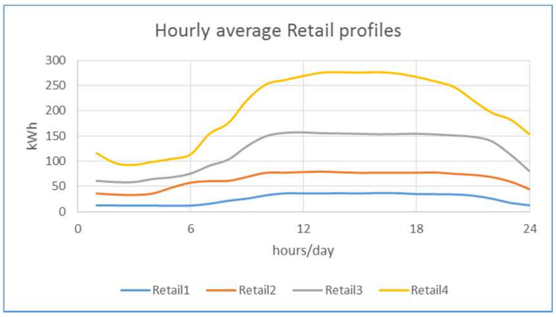

Figure 2. Hourly average Retail profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

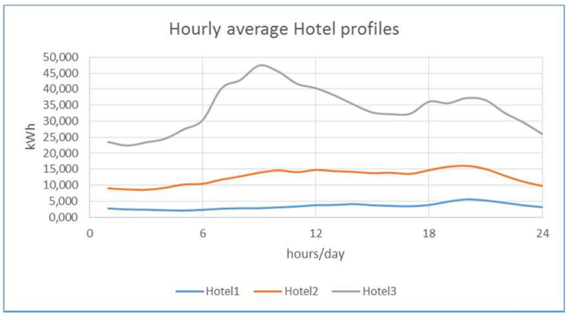

Figure 3. Hourly average Accommodation profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

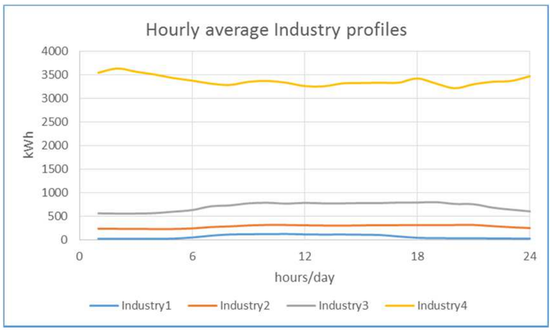

Figure 4. Hourly average Industrial profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

In the hotel industry, demand follows a diary cycle, perceiving an increase of consumption during weekends and holidays, as supposed for a spare-time service.

Industry could be the sector where aggregation is more difficult to epitomize. Generally, Industry retains a weekly profile, during working days, where the utilization is regular and very low during weekends.

3.2 Production

The production profiles have been built with the PV software *PVSYST V5.54*. The type of solar panel employed has been a 250W polycrystalline panel; built by the manufacturer *SolarWorld AG* being the model *Sunmodule Plus SW 250 poly*. The efficiency per module area is 15.18%.

The choice of sc-Si panels owes to the unrestrictive are basis, Portuguese mild meteorology (which allows to operate with practically all commercial technologies available) and a moderate budget assumption (sc-Si is more affordable than mono-Si).

The simulation encompasses a wide range of capacities, from low residential demand to massive industries. Hence it has been utilized two types of inverters. A microinverter of 250W (Inverter´s brand: *Enphase* and model *M250-60-208-S22/S24*) and a bigger inverter of 20kW (*Brand: Steca and model StecaGrid 20000).*

Twenty seven PV production profiles per inverter (fifty four in total) have been therefore created, in regard to:

- Three different locations: Lisbon, Porto and Faro

- Three PV panels' inclinations, 10º, 20º, 30º

- Three PV panels' orientations: South (S), Southwest (SW), Southeast (SE).

The hourly based power (kW) results were exclusively calculated at the inverter output.

3.3 Sizing of Self-consumption systems

With the goal of assessing the segments with the highest adoption potential, defined by the number of adopters and installed capacity, a series of profiles and analyses have been realized. Demand and generation profiles are compared with each other to determine exportation and SC profiles. For residential and Hotel1, 0.25kW inverter profiles are employed whilst for Retail, Industry, Hotel2 and Hotel3, 20kW inverter. The techno-economic assessment takes into account the valorization of the exported and self-consumed energy expressed into economic and energy indicators. The scenario presumed has a SC penetration lower than 1%, to avoid grid compensation as disposed in the legislation, Decree Law 153/2014.

The economic indicators utilized to represent PV performance and size the SC systems are:

The internal rate of return (IRR) which performs as the discount rate at which the present net present value (NPV[2]) equals zero and is commonly interpreted as the annualized return on investment. IRR is useful for comparing the returns on two or more investment opportunities [14].

$$IRR: NPV = \sum_{t=0}^{N} \frac{Revenue_t - Cost_t}{(1+IRR)^t} = 0 \qquad (1)$$

N: number of years for the economic analysis

t: year variable in each summation

$Revenue_t$: revenue generated by the SC system in year t

$Cost_t$: cost of the system in year t

And the Payback time (PBT), being the length required for the PV SC investment to pay for itself through solar energy savings. The energy bill savings from solar represent an avoided cost, and therefore gives money back to the prosumer, as revenue.

$$\sum_{t=0}^{PBT} Revenue_t - Cost_t = 0 \qquad (2)$$

In essence, the election of the economic performance metrics by each prosumer sector can quite shape the customer's perception of PV investment value and eventually their adoption decision.

One of the most relevant decisions is to attribute correctly the optimum installed power for each demand profile. Apart from the simulated 0.25kW and 20kW inverters, it is employed a 10kW model (divisor from the 20kW inverter). It has been created an optimization criteria/metrics as exposed in the ensuing Table 1.

Table 1. Optimization criteria for the correct number of inverters according to each demand profile.

Metrics	Residential	Retail	Hotels	Industry
PBT (years)	<13	<7	<7	<7
Energy surplus (%)	<10	<20	<10	<20
IRR (%)	Better IRR for 25 years			

The PBT of residential is assumed to be longer than for the other demand profiles given the impossibility to opt with reduce consumption for an economy of scale.

The maximum energy surplus accepted varies depending on the project dimensions. For substantial demands, as it is typically the case of retail and industry more energy excess is accepted because any production-consumption mismatching can account for a massive feed back into the grid and therefore a higher percentage. Anyhow, 20% of energy exported would be the limit.

There are particular project parameters, which are adopted according to demand profiles, impact PV economic performance metrics:

[2] NPV represents the net profit generated by an investment, calculated from the discounted sum of future costs and revenues.

PV Prices. PV project investment expenditure per unit of capacity (€/$Wp_{installed}$) is principally driven by installation size and type. Large SC projects are significantly cheaper per unit of installed capacity than smaller ones, based on unavoidable fixed costs, generating an economy of scale. As a result a monetary factor is applied to calculate the investment per W_{peak} installed as presented in Table 2. It is estimated a 2.8% of electricity price annual increase [15].

Table 2. Summary of the monetary factor per $Wp_{installed}$ depending on the range of installed capacity (kW

Monetary factor €/Wp installed	Range of Installed Capacity, IC, (kW)
2.0	1.5 > IC
1.7	1.5 ≤ IC < 5
1.5	5 ≤ IC < 20
1.2	20 ≤ IC < 100
1.1	100 ≤ IC < 150
1.0	150 ≤ IC

The aging of the solar panels affects performance. The rated power output of polycrystalline solar panels employed is considerate that degrades at about 0.8%/year [15]. Aging rate and electricity inflation are calculated on the original principal only. Accumulated rate from each year is not used in calculations for the following periods.

The European Energy Taxation Directive 2003/96 [16] came into force in 2003, setting a minimum level of taxation for energy products. It was not until the Troika, applying the Portuguese Bailout program imposed to enact this directive by the Special electricity consumption tax (IEC) through the law 64-B/2011. All suppliers were obligated to charge 0,001€/kWh to all clients but the social tariff holders [17].

To assess accurately the annual energy savings for the prosumer is necessary to fully itemize and resolve which would be the most likely energy tariff or tariffs to be assigned to each demand profile constituting one of the most relevant parts for the execution of this study. Hourly PV generation monetization accounts for the seasonal and daily variations in electricity value based on electricity prices in wholesale markets or different retail electricity rate structures as the one implemented here, which is the time-of-use rate based on time of day and season. Other options might be available like demand-based/ time-based rates formed on peak customer power use, or tiered rates based on total energy use. Intervening factors on the electricity rate and how this is adjusted to each scenario, are described next.

1. Within each Voltage contracted, it can be found time-based pricing, varying the rate depending on the time of the day when the energy is provided: can be simple (same cost 24h) or time-of-use (TOU), allowing to be dual, or tri according to the contracted power. Also it can be daily or weekly cycle.

Time of Day tariff is performed to cut down consumption of electricity during peak hours. To do this, electricity prices are raised during peak hours so that consumers have lower demand. Higher loads entail a higher hourly discretization. The more discretized is a tariff thought out the day, the more feasible is for prosumers to actively manage their demand, being translated in an improvement of the cost-effectiveness of the installation by switching demand to a time when prices are lower or by using efficient appliances.

2. Apart from the regular tariff, it can be find an extraordinary peak contracted charge, only for relevant loads, which exclude LV.

3. Contracted voltage determine the power costs (fixed tariff per day) and the energy costs (tariff per kWh consumed).

4. The energy supplier choice is as well an important parameter for the electricity value.

As the market is liberalized, each SC unit must embrace a certain operator. In the case of the study the tariff EDP “*casa com débido direito*” [18] for LV is selected. Medium voltage prices, are always negotiated with the energy provider, therefore tailored depending on consumption. In this particular case, rates are gleaned from a real industrial case. For retail calculous 5% over the active energy price is exercised, since it is presumed that the higher is the use, a better deal is obtained.

For special low voltage (consumers in LV with high contracted powers <100 kW), as real data is not accessible, the transitory active energy price available online [19] is adapted by reducing 10% its price.

For SLV there is a medium utilization regime (300h of full pricing/month) and a long utilization regime (500h full pricing/month) [20]. Medium usage is applied for the calculation.

4. Results and discussion

Subsequently in Table 3, Table 4, Table 6 and Table 8 are displayed the summary of the best PV economic and energetic indicator results by exercising the optimization criteria for each demand division and location. The first-rate outcome within each city is highlighted. It has been observed a correlation among PBT, IRR and SC energy results, i.e., the best economic figures correspond to the highest SC %. Normally it also coincides with highest surplus percentage (black font color), in which case, it is not the most favorable outcome, since it is translated into potential grid disturbances (if the SC solar penetration rises) and little monetization.

The green font means that there is another orientation/tilt within each demand profile which hold the highest value; e.g. Hotel 1 surplus production in all locations present higher figures for SW compared to the best economically energy self- consumed performing orientation, S.

Red font it has been used to highlight the change of orientation for the optimum PBT and IRR depending on the location (Porto) and tariff (SLV). In Hotel3 and Retail1 Lisbon and Faro share the same orientation for the best IRR (SW), although the maximum value for the self-consumed energy (S) coincides with the optimum economic and energetic indicators or Porto.

Under the information colophon it is compiled the information about the tariff, the power of each inverter, the total installed capacity (breaking capacity) and annual mean power consumption and mean power consumption under irradiation. To a certain extent, some aspects of the outcomes are predictable such as:

- Due to the economy of scale, normally, larger installations obtain better economic performance, with the exception of extremely favorable tariffs as SLV. Antagonistically, energy indicators achieve the lowest figures. This fact responds to the economic indicator calculation base, IRR (25 years), given that to cover a higher percentage of the massive energy consumption for the industrial and in a lower degree the retail sector, an immense capital investment is required, which will not be able to easily amortize, so better results are obtained for little installed capacity.

- Climatically, Faro (in the south of Portugal) is characterized for sunnier and milder weather, therefore it possess favorable conditions for PV deployment and therefore would obtain better results than Lisbon and Porto.

- It can be anticipated that the optimum tilt would be 30, since it is closer to Portuguese latitude and the optimum orientation south, unless the consumption profile subjugates it to a specific morning (SE) or evening (SW) load as presented in Hotel and Retail 1.

- Even if the special tariff obtain from the transitory regime was reduced in order to better adequate to theoretically real one, the results when operation under its pricing are spectacular. The value which is responsible for such as *rara avis* is the levy for peak hours, which in SLV almost doubles the MLV, since peak hours generally corresponds with solar production the bill savings are really high for Retail 1 and Hotel 3.

- Higher discretization between same prosumer profiles as demonstrated in Demand 2 and 3 implies better results.

Apart from the Location, which is the factor with the highest impact on the economic and energetic indicators, it is the orientation, rather than the inclination (except 10º) the aspect more relevant for a better performance. Generally, the hierarchical choice in the absence of a bias demand profile (higher consumption during mornings or evenings) would be S-30 and S-20.

It is important to mention and reflect upon the self-consumed percentage in each sector to prospectively be able to find solutions to satisfy higher demand by means of complementary RES-E or/and storage, implying higher installed capacity. Retail sector presents the highest self-consumed percentage, reaching numbers over 30%, followed by the accommodation sector. In the case of the domestic sector, owing to low demand and deeply uncoupled prosumer profiles, self-consumed energy decreases to 6-20%. In Industrial sector, Self-consumed percentages show truly low figures, barely surpassing the 10% and sometimes presenting higher percentages of exported energy.

Below is detailed the particularities concluded of each demand stratum.

4.1 Residential sector

Only simple and bi-hourly tariff are assigned for residential demands, being bi-hourly rates more financially successful owing to discretization, which provides the opportunity to manage more efficiently households' loads. The consumption of Demand1 is so minimal, that only the smallest

Table 3. Summary of the best results of each residential benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA Tilt	LISBOA Or.	LISBOA PBT	LISBOA IRR (25 years)	LISBOA SC energy (% Total demand)	LISBOA Surplus (% production)	PORTO Tilt	PORTO Or.	PORTO PBT	PORTO IRR (25 years)	PORTO SC energy (% Total demand)	PORTO Surplus (% production)	FARO Tilt	FARO Or.	FARO PBT	FARO IRR (25 years)	FARO SC energy (% Total demand)	FARO Surplus (% production)
Demand1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_S 0.25 1 0.25 0.22 0.20	30	S	8	8.74%	17.62%	5.01%	30	S	8	8.33%	17.19%	5.13%	30	S	7	11.22%	20.00%	7.11%
Demand2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW):	LV_S 0.25 6 1.5	30	S	7	12.21%	15.07%	2.22%	30	S	7	11.87%	14.79%	1.81%	30	S	6	15.15%	17.53%	2.04%
	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_B 0.25 8 2 1.63 1.74	30	S	6	14.00%	19.80%	3.66%	30	S	6	13.56%	19.42%	3.27%	30	S	5	17.17%	22.93%	3.90%
Demand3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW):	LV_S 0.25 1 0.25	30	S	8	9.42%	6.60%	0.16%	30	S	8	9.03%	6.44%	0.19%	30	S	7	12.22%	7.65%	0.25%
	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_B 0.25 1 0.25 0.63 0.47	30	S	7	11.17%			30	S	7	10.69%			30	S	6	14.14%		

possible installed capacity has been calculated (250W), holding the highest surplus among the residential profiles. It is notorious the uncorrelated results of Demand3. In this case, the installed capacity is for first time evidently lower than the mean power consumption entailing quasi no energy fed into the grid. This fact reflects the extremely asymmetry between production and demand, so it would be certainly recommended the installation of some kind of energy storage or V2G system. Tariff applied is not to be underestimated, since it can also modify the optimum installed capacity (for better economic performance), as reflected in Demand2, i.e. the installed capacity of LV_S is 1.5kW and 2kW for LV_B. It is this last one, among residential profiles, which obtains the better economic and energetic results.

Table 4. Summary of the best results of each Hotel benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA Tilt	LISBOA Or.	LISBOA PBT	LISBOA IRR (25 years)	LISBOA SC energy (% Total demand)	LISBOA Surplus (% production)	PORTO Tilt	PORTO Or.	PORTO PBT	PORTO IRR (25 years)	PORTO SC energy (% Total demand)	PORTO Surplus (% production)	FARO Tilt	FARO Or.	FARO PBT	FARO IRR (25 years)	FARO SC energy (% Total demand)	FARO Surplus (% production)
Hotel1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_T 0.25 20 5 3.42 3.60	30	S	6	14.43%	22.83%	6.65%	30	S	6	14.02%	22.42%	6.14%	30	S	5	17.41%	26.07%	8.19%
Hotel2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_T 20 1 20 12.632 14.39	30	S	4	20.46%	27.86%	3.73%	30	S	5	19.49%	26.69%	3.75%	30	S	4	23.57%	31.34%	4.95%
Hotel3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	SLV 20 2 40 33.90 38.48	30	SW	4	24.87%	20.36%	0.73%	30	S	4	23.31%	20.54%	0.63%	30	SW	3	27.68%	22.79%	0.99%

Table 5. Hotel 2 and Hotel 3 comparative chart for LV_T and SLV.

	INFORMATION		LISBOA Tilt	LISBOA Or.	LISBOA PBT	LISBOA IRR (25 years)	LISBOA SC energy (% Total demand)	LISBOA Surplus (% production)	PORTO Tilt	PORTO Or.	PORTO PBT	PORTO IRR (25 years)	PORTO SC energy (% Total demand)	PORTO Surplus (% production)	FARO Tilt	FARO Or.	FARO PBT	FARO IRR (25 years)	FARO SC energy (% Total demand)	FARO Surplus (% production)
Hotel2	Tariff:	LV_T SLV	30	S	4	20.46% 23.87%	27.86%	3.73%	30	S	5 4	19.49% 22.69%	26.69%	3.75%	30	S	4 3	23.57% 26.62%	31.34%	4.95%
Hotel3	Tariff:	LV_T SLV	30	SW	5 4	17.57% 24.87%	21.45%	0.60%	30		5 4	16.91% 23.31%	20.54%	0.63%	30	SW	4 3	19.97% 27.68%	24.38%	0.80%

Table 6. Summary of the best results of each retail benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA Tilt	LISBOA Or.	LISBOA PBT	LISBOA IRR (25 years)	LISBOA SC energy (% Total demand)	LISBOA Surplus (% production)	PORTO Tilt	PORTO Or.	PORTO PBT	PORTO IRR (25 years)	PORTO SC energy (% Total demand)	PORTO Surplus (% production)	FARO Tilt	FARO Or.	FARO PBT	FARO IRR (25 years)	FARO SC energy (% Total demand)	FARO Surplus (% production)
Retail1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	SLV 10 5 50 25.68 34.45	30	SW	4	24.36%	33.16%	2.12%	30	S	4	23.05%	33.39%	2.21%	30	SW	3	27.02%	36.92%	2.87%
Retail2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 10 11 110 63.90 76.65	30	S	5	16.61%	30.90%	1.94%	30	S	6	15.66%	29.64%	1.82%	30	S	5	19.10%	34.86%	2.89%
Retail3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 10 200 120.34 152.26	30	S	5	18.80%	30.17%	0.83%	30	S	5	17.80%	28.90%	0.87%	30	S	4	21.50%	34.19%	1.36%
Retail4	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 18 360 202.54 266.95	30	S	5	18.60%	31.71%	2.55%	30	S	5	17.62%	30.44%	2.38%	30	S	4	21.22%	35.75%	3.57%

Table 7. Comparative chart for Retail1 comparative chart for LV_T and SLV.

	INFORMATION		LISBOA Tilt	LISBOA Or.	LISBOA PBT	LISBOA IRR (25 years)	LISBOA SC energy (% Total demand)	LISBOA Surplus (% production)	PORTO Tilt	PORTO Or.	PORTO PBT	PORTO IRR (25 years)	PORTO SC energy (% Total demand)	PORTO Surplus (% production)	FARO Tilt	FARO Or.	FARO PBT	FARO IRR (25 years)	FARO SC energy (% Total demand)	FARO Surplus (% production)
Retail1	Tariff:	LV_T	30	SW	5	18.72%	33.16%	2.12%	30	S	5	19.75%	33.39%	2.21%	30	SW	4	21.42%	36.92%	2.87%
				S	4	20.65%	34.73%	2.56%								S		23.81%	39.14%	3.60%
		SLV		SW		24.36%	33.16%	2.12%			4	23.05%				SW	3	27.02%	36.92%	2.87%

Table 8. Summary of the best results of each Industrial benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA Tilt	LISBOA Or.	LISBOA PBT	LISBOA IRR (25 years)	LISBOA SC energy (% Total demand)	LISBOA Surplus (% production)	PORTO Tilt	PORTO Or.	PORTO PBT	PORTO IRR (25 years)	PORTO SC energy (% Total demand)	PORTO Surplus (% production)	FARO Tilt	FARO Or.	FARO PBT	FARO IRR (25 years)	FARO SC energy (% Total demand)	FARO Surplus (% production)
Retail1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	SLV 10 5 50 25.68 34.45	30	SW	4	24.36%	33.16%	2.12%	30	S	4	23.05%	33.39%	2.21%	30	SW	3	27.02%	36.92%	2.87%
Retail2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 10 11 110 63.90 76.65	30	S	5	16.61%	30.90%	1.94%	30	S	6	15.66%	29.64%	1.82%	30	S	5	19.10%	34.86%	2.89%
Retail3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 10 200 120.34 152.26	30	S	5	18.80%	30.17%	0.83%	30	S	5	17.80%	28.90%	0.87%	30	S	4	21.50%	34.19%	1.36%
Retail4	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 18 360 202.54 266.95	30	S	5	18.60%	31.71%	2.55%	30	S	5	17.62%	30.44%	2.38%	30	S	4	21.22%	35.75%	3.57%

4.2 Accommodation sector

Hotel1 profile is not homogeneous along the year, daily load presents unevenness, plus the demand requests is the most reduced among the hospitality benchmark resulting in inevitable greater fixed cost. Therefore, financially is the most unattractive. The best economic score derives from Hotel3, holding the highest demand which apparently would be more focalized during afternoon hours due to the fact that the optimum inclination in SW. Likewise, it has an especial low voltage tariff, which as aforementioned receives high peak pricing. It can be inferred that it is principally the tariff, the decisive factor which leads to better economic for Hotel3, having Hotel2 higher self-consumed energy percentage. Table 5 pictures a comparative between Hotel2 and Hotel3 exclusively interchanging tariffs. Even if still Hotel 3 obtains better indicators, the differences are greatly reduced.

4.3 Retail sector

As the profiles adapt reasonably satisfactory, the group´s financial analysis is attractive, particularly with the especial low voltage tariff, even if during weekends no demand is required. As realized with the SLV of the accommodation sector, it has been also evaluated how Retail1 would perform under the LV_T tariff (Table 7). In this case, the profile Retail1 coupling prevails over the SLV tariff benefits, attaining better economic indicators with LV_T. On the other hand, with the modification of tariff, also the optimum orientation of the profile changes (to S), adjusting to the optimum self-consumed energy value. This means that during the afternoon-evening there is higher demand, concurring with peak time, therefore under SLV the prosumer avoids the peak contracted charge.

4.4 Industrial sector

The results presented are pretty homogenous, bus as expected Industry4 offers the better outcome due to the weekend coupling.

5. Conclusion and future work

Active demand management represents a way to transfer electrical consumption to hours when solar production occurs, offering the opportunity of changing the demand profiles for a better coupling with generation. Thus, it allows an increase of self-consumed energy utilization and a way to avoid grid constraints. The possibility of storing the energy generated at the consumption point (by storage devices such as batteries, electric cars…) can equally potentiate the growth of SC. In this case storage adapts production to demand profiles, mitigating likewise the costs associated with distributed energy grid integration.

Furthermore, ongoing studies should involve further knowledge on:

Effects of the diverse demand management approaches available and the different ways to perform storage (thermal, electrochemical…)

Potential distributed production sources associations to improve SC range, as the introduction of a backup biomass energy generation.

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