Small Scale Photovoltaic Analysis for the Residential and Commercial Market in Portugal

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Abstract

New Self-Consumption regulation in Portugal was released in the beginning of 2015. It allows self-consumption and the injection of the exceeding energy in the grid based on 90% of the Operator of the Iberian Energy Market electricity market price (approximately 0.04€/kWh). The electricity tariff for the consumer is 4 times higher (0.16€/kWh) giving self-consumption the main role to obtain payback on the investment and forcing the consumer to limit his installation to the attainable levels of self-consumption. This change in the regulations forces the consumer to opt for a high level of self-consumption, but the application of an instant Net-Metering system will scare informed investors. Considering these changes, this work analyzes the economic feasibility of different size PV systems (1kW, 3kW, 5kW, 10kW and 20kW) which could be installed in residential and commercial sites. Five different scenarios with 100%, 70%, 50%, 30%, and 0% self-consumption levels are analyzed for each of the PV system sizes, considering the different conditions: hourly electricity tariffs (mono, bi, tri, and tetra-hourly). The work also covers the different areas of the country since administratively Portugal has three regions: mainland, archipelago of Madeira and archipelago of Azores. As result, it was found that for the residential sector the mainland presents the best results while for the commercial sector the mainland and the island of Madeira presented the most attractive results. Globally it can be found that the new regulation, mostly considering the instant Net-Metering detail is prejudicial for the development of photovoltaic area since high levels of self-consumption can only be achieved with very low installed power levels.

Keywords: Grid-tied PV system, Internal Rate of Return, Profitability Index, Residential and Commercial settings, Self-Consumption.

1. Introduction

In Portugal, the market introduction of small-scale Photovoltaic (PV) system (up to 3.68kW) started with a Feed-in Tariff (FIT) in 2008 with a value of 0.65€/kWh. Since then, this feed-in tariff has been declining mainly due to the bad economic situation of the country and connected to the cost reduction of the PV systems [1], [2].

This FIT was decreased by the introduction of several rules in the following years and since 2012, the number of new PV system installations has been decreasing, in spite of the fact that the installation prices also decreased. Pressed by European regulations, Portugal set a target of 720 MW of solar PV system installed power to be working by 2020, [3]. In spite of this, in January 2015, the buying price of energy produced by PV systems was changed and a new tariff based on 90% of the last month's price of the OMIE (Operator of the Iberian market) value is attributed to the producers who inject energy into the grid. This is no longer a FIT value since it is lower than the market price.

Until the release of the new regulation, self-consumption was not recognized in Portugal and currently the producers can self-consume as well as inject the exceeding energy into the grid.

This new regulation describes two types of units that fall in different regulation regimes and apply to all the different renewable energy systems: solar, wind, and other types. The two types of units are: Self-Consumption Producing Unit (SCPU) and the Small Producing Unit (SPU). The SCPU regime allows self-consumption and grid injection and the SPU regime is used only for grid injection[1]. Under the SCPU, the grid injection tariff is approximately 0.04€/kWh and varies according to the OMIE electricity market price. The grid injection tariff of the SPU is 0.0949€/kWh and undergoes a tender scheme. On the other hand, the electricity price to the consumer is approximately 0.16€/kWh (excluding VAT) and is almost four times higher than the grid injection tariff. In order to export energy into the grid, both the SCPU and SPU have to be registered to get a license of production. The registration fee for the 1kW PV system is 30€, for the 3kW PV system is 100€ and for the rest of the PV systems is 250€. Only the solar production on both regimes, SCPU and the SPU is considered in this work [4].

Considering that the savings made under self-consumption are much higher than the money generated when injecting the solar production into the grid, the new regulation favors the self-consumption regime and limits the development of this market [4]. The motivation of this work was to analyze the economic feasibility of different size PV systems that can be applied to grid-tied PV systems in both residential and commercial settings according to the new self-consumption regulation. To this end, different scenarios of the installation, location and self-consumption level are considered.

Portugal can administratively be divided into three regions: mainland, archipelago of Madeira and archipelago of Azores, where taxes and prices are different and those differences are considered in this work. The cities that presented the highest solar radiation in each region are respectively Aljustrel, Calheta, and Vila do Porto.

The overall organization of the paper is as follows. After the introduction, the methodology used to calculate the economic measures to analyze the economic assessment of the PV systems is described in Section II. The results of the collected data analysis are reported and discussed in Section III. The main conclusions obtained in this paper are explained in Section IV.

2. Methodology

All the methods used to calculate the profit of the investment are described in this section and the economic feasibility methods used are namely the Internal Rate of Return (IRR), the Net Present Value (NPV), the Discounted Payback Period (DPBP) and the Profitability Index (PI). A brief description of all the economic methods is provided as follows.

2.1. Economic Methods IRR, DPBP, and PI

Before calculating the IRR, DPBP, and the PI, the annual simple cash flow (SCF) has to be calculated by subtracting the cash inflow from the cash outflow, as shown in equation 1 [5], [6].

$$SCF_y = Cash\ inflow_y - Cash\ outflow_y$$
$$SCF_y = \sum_{y=1}^{Y} (Ts \times Es + Te \times Ee)_y - \sum_{y=1}^{Y} (M)_y \qquad (1)$$

Y is the lifetime of the investment, Ts and Te are respectively the self-consumption and the grid injection tariffs, Es is the annual electricity (kWh) generated by the PV system used in self-consumption, Ee is the electricity produced by the PV system that is exported into the grid and M is the maintenance cost.

The Discounted Cash Flow (DCF) value is updated with the interest rate (r value in equation 2) and represents the SCF value of money over time.

$$DCF_y = \frac{SCF_y}{(1+r)^y} \qquad (2)$$

The DPBP considers the value of money over time since it uses the DCF values to calculate the number of years needed to make a breakeven on the investment. The NPV compares the present value of all cash inflows with the present value of all cash outflows associated to an investment project and considers the value of money over time. When the investment opportunity is favorable, the IRR value is higher than the interest rate [7]. Additionally, a comparison between regions can be made without considering the regional interest rates [8]. Equation 3 shows the IRR formula where C_y is the annual net cash flow and C_0 is the initial investment of the PV system.

$$0 = \frac{\sum_{y=1}^{Y} C_y}{(1+IRR)^y} - C_0 \qquad (3)$$

The PI indicates how much profit is made during the lifetime of the project and is calculated by dividing the NPV of a project by its initial investment and adding 1, just as shown on equation 4. Breakeven happens when PI=1.00 and the investment is doubled when PI=2.00. The time of the investment assumed for this work is 25 years [9].

$$PI = \frac{\text{NPV}}{\text{Initial Investment}} + 1 \qquad (4)$$

2.2. Assumptions

All the assumptions are defined in this section, in order to describe how the results of this study are obtained.

In this work, five different PV system sizes are considered namely the 1kW, 3kW, 5kW, 10kW and

20kW PV systems. The 1kW and 3kW PV systems are related to the residential sector and the 5kW, 10kW and 20kW PV systems are associated to the commercial sector. There are five self-consumption scenarios, which are explained as follows:

- **Scenario 1** – **100%** self-consumption (**SCPU** regime)
- **Scenario 2** – **70%** self-consumption (**SCPU** regime)
- **Scenario 3** – **50%** self-consumption (**SCPU** regime)
- **Scenario 4** – **30%** self-consumption (**SCPU** regime)
- **Scenario 5** –**0%** self-consumption (**SPU** regime)

Portugal currently practices an instantaneous net-metering scheme, in other words self-consumption only takes place if the energy is consumed at the same instant as it is produced, as opposed to other net-metering systems (see the United States or Brazil) where a monthly balance is done between the consumption and production. As a result, Portuguese consumers receive approximately 0.04€/kWh (on average) while paying 0.19€/kWh (including VAT). Because of the instantaneous net-metering scheme, the 70% self-consumption scenario (or lower if the PV system is over-sized) is very likely to occur in Portugal.

In this work, it is assumed that only the 1kW PV system would not inject any solar production into the grid since the costs associated to implementing a grid injection PV system are very high. The grid injection PV system includes an extra meter, a registry fee, extra cabling and labor costs. Therefore, the surplus energy that is not used in self-consumption is considered a loss at 0.00€/kWh in all the scenarios except for the 100% self-consumption scenario. The SCPU regime price (0.04€/kWh) of the surplus solar energy that is injected into the grid will be used in scenarios 1, 2, 3 and 4. In scenario 5 all of the surplus solar energy is injected into the grid, and in order to maximize profit the surplus energy tariff is associated to the SPU regime auction price (0.0949€/kWh).

The SCPU production contract is limited to 10 years (renewable every 5 years after that) and the SPU production contract is limited to 15 years. As the grid injection tariff is not known after the contract limits for the SCPU and SPU regimes it is assumed in this work that the tariffs would continue until the 25th year.

Since grid injection is much less profitable than self-consumption, the PV system should be sized so that the solar production is not injected into the grid as shown on Fig. 1. Accordingly, the PV system size is limited to the consumption value of the household or company during the day.

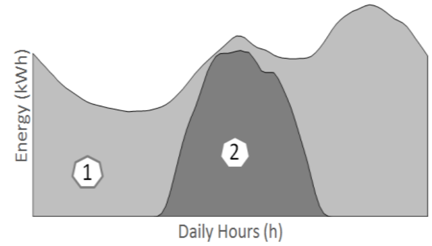

Figure 1. Consumption and 100% Self-Consumption
1 – Household/Company Consumption
2 – Self-consumption

Since Portugal practices an instantaneous net-metering scheme, the relation between the contracted power (CP) and the PV system size depends on the consumer behavior. In general, the CP recommended for the 1kW PV system is 10.35kVA, for the 3kW PV system is 20.7kVA, for the 5kW PV system is 27.6kVA, for the 10kW and 20kW PV systems is > 41.4kVA.

In Portugal, four hourly tariffs are practiced and they are namely the mono-hourly, bi-hourly, tri-hourly, and tetra-hourly tariff. The mono-hourly tariff has the same tariff throughout the day. The bi-hourly tariff is divided into the on-peak (day time) and off-peak (night time) tariffs. The tri-hourly tariff is associated to the on-peak (mid part of the day), regular (morning and afternoon) and off-peak (night time) tariffs. The tetra-hourly tariff is distributed into four different tariffs namely the on-peak (mid part of the day), regular (morning and afternoon), off-peak (early night and late morning) and super off-peak (late night and early morning) as explained in detail by [10].

The hourly tariffs associated to the contracted power of up to 20.7kVA are chosen between the mono and the bi-hourly tariff and are associated to the residential sector. For contracted powers between 27.6kVA and 41.4kVA only the tri-hourly tariffs can be used and for contracted powers superior to 41.4kVA only the tetra-hourly tariffs may be used. The hourly tariff that most benefits the residential sector PV system that practices a self-consumption regime is the bi-hourly tariff as the savings are higher during the on-peak hours, when self-consumption takes place, compared to the mono-hourly tariff practiced in the same hours.

Solterm is a PV system dimensioning software developed in Portugal in which the climate information of 308 cities are considered but unfortunately only has one year of climate data for each of the cities. The meteorological information includes the solar radiation and respective location (latitude and longitude) of each of the cities [11]. Since *Solterm´*s climate data is limited, *Retscreen* version 4 [12] software is used instead. *Retscreen* uses the NASA meteorological database [13] which is based on a monthly average over a 23 year period. *Retscreen* is a world widely used software tool that analyses energy projects, in which specific location climate analysis is possible to realize if the latitude and longitude coordinates are provided. The cities that presented the highest horizontal solar radiation values in Retscreen are presented in Fig. 2, and they are namely Aljustrel (mainland) with 5.05kWh/m2/d, Calheta (Madeira Island) with 5.33kWh/m2/d and Vila do Porto (Azores Island) with 4.71kWh/m2/d. The annual solar production of each of the PV system sizes in all the cities is calculated via Retscreen by first selecting the solar module and inverter type. Then secondly, filling the slope and azimuth values according to the specific city, in which the optimum slope for Aljustrel is 33º, for Calheta is 28º and for Vila do Porto is 32º. These result outcomes are shown in the results section on Table 3.

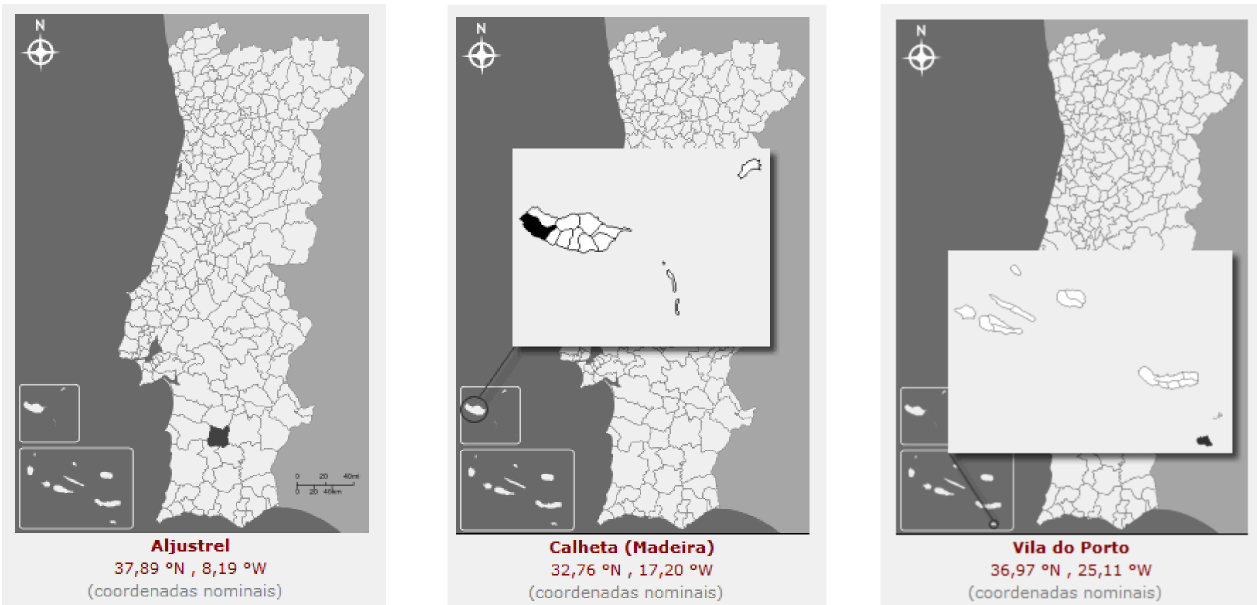

Figure 2. The Cities with the highest solar radiation values in Portugal – Aljustrel (mainland); Calheta (Madeira Island); Vila do Porto (Azores Island).

The following subsections describe the steps that need to be taken in order to obtain the annual solar production values from each of the regions.

2.3. PV Module and Inverter Selection

The SolarWorld 245W Polycrystalline PV modules were selected since they were evaluated as "very good" in 2013 according to [14] and have a lifecycle of 25 years which is within the range assumed in [15].

The inverter is expected to be replaced at least twice within the lifetime of the PV system which is commonly every 10 years [16]. Therefore, in this work the inverter replacement is considered in year 10 and in year 20. The inverters selected to be connected to the PV systems were namely the SMA-Sunny boy 1300TL, 3000TL, 5000TL, 10000TL and 20000TL since they present the best efficiency values which are 94.3%, 96.1%, 97.5%, 98.0% and 98.2% respectively [17]. The following describes the flow of the solar production, from the PV system to the grid. First, the solar energy is injected into the household/company grid for self-consumption, and secondly the surplus energy is injected into the distribution grid. Table 2 presents the inverter replacement cost rate assumed for each of the PV system sizes.

2.4. Performance Ratio (PV system losses)

A performance ratio (PR) between 75-90% is commonly considered for PV systems due to losses caused by the inverter, wiring, and module soiling (i.e. dust, snow, etc.) [18],[19]. In [20], a default PR value of 0.75 for roof-top installations was recommended and therefore for this work a PR of 0.80 is assumed.

The economical methods (IRR, DPBP and PI) are calculated based on the following parameters:

- Annual solar production;
- Average electricity evolution rate;
- Average grid injection evolution rate;
- Euribor Interest rate;
- Inflation rate;
- Electricity tariff;
- PV system cost (initial investment);
- Maintenance and Operations cost rate;
- Inverter substitution cost rate;
- PV module degradation rate.

The steps taken to obtain all the parameters mentioned above are explained in the following subsections and the outcome is presented in Table 2 and 3 in the results section.

2.4.1. Economical Parameters

The electricity price during the next 25 years is predicted by calculating an average evolution rate of the electricity price based on the past 25 years [21] and the calculation of an average grid injection evolution rate is based on the OMIE values since the year 2011 [22]. The electricity tariffs considered as initial values are the ones practiced at the present moment (year 2015) in all the cities [23]–[25].

The Euribor interest rate for the next 25 years is based on an average calculation of the Euribor rate of the past 16 years [26]. The inflation rate is considered in this work to obtain realistic values for the maintenance labor and operations costs during the next 25 years [27].

In all the self-consumption scenarios, the 1kW and 3kW PV system will be associated to both mono and bi-hourly tariffs since both of them are frequently used in the residential sector. For the commercial sector the 5kW PV system will be associated only to the tri-hourly tariff and tetra-hourly tariffs will be associated to the 10kW and 20kW PV systems.

A portion percentage of the total annual production is associated to the on-peak, regular and off-peak hours of the hourly tariffs according to the summer and winter months, as shown in Table 1 [10].

Table 1. Portion percentages of the Hourly Tariffs

	Mainland		Madeira		Azores	
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Bi-hourly tariff						
on-peak	77%	78%	96%	95%	99%	99%
off-peak	23%	22%	4%	5%	1%	1%
Tri-hourly tariff						
on-peak	22%	19%	20%	26%	18%	22%
regular	56%	59%	76%	70%	81%	77%
off-peak	23%	22%	4%	5%	1%	1%
Tetra-hourly tariff						
on-peak	13%	18%	10%	29%	14%	16%
regular	57%	62%	89%	70%	85%	83%
off-peak	29%	18%	0%	0%	0%	0%

The Energy Services Regulatory Authority (ERSE – *Entidade Reguladora dos Serviços Energéticos*), provided solar production data with15 minute sampling times from a microproduction installation in the mainland and this is used to calculate the portion percentage of each hourly tariff for both summer and winter months [28]. Overall, the on-peak hours in the islands have higher portion percentages than in the mainland, therefore contributing to higher savings in the islands than those made in the mainland.

Solterm provides the solar production profile of each city in Portugal therefore providing information about the monthly solar production of each city. Only the mono-hourly tariff did not have a portion percentage associated to it since its tariff is the same in all hours of the day.

In order to use realistic investment costs in this paper, at least three quotes had to be received from different companies from each region. After receiving the quotes, an average investment value is calculated for each region. More than three quotes were received from the mainland and three quotes were received from each of the islands. All quotes are associated to turnkey solutions, which include all the components of the PV system, mounting structure, delivery, and installation costs. These prices are not easy to obtain since many companies are not familiar with the new self-consumption regulations.

2.4.2. Operating and Maintenance Cost (O&M)

The economic feasibility of the PV system investment considers not only the inverter replacement costs but also the costs associated with the operations and maintenance (O&M) during the lifecycle of the system. According to [28]–[30], the maintenance cost is estimated between 1-3% of the initial investment per year. Table 2 presents the operations and maintenance cost rate for each of the PV system sizes.

2.4.3. Degradation Rate

The solar production efficiency of the PV modules can be significantly influenced by the degradation phenomena by being reduced over time [20]. Consequently, this issue can affect the predicted generation of the PV system and its economic payback period analysis. The methodology guidelines on the lifecycle assessment of PV systems statements, recommends considering a linear degradation, reaching 80% of the initial efficiency at the end of a 30 years lifetime (i.e., 0.7% per year) [20], [31]. A 0.7%/year is assumed as the PV degradation for this work.

3. Results and Discussion

This section presents all the results obtained from the methodology section.

The parameters presented in Table 2 are common to all the regions in Portugal and they include O&M cost rate, the inverter replacement cost rate, the SCPU/SPU register fees, the grid injection tariff, the grid injection evolution rate, electricity evolution rate, the Euribor interest rate and the inflation rate.

Table 3 presents the results that differ in all three regions and these include the solar production values, PV system Investments, electricity tariffs, and VAT tax rates. The values presented in Table 3 are used together with the values from Table 2 to calculate the economic methods (IRR, PI and DPBP) for all the PV system sizes of each region in each of the five different scenarios.

Table 2. Information common to all regions in Portugal

Parameter Description		Value
Maintenance and operations rate	**1kW**	3.0%
	3kW	1.5%
	5kW	1.5%
	10kW	1.0%
	20kW	1.0%
Inverter Replacement rate	**1kW**	15.0%
	3kW	13.0%
	5kW	10.0%
	10kW	9.0%
	20kW	9.0%
SCPU/SPU Register Fees	**1kW**	30.00 €
	3kW	100.00 €
	5kW, 10kW and 20kW	250.00 €
Grid injection tariff	**SPU**	0.0949 €
	SCPU	0.0377 €
Grid injection Evolution rate		4.250%
Electricity Evolution rate		2.428%
Euribor Interest rate		2.644%
Inflation Rate		1.48%

Madeira Island has the highest solar production values while the Azores Island has the lowest. The overall investment costs for the self-consumption PV systems are the lowest in the mainland and highest in the Madeira Island. The value cost per watt is indicated next to the PV system investment cost and in general, the bigger the PV system size, the cheaper the investment cost per watt in all the regions except for the mainland in which the 1kW PV system (1.99€/W) is cheaper per watt than the 3kW and 5kW PV systems. This is due to the fact that the 1kW PV system is very popular at the moment and special prices are attributed to this PV system size in particular.

There is no solar production during the super off-peak hours, therefore these tariffs are not indicated in Table 3. All investment costs and electricity tariff prices presented in Table 3 do not include the VAT tax rate, but the calculations of the IRR, PI and DPBP do include the VAT tax and only for the residential sector PV systems.

As previously stated, the PI indicates the amount of profit that an investment makes during the 25-year period of the project. Breakeven takes place on the year of the DPBP which is presented in Table 4. In this case, when the DPBP takes place before the 12^{th} year there is a good chance of doubling the investment. It is assumed for this paper that a good investment is considered when the investment is doubled (PI=2.00) before the end of 25 years which is the lifecycle of the PV system.

Table 4 shows how the bi-hourly tariffs offer higher profit on the investment when compared to the mono-hourly tariff. As mentioned before, there would not be any grid injection for the 1kW PV system, but even so the PI of the 1kW PV system under the bi-hourly tariff is almost equal to 2.00 (it is PI=1.99), therefore it can be considered as a good investment in the mainland and this is due to the low investment cost and high electricity tariff. The investment is doubled in scenario 1 for the 3kW, 10kW and 20kW PV system in all three regions and curiously, the 5kW PV system investment is doubled only in the islands. The mainland does not make double the investment with the 5kW PV system under the tri-hourly tariffs due to the low on-peak hour portion percentages, but in the islands, more than double the investment can be made since their on-peak portion percentages are high.

This indicates how the higher portion percentages in the on-peak hours, as shown in Table 1, can be an advantage to compensate for the high PV investment costs in the islands. For the 20kW PV system in scenario 1, both the mainland and Madeira Island present profitability values that triple the investment while in scenario 2, Madeira Island is the only region that makes a little more than double the investment with the 10kW PV system.

All three regions present profit values higher than 2.00 for the 20kW PV system in scenario 2. Scenarios 3 and 4 are not considered a good investment in any region and for any PV system size because the PI values are lower than 2.00.

All the solar production is injected into the grid in scenario 5 and the PI values are lower than 1.00 for the PV systems smaller than 10kW, even though the grid injection tariff in this scenario is the SPU tariff, which is higher than the SCPU tariff (0,0949€/kWh instead of the SCPU tariff 0.0377€/kWh). Since the PI values for the 10kW and 20kW PV systems are barely over 1.00, all the investments in scenario 5 are considered not viable.

If Table 4 were to have a diagonal line going across the top left corner to the bottom right corner, the PI values above the line are inferior to 1.00 and, the PI values below the line are superior to 1.00. The PI values in the mainland have mostly the highest values for the 1kW, 3kW (mono-hourly tariff) and 20kW PV systems. The island of Madeira presents the highest PI values for the 5kW and 10kW PV systems, which reflects the advantages that the on-peak portion percentages contributes to making more profit.

Table 3. 1kW, 3kW, 5kW, 10kW and 20kW PV System Information

			Mainland - Aljustrel		Madeira Island - Calheta		Azores Island - Vila do Porto	
PV System Solar Production (kWh)	**1kW**		1529		1566		1409	
	3kW		4577		4687		4218	
	5kW		7610		7793		7014	
	10kW		15206		15571		14014	
	20kW		31159		31908		28716	
PV System Investment for self-consumption	**1kW**		1,991.42 €	1.99 €/W	2,413.56 €	2.41 €/W	2,342.37 €	2.34 €/W
	3kW		6,472.68 €	2.16 €/W	6,955.77 €	2.32 €/W	6,353.85 €	2.12 €/W
	5kW		10,129.12 €	2.03 €/W	10,262.65 €	2.05 €/W	9,275.10 €	1.86 €/W
	10kW		16,831.32 €	1.68 €/W	17,979.41 €	1.80 €/W	16,786.27 €	1.68 €/W
	20kW		29,244.20 €	1.46 €/W	33,957.25 €	1.70 €/W	31,638.16 €	1.58 €/W
Electricity tariff Price	**Mono-hourly**		0.1587 €		0.1609 €		0.1624 €	
	Bi-hourly	**On-Peak**	0.1890 €		0.1843 €		0.1878 €	
		Off-Peak	0.0978 €		0.0979 €		0.0990 €	
	Tri-hourly	**On-Peak**	0.2144 €		0.2095 €		0.2150 €	
		Regular	0.1704 €		0.1678 €		0.1638 €	
		Off-Peak	0.0978 €		0.0979 €		0.0990 €	
	Tetra-hourly	**On-Peak**	0.3284 €		0.3135 €		0.3112 €	
		Regular	0.1215 €		0.1219 €		0.1219 €	
		Off-Peak	0.0810 €		0.0801 €		0.0798 €	
VAT tax rate			23%		22%		18%	

Table 4: The IRR, PI, and DPBP of Scenarios 1, 2, 3, 4 and 5 - PV System for Self-Consumption

	Scenario 1 100% self-consumption			Scenario 2 70% self-consumption			Scenario 3 50% self-consumption			Scenario 4 30% self-consumption			Scenario 5 0% self-consumption		
	IRR	**PI**	**DPBP**	**IRR**	**PI**	**DPBP**	**IRR**	**PI**	**DPBP**	**IRR**	**PI**	**DPBP**	**IRR**	**PI**	**DPBP**
	1kW - Mono-hourly tariff – Residential sector														
Mainland	7.78%	1.76	14	2.31%	0.96	> 25	-3.04%	0.42	> 25	a	-1.11	> 25	a	-1.91	> 25
Madeira	5.97%	1.44	16	0.42%	0.76	> 25	-5.62%	0.30	> 25	a	-0.16	> 25	a	-0.84	> 25
Azores	4.42%	1.24	21	-1.06%	0.60	> 25	-7.46%	0.17	> 25	a	-1.26	> 25	a	-1.90	> 25
	1kW - Bi-hourly tariff – Residential sector														
Mainland	9.47%	1.99	12	3.78%	1.14	22	-1.56%	0.57	> 25	-15.85%	-0.99	> 25	a	-1.84	> 25
Madeira	8.14%	1.77	13	2.55%	0.99	> 25	-2.96%	0.46	> 25	a	-1.06	> 25	a	-1.84	> 25
Azores	6.66%	1.57	15	1.22%	0.83	> 25	-4.37%	0.33	> 25	a	-1.16	> 25	a	-1.90	> 25
	3kW - Mono-hourly tariff – Residential sector														
Mainland	9.27%	1.96	12	5.64%	1.40	17	2.84%	1.02	24	-0.56%	0.65	> 25	-4.88%	0.42	> 25
Madeira	8.77%	1.88	13	5.18%	1.33	18	2.40%	0.97	> 25	-1.00%	0.61	> 25	-5.60%	0.39	> 25
Azores	8.69%	1.86	13	5.14%	1.33	18	2.39%	0.97	> 25	-0.96%	0.61	> 25	-5.27%	0.40	> 25
	3kW - Bi-hourly tariff – Residential sector														
Mainland	9.82%	2.05	12	6.08%	1.46	16	3.21%	1.07	24	-0.27%	0.68	> 25	-4.88%	0.42	> 25
Madeira	10.80%	2.22	11	6.82%	1.57	15	3.78%	1.14	22	0.07%	0.71	> 25	-5.60%	0.39	> 25
Azores	10.86%	2.23	11	6.89%	1.59	15	3.86%	1.15	22	0.18%	0.72	> 25	-5.27%	0.40	> 25
	5kW - Tri-hourly tariff – Commercial sector														
Mainland	8.11%	1.78	13	5.17%	1.34	18	2.98%	1.04	24	0.47%	0.75	> 25	-0.07%	0.75	> 25
Madeira	12.64%	2.56	9	8.74%	1.89	13	5.87%	1.44	17	2.57%	0.99	> 25	0.08%	0.76	> 25
Azores	12.56%	2.55	9	8.68%	1.88	13	5.81%	1.43	17	2.52%	0.98	> 25	0.02%	0.75	> 25
	10kW - Tetra-hourly tariff – Commercial sector														
Mainland	12.79%	2.59	9	9.32%	1.99	12	6.82%	1.59	15	4.07%	1.19	21	3.66%	1.11	22
Madeira	14.01%	2.82	8	10.19%	2.14	11	7.43%	1.68	14	4.37%	1.23	21	3.11%	1.05	23
Azores	11.98%	2.44	9	8.59%	1.87	13	6.12%	1.48	16	3.37%	1.09	23	2.63%	1.00	26
	20kW - Tetra-hourly tariff – Commercial sector														
Mainland	15.54%	3.12	7	11.66%	2.41	10	8.91%	1.93	13	5.93%	1.46	17	5.88%	1.37	15
Madeira	15.40%	3.09	7	11.36%	2.35	10	8.47%	1.85	13	5.29%	1.36	18	4.17%	1.17	19
Azores	13.29%	2.69	8	9.71%	2.06	12	7.13%	1.64	15	4.29%	1.22	21	3.72%	1.12	21

a - The IRR calculation for accumulated negative cash flows resulted in a very large absolute number that is not represented by excel. Nevertheless, the conclusion should be that the investment is not viable.

The Azores Island presents the best values for the 3kW PV system when associated to the bi-hourly tariff. Three times the investment is possible in scenario 1 with a 20kW PV system in the mainland and in the Madeira Island. In general, the IRR values are always higher than the Euribor interest rate (2.644%) assumed in this work, which means that investing in a PV system in a self-consumption regime is viable all over Portugal. In order to double the investment in this work, the IRR has to be a little under 10% and the DPBP has to be just under 12 years.

4. Conclusion

Considering the new Portuguese regulation, to maximize the profitability of the PV system, it should be dimensioned only to cover only the instantaneous consumption because of the difference between the price of energy to the consumer and price paid to the producer.

In the residential sector, the mainland is the region that generates the most profit for 1kW PV system. For 3kW PV systems, the best result is obtained in the mainland when associated to the mono-hourly tariff and the Azores Island when associated to the bi-hourly tariff. The 3kW PV system presents more profit when a bi-hourly tariff is practiced compared to the mono-hourly tariff. Considering the commercial sector (5kW, 10kW and 20kW), the mainland and Madeira Island are the regions that present the best results.

Overall, the portion percentages over the daytime associated to the mono, bi, tri and tetra-hourly tariffs influence the profitability of the investment. The tetra-hourly tariffs impacts the profitability values the most since there are greater savings in the on-peak hours due to the high electricity tariff price.

Generally, the 1kW PV system is the worst to invest in at the moment since it presents the lowest profitability values and only in the mainland it is possible to almost double the investment (PI=1.99) by the end of a 25-year period when associated to a bi-hourly tariff. The majority of households have an annual consumption that can only support a 1kW PV system since under the instantaneous net-metering scheme it is not possible to take full advantage of the higher power coming from the PV system.

To justify a 3kW PV system at home for self-consumption, it is estimated that the contracted power should be 20.7kVA and consumption during the day time hours should add up to a total of 20kWh in order to prevent grid injection and maximize the return. However, for the commercial sector, investing in a PV system is profitable because there is enough consumption during the day to absorb the solar production from the PV system as self-consumption and the hourly tariffs are high enough to reflect as profitable savings in the electric bill.

With this new regulation associated to self-consumption, the target of the Kyoto 2020 Protocol goal for Portugal is at risk and in the best case will be achieved by investing in the commercial sector rather than in the residential sector because in the latter the investment is not very attractive.

In conclusion, a PV system associated to scenario 1 in which 100% of the solar production is used for self-consumption is more profitable than any other scenario. Nevertheless, 100% self-consumption is almost unachievable. At the moment, it is not viable to invest in a PV system for the residential sector but it is viable to invest in a PV system for the commercial sector (except in the mainland with the 5kW PV system). The PV systems can become more viable if the PV system prices drop and the electricity tariff prices rise.

Both the PV system investment cost and the electricity tariff price, apart from the solar radiation values, play an important role in the profitability values of the investment during the 25-year period.

Globally it can be found that the new regulation, mostly considering the instant Net-Metering detail is prejudicial for the development of photovoltaic area since high levels of self-consumption can only be achieved with very low installed power levels.

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