# The Current Situation of the Residential and Commercial PV System Self-Consumption Market in Portugal

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## ABSTRACT

The Self-Consumption regulation was introduced in Portugal in the beginning of 2015 and it states that grid injection of the surplus solar energy into the grid is allowed at an average tariff of approximately 0.04€/kWh and this value varies according to the Operator of the Iberian Energy Market electricity market price. The electricity tariff (0.16€/kWh) is 4 times higher than the grid injection tariff which indicates that the savings made on self-consumption are much higher than those made when injecting the solar production into the grid. Therefore, the new regulation favors the self-consumption regime and helps limit the possibility to oversize the Photovoltaic (PV) systems. These new measures seem to compel the PV system investors to adopt the 100% self-consumption regime, but the use of instant Net-Metering will probably keep investors away. Based on this information we were motivated to analyze the economic feasibility of different size PV systems (1kW, 3kW, 5kW, 10kW and 20kW) that can be applied in a residential and a commercial setting according to the new self-consumption regulation. Five self-consumption scenarios (100%, 70%, 50%, 30%, and 0%) are studied for each of the PV system sizes, considering the different hourly electricity tariffs (mono, bi, tri, and tetra-hourly). Geographically, Portugal can be divided into three regions namely the mainland, the archipelago of Madeira and the archipelago of Azores. The purpose of this paper is to determine the attractiveness of the PV system investment in Portugal, since the good incentives were cut, and to determine which size PV system and respective region generates the most profit. Overall, the mainland presented the best results for the residential sector while for the commercial sector the mainland and the island of Madeira presented the most attractive results. These findings are of interest to the PV system investor.

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

# 1. INTRODUCTION

In Portugal, the small-scale (until 3.68kW) PV system feed-in tariff scheme started 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].

Since 2012, the number of new PV system installations in Portugal has been decreasing due to the continuous cuts made to the feed-in tariffs making the PV system less economically attractive. By 2020, Portugal set a target of 720 MW of solar PV system installed power [3]. In January 2015, the feed-in tariffs for the small-scale solar productions were cut and a new tariff based on the OMIE (Operator of the Iberian market) value is attributed to the producers who inject energy into the grid. Up until now, self-consumption was not recognized in Portugal, but from this moment on solar producers will be able to self-consume as well as inject the excess energy into the grid.

This new regulation introduced in the beginning of 2015 in Portugal, describes two types of units that follow different methods in using the energy production from the renewable energy systems (solar, wind, and others) namely the self-consumption Producing Unit (SCPU) and the Small Producing Unit (SPU). The SCPU regime allows for self-consumption and grid injection and the SPU regime is used only for grid injection just like in the previous microproduction regime [1]. The grid injection tariff of the SCPU 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. The electricity price is approximately 0.16€/kWh (Excluding VAT) used in self-consumption and therefore 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].

As the savings made on self-consumption are much higher than those made when injecting the solar production into the grid, the new regulation favours the self-consumption regime and helps limit oversizing the PV systems [4]. Based on this information we were motivated to analyse 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. The economic feasibility of various PV system sizes according to five self-consumption scenarios considering different hourly electricity tariffs is studied.

Portugal can be divided into three regions namely the mainland, the archipelago of Madeira and the archipelago of Azores. The cities that presented the highest solar radiation 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 analyse the economic assessment of the PV systems is described in Section II. The results of the main findings of the data analysis are reported and discussed in Section III. The main conclusions made in this paper are explained in Section IV.

# 2. METHODOLOGY

In this section, all methods used to calculate the profit of the investment are described.

To analyse the cost-effectiveness of the PV system sizes considered in this work, 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 in the next section.

### *2.1. IRR, DPBP, and PI*

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

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

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.

$$DCF_y = \frac{SCF_y}{(1+r)^y} \qquad (2) \qquad\qquad 0 = \frac{\sum_{y=1}^{Y} C_y}{(1+IRR)^y} - C_0 \qquad (3)$$

The DPBP considers the value of money over time since it uses the DCF values to calculate the number of years needed to breakeven. The NPV compares the present value of all cash inflows with the present value of all cash outflows associated with an investment project and considers the value of money over time. A high IRR indicates that the investment opportunity is favourable, and it should be higher than the interest rate [7]. Additionally, it allows a comparison across locations 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.

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 profit is double the investment 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*

In this section, all the assumptions are defined in order to explain how the results of this study are obtained.

In this work, five different PV system sizes namely the 1kW, 3kW, 5kW, 10kW and 20kW PV systems are considered. The 1kW and 3kW PV systems belong to the residential sector and the 5kW, 10kW and 20kW PV systems are associated to the commercial sector. There are five self-consumption scenarios and they 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 has currently an instantaneous net-metering regime which means that self-consumption only happens if the energy is consumed at the same instant as it is being produced, as opposed to other net-metering systems (see the United States or Brazil) where a monthly balance is done in order to define the resulting balance between consumption and production. As a result, Portuguese consumers receive approximately 0.04€/kWh while paying 0.16€/kWh (plus VAT). Because of the instantaneous net-metering system, the 70% self-consumption scenario (or even lower if the PV system is over-sized) is very likely to happen in Portugal.

It is assumed that only the 1kW PV system would not have the option to inject any solar production into the grid since the costs associated to grid injection are very high since the PV systems that inject the solar production into the grid are obliged to have a meter to measure the energy production. Therefore in scenarios 2, 3, 4 and 5 of a 1kW PV system, all the surplus energy that is not used in self-consumption is considered a loss at 0.00€/kWh. In scenarios 1, 2, 3 and 4 the price of the surplus energy is associated to the SCPU price (0.0377€/kWh). In scenario 5 all the energy produced by the PV system is injected into the grid and to maximize profit, it is assumed that the surplus energy tariff is to be associated to the SPU auction price (0.0949€/kWh).

Since instantaneous net-metering is applied in the self-consumption regime in Portugal the relation between the contracted power (CP) and the PV system size depends on the consumer behaviour. 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. The PV system size is limited to the consumption value of the household or company during the day.

There are four different hourly tariffs practiced in Portugal namely the mono-hourly, bi-hourly, tri-hourly, and tetra-hourly tariff. The mono-hourly tariff is the same in all hours of the day. The bi-hourly tariff is associated to two tariffs namely the on-peak (day time) tariff and the off-peak (night time) tariff. The tri-hourly tariff is associated to three tariffs namely the on-peak (mid part of the day), regular (morning and afternoon) and off-peak (night time) tariffs. The tetra-hourly tariff is associated to 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]. In Portugal the hourly tariffs associated to the contracted power of up to 20.7kVA is chosen between the mono and the bi-hourly tariff. 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 are used. The hourly tariff that most benefits the residential sector PV system when practicing a self-consumption regime is the bi-hourly tariff since the savings are higher during the on-peak hours (when self-consumption takes place) compared to the mono-hourly tariff.

*Solterm* is a PV system dimensioning software developed in Portugal and uses climate information of 308 cities. The meteorological information includes the solar radiation and respective location (latitude and longitude) of each of the cities [11]. Unfortunately, *Solterm* has only one year of climate data for each of the cities therefore *Retscreen* version 4 [12] software is used instead which uses NASA meteorological database [13] based on the monthly average over a 23 year period. *Retscreen* is a software tool that analyses energy projects and specific location climate analysis is possible to obtain if the latitude and longitude coordinates are provided. The cities that presented the highest horizontal solar radiation values in *Retscreen* are 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. *Retscreen* calculates the annual solar production of each of the PV system sizes in all the cities by, first selecting the solar module and inverter type. Secondly, by filling the slope and azimuth values according to the associated 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.

The following subsections describe the steps taken to obtain the annual solar production.

#### 2.2.1. PV Module and Inverter Selection

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

Among the components of a residential and commercial PV system, only the inverter is expected to be replaced, within the lifetime of the PV system which is commonly every 10 years [16]. Therefore, in this work it is assumed that the inverter replacement takes place in year 10 and in year 20. The inverters selected for the PV systems for this work were 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]. Table 2 presents the inverter replacement cost rate assumed for each of the PV system sizes.

### *2.2.2. Performance Ratio (PV system losses)*

For PV systems, a performance ratio (PR) between 75-90% is commonly considered, which is caused by all losses that can be generated in 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.

In order to calculate the economical methods (IRR, DPBP and PI) every region had to consider 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;
- Maintenance and Operations cost;
- Inverter substitution cost;
- 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.

### *2.2.3. Economical Parameters*

The electricity price during the next 25 years was predicted by calculating an average evolution rate of the electricity price based on the past 25 years [21] and an average grid injection evolution rate was 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 labour 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 share 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]. The Energy Services Regulatory Authority (ERSE – *Entidade Reguladora dos Serviços Energéticos*), has solar production data (15 minute sampling time) from a microproduction installation in the mainland and this is used to calculate the share percentage of each hourly tariff for both summer and winter months [28]. Overall, the on-peak hours in the islands have higher share percentages than in the mainland when comparing the same hourly tariffs therefore contributing to higher savings in the islands than those 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 share 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 referring the costs of each PV system size.

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.

**Table 1.** Share 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% |

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.

### *2.2.4. Operating and Maintenance Cost (O&M)*

The economic feasibility of the PV system investment also considers the costs associated with the O&M during the lifecycle of the system. According to [29]–[31], the O&M cost is estimated between 1-3% of the initial investment per year. Table 2 presents the operations and maintenance rate for each of the PV System sizes.

### *2.2.5. Degradation Rate*

The PV module degradation phenomena reduces production efficiency over time [20], consequently affecting the predicted generation of the PV system and its economic payback period analysis. According to [20], [32] a linear degradation, reaching 80% of the initial efficiency at the end of a 30 years lifetime (i.e., 0.7% per year) is recommended therefore a 0.7%/year is assumed as the PV degradation for this work.

## 3. RESULTS AND DISCUSSION

All the results obtained from the methodology section are presented in this section.
The parameters presented in Table 2 are common to all the regions in Portugal and they include O&M rate, inverter replacement rate, SCPU/SPU register fees, grid injection tariff, grid injection evolution rate, electricity evolution rate, the Euribor interest rate and the inflation rate.
Table 3 shows all the values of the results associated to the three different regions and all have different solar production values, PV system Investments, electricity tariffs for the various hourly electric supply charges, and VAT tax rates. Madeira Island has the highest solar production values while the Azores Island has the lowest.
The values presented in Table 3 are used together with the values from Table 2 to calculate the IRR, PI and DPBP for all the PV system sizes of each region for each of the five different scenarios. Table 3 shows us that the overall investment costs for the self-consumption PV systems is the lowest in the mainland and highest in the Madeira Island. Next to the PV system investment cost, is the value cost per watt. In general it is verified that, the bigger the PV system size, the cheaper the investment 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. The price of the super off-peak hourly tariff is not mentioned in Table 3 because there is no solar production during the night time hours. All investment costs and electricity tariff prices presented in Table 3 are excluded from the VAT tax rate, but the calculations of the IRR, PI and DPBP do include the VAT tax for the residential sector only.

**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% |

As previously stated, the PI gives us an idea of the amount of profit a certain investment can make during the 25-year period of our project. Breakeven takes place on the year of the DPBP presented in Table 4, and in this paper, when the DPBP takes place before the 12th year there is a good chance of doubling the profit of the investment. A good investment is considered when the investment is doubled (PI=2.00) before the end of 25 years. Table 4 presents the IRR, PI and DPBP values of all the self-consumption scenarios. The bi-hourly tariffs offer higher profit on the investment when compared to the mono-hourly tariff. It is assumed that the 1kW PV system would not inject energy into the grid but even so the PI of the 1kW PV system under the bi-hourly tariff is not exactly 2.00 (it is PI=1.99) it can considered as a good investment in the mainland and this is due to the low investment cost and high electricity tariff. The profit over 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 profit is doubled only in the islands. The mainland does not make double the profit on the investment with the 5kW PV system under the tri-hourly tariffs due to the low on-peak hour share percentages, but in the islands more than double the profit on the investment can be made since their on-peak share percentages are high.
This shows that the higher share 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. In scenario 1 for the 20kW PV system the mainland and Madeira Island present profitability values that triple the profit on the investment while in scenario 2, Madeira Island is the only region that makes double the profit with the 10kW PV system.
All three regions present profit values higher than 2.00 for the 20kW PV system. Scenario 3 and 4 is not considered a good investment in any region and for any PV system size.
All the solar production is injected into the grid in scenario 5 and even though the grid injection tariff in this scenario is the SPU tariff (0,0949€/kWh instead of the SCPU tariff 0.0377€/kWh), the PI values are lower than 1.00 for the PV systems smaller than 10kW. The PI values for the 10kW and 20kW PV systems are barely over 1.00 making all the investments in scenario 5 not viable. If Table 4 were to have a diagonal line starting from 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 share percentages bring 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 profit on 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 profit of the investment, the IRR has to be a little under 10% and the DPBP has to be just under 12 years.

## 4. CONCLUSION

The PV system should be dimensioned only to cover the instantaneous consumption because more power than that will generate less return on the investment since the surplus energy is injected into the grid.

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

Overall, the share percentages over the daytime associated to the mono, bi, tri and tetra-hourly tariffs influence the profitability of the investment. The tetra-hourly tariffs influence 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 profit (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. In order to have a 3kW PV system at home to use solely 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. 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 these new regulations associated to self-consumption, the target of the Kyoto 2020 Protocol goal for Portugal will probably 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 thus indicating that injecting the surplus solar energy into the grid is not advised. 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 a big role on the probability values of the investment during the 25-year period.

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