A Work Project, presented as part of the requirements for the Award of a Master's degree in Finance from the Nova School of Business and Economics.

# ECONOMIC ANALYSIS OF A RESIDENTIAL ROOFTOP PHOTOVOLTAIC SYSTEM IN PESO DA RÉGUA, PORTUGAL

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## Executive Summary

### Summary of Rooftop Solar Analysis

**Location**: Peso da Régua, Portugal **Date of analysis**: Dec/2023

***Recommendation****: install 5 solar panels (7.85 $m^2$), for a net present value of 4 749 euros, with a payback of 2.3 years.*

### Main Economic Results

| Financing | NPV (EUR) | Payback (years) | IRR (%/year) | LCOE (EUR/kWh) |
|---|---|---|---|---|
| Gov. subsidies and 75% bank debt | 4749 | 2.3 | 47.0 | 0.0392 |
| Gov. subsidies and 100% equity | 4820 | 4.8 | 21.9 | 0.0381 |
| No gov. subsidies and 100% equity | 3720 | 8.0 | 12.6 | 0.0556 |

(All rows are for the same number of panels)

### Additional Results

For the same system of panels, switching from a simple tariff to a time-of-use tariff raises the net present value to 5 718 euros. Installing 6 panels of 410 Wp with a 5.8 kWh battery yields an NPV of 4 259 euros with subsidies.

### Main Inputs and Assumptions

| *Household and Economics* | | | | | |
|---|---|---|---|---|---|
| Electricity Consumption | 4300 | kWh/year | Inflation | 2.0% | per year |
| Electricity price – buy | 0.18 | EUR/kWh | Bank loan interest rate | 4.5% | per year |
| Electricity price – sell | 0.03 | EUR/kWh | Bank loan maturity | 10 | years |
| | | | Equity cost of capital | 3.28% | per year |

| *PV panels* | | | | | |
|---|---|---|---|---|---|
| Peak power | 410 | W/panel | System losses | 13.5% | of output |
| Panel area | 1.57 | $m^2$/panel | Degradation with age | 0.5% | Per year |
| Useful life | 25 | Years | Maintenance costs | 9 | EUR/year per panel |
| | | | Total cost of optimal installation size (without subsidies) | 2600 | EUR |
| | | | Total cost of optimal installation size (after subsidies) | 1500 | EUR |

### Government Subsidies

The Portuguese government refunds up to 95% of the initial investment outside of Lisboa and Porto, up to a maximum of 1 100 euros for the installation of photovoltaic panels, with rolling admissions until the fund reaches its endowment of 30 million euros. Subsidy is paid ex-post, and requires that the project is paid for upfront, prior to application.

## 1. Introduction

The aim of this paper is to perform a financial analysis on the implementation of a residential rooftop photovoltaic system in the city of Peso da Régua, in Portugal, and propose the resulting optimal installation size.

The relevance of this topic lies in its timeliness, as the climate emergency gathered the attention of the public eye over the past years, ignited by the already visible, devastating, and far-reaching consequences that the crisis has already imposed, namely the rising temperatures and weather extremes (United Nations 2019). Verily, the prevailing reliance on fossil fuels, non-renewable resources, is a major contributor to the emission of harmful and polluting greenhouse gases (UN n.d.). Consequently, transitioning to renewable energies, which provide clean, sustainable, and accessible energy (UN n.d.), emerges as a pivotal solution to mitigate the nefarious and exacerbating effects of the climate crisis on the environment. Solar energy, in particular, is the most abundant energy resource (UN n.d.), and can be availed by both photovoltaic (related to sunlight) and thermal (heat) technologies (Acciona n.d.). Statista (2023) identified a pattern of continuous growth of global cumulative solar photovoltaic capacity since 2015 and predicts that this trend will continue at a steeper pace over the next years. Portugal is no exception, presenting an increasing adoption of renewable energies in both absolute and relative terms (Pordata n.d.).

Researching the Douro region permitted an enhanced comprehension of its massive potential, but also of the severe problems faced daily. The fact that many places still do not have a reliable source of energy from power plants, combined with severe heat and recurrent droughts (Diário de Notícias 2017; Dias 2022) gravely affects the agricultural lands of grapes and olives (Martins 2023), which in turn affects the production and quality of wine and olive oil, two acclaimed regional products (Douro 2020). Installing systems of photovoltaic panels would therefore stand as an opportunity for the impoverished population to make the most of its cultures, by leveraging on preventing substandard production, and even earning an additional source of income.

## 2. Data Collection and Assumptions

The model lies under the premise that the residential household is occupied by a standard family of four, with both parents going to work and both children going to school during weekdays, which justifies minimal activity in the house registered during the day. Moreover, it should be assumed that the panels would be installed in the roof of an isolated home, more common in the region, with full sun exposure and no size restrictions.

The estimated lifetime of the project is 25 years, in line with suppliers declared useful life for the photovoltaic panels analysed in *Section 2.4.* After a 25-to-30-year period, while not expected to abruptly cease to function, there is a noticeable decrease in power output, as a result of continuous degradation of the panels (Walker 2022).

### 2.1. Solar Irradiance

In the first instance, local hourly radiation was retrieved from the European Commission Photovoltaic Geographical Information System (EC PVGIS 2022) database (PVGIS-SARAH2), considering the following pair of coordinates: 41.165N, 7.750W, from the centre of the city of Peso da Régua. Data collected ranged from 2005 to 2020, assuming a fixed position of the panels, an optimal slope and azimuth. Then, an annual hourly average was computed using the twelve common years comprised in the previously mentioned period.

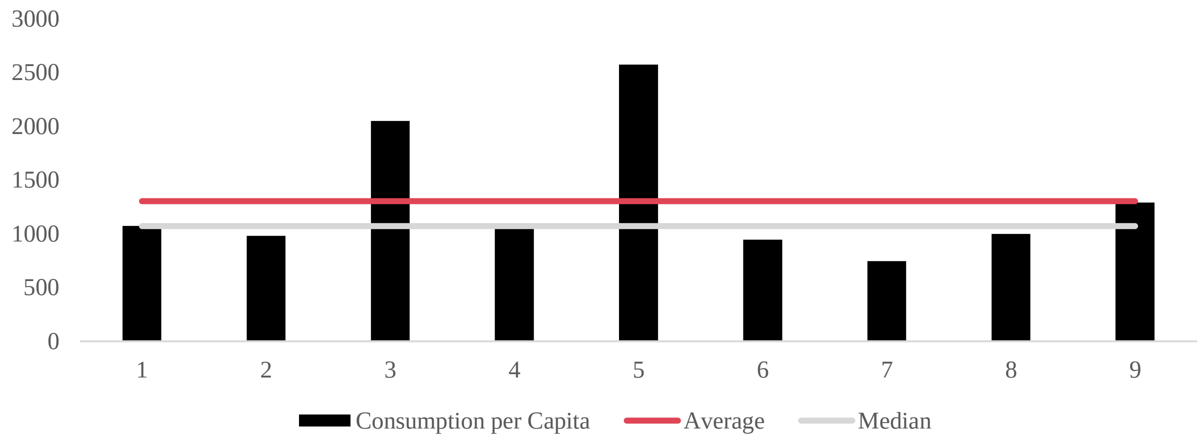
As for system losses, in accordance with the expected loss already accounted for in the EC PVGIS 2022 database, a default of 14% was assumed, based on an estimated degradation of between 0.5% to 0.8% per year (National Renewable Energy Laboratory n.d.), in combination with the expected useful life of 25 years for the panels guaranteed by major suppliers. The constant exposure to ultraviolet rays, adverse environmental conditions, as well as debris accumulation, help explaining expected yearly losses in efficiency (Evergreen Electrical Services n.d.).

## 2.2. Electricity Consumption

A questionnaire was run in order to estimate the yearly consumption of electricity per household. As such, the survey included a section for the respondent to specify its monthly consumption and chosen tariff, in addition to a set of complementary questions regarding general household information (e.g., description of the household, type of housing, size, construction year, current insulating features), major household appliances characteristics (age, efficiency, weekly usage), other possible sources of consumption (e.g., space heating and cooling, electric water heating, general lighting), and considerations on possible variations in yearly usage. Main qualitative findings from the sample collected for the region include relatively small households (maximum of four people), and the co-existence of apartments, houses, and vacation homes with large vineyards (see *Table A1* in Appendix). For the latter, for the purpose of the analysis, it was deemed as a one-person household due to its occasional use.

Quantitatively, it was found that the average annual per capita consumption based on the sample of nine households was 1302 kilowatt-hour (kWh), as seen in *Graph 1*, aligning with the projected domestic consumption of 1361 kWh from Pordata (n.d.) for 2021. For a standard family of four that this study assumes, the median consumption per capita was quadruplicated to mitigate potential outliers surveyed, yielding a final estimate of 4300 kWh.

***Graph 1 – Consumption per capita of the 9 households surveyed in kWh***



## 2.3. Load Profile

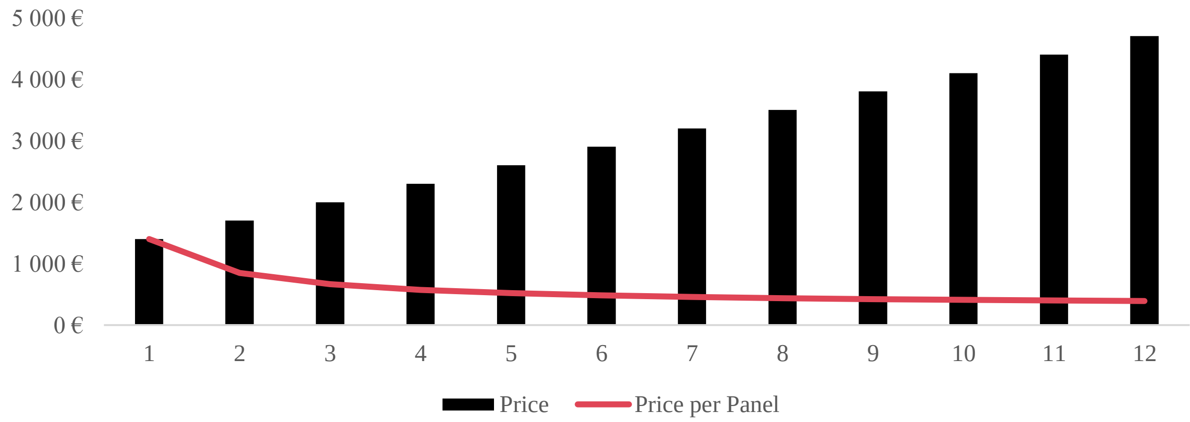
The ideal number of panels will depend on the energy consumed during daylight hours (Contigo Energía n.d.). As a means to distribute the annual consumption of electricity along each hour of the year, it is useful to consult the load distribution estimated by the Portuguese electricity distribution firm E-REDES (2022). E-REDES predicts a fraction of energy consumption for each quarter-hour period of the day in a year, allowing to infer on the yearly load distribution on an hourly basis. From the load profiles provided by E-REDES (2021) *(Excerpts A1 and A2, Table A2*), Profile BTN C was chosen, since it more accurately resembles domestic consumption (annual consumption below 7140 kWh and apparent power below 13.8 kilo-volt-amperes [kVA]).

## 2.4. Photovoltaic Panels

An extensive benchmark analysis was performed on the current offer of solar panels in the region, to gather information on peak power and price per panel, the predicted useful life, and the warranties for the panels, the inverter or microinverter, and the installation process. Commonly available photovoltaic panels are usually manufactured from monocrystalline solar cells (EDP n.d.), each derived from a single silicon crystal (Wallender and Tynan 2023). For each peak power per panel offered in the market (370 Peak Watts [Wp], 375Wp, 380Wp, 400Wp, 405Wp, 410Wp, 415Wp, 455Wp), the most competitive unitary price was selected on up to 12 panels, selecting offers with similar terms. After gathering publicly available quotes from several suppliers, linear interpolation was used to fill in missing total prices. In cases where more than one firm offered panels with the same peak power, the best price was picked (check *Table A3*).

From analysing the example portrayed in *Graph 2*, which depicts the total price for a system of panels of 410 Wp and the respective price per panel, one can deduce that the marginal cost of purchasing an additional unit decreases as the total number of panels increases.

*Graph 2 - Total Price and Price per Panel for a system of panels of 410 Wp*




## 2.5. Maintenance Expenses

In regard to maintenance services, it is advisable that solar panels have frequent upkeeping, to preserve their initial performance conditions (Lam and Gobler 2023) and ensure their durability (Hoskyn 2023). The required frequency to undergo this procedure may vary due to regional specificities, such as regular exposure to extreme adverse weather (Lam and Gobler 2023). While periodic light cleaning can be easily performed by the owner itself, in order to strictly follow the supplier's instructions, it is recommended that biennial thorough check-ups and subsequent repairs and replacements are done by professionals (Solar Victoria 2023).

After reviewing various prices for this service, it is possible to conclude that maintenance costs per panel tend to be lower the higher the quantity of panels installed (*Table A4*). In fact, providers usually propose a fixed amount for a range of number of panels. In the interest of this research, this expense was estimated as an average of 9 € (euros) per panel per year, subject to yearly inflation (*Section 2.9.*).

## 2.6. Government Incentives

Transitioning to sun-generated energy requires a considerable upfront investment, which can hinder the consumer's shift towards renewable energies. As such, the government plays a crucial role in enabling its access and assuring its affordability, through public policies and financial incentives (VR 2023). In light of this, since 2022, the VAT (value-added tax) charged on thermic and photovoltaic panels decreased from 23% to 6% in Portugal (Lança 2022).

From several national and regional public subsidies analysed (*Table A5*), "Programa de Apoio a Edifícios + Sustentáveis" (PAE+S) was considered the most appropriate to be included in the model. This is usually a yearly initiative on the part of the Portuguese government alongside the European Union, as part of "Fundo Ambiental", and regards expenses undertaken in buildings to enhance their sustainability and efficiency, ranging from the inclusion of insulating features in windows, doors, and roofs, to the installation of solar panels.

One can only apply for the fund after undertaking the expense, which has to be paid in full upfront to qualify, with the reimbursement occurring ex post. Until the 31$^{st}$ of October of 2023, the subsidy conveyed a reimbursement of up to 95% of total value spent without VAT, up to a total of 1 100 €, outside the districts of Lisboa and Porto. Now, since PAE+S is structured retroactively, one can incur in the expense now and apply for the grant in an upcoming stage, eliminating the need to delay the installation. Namely, PAE+S 2023 accepted admissions from investments made from the 1$^{st}$ of May of 2022 onwards (Fundo Ambiental 2023).

Another relevant incentive in Portugal is "Vale Eficiência". This program, currently in its second edition, aims to finance, through the offer of pre-paid vouchers, the hiring of services and the acquisition of products that contribute towards the enhancement of houses' energy performance, such as the replacement of windows and the installation of photovoltaic panels (Fundo Ambiental 2023). Eligible beneficiaries can receive up to three vouchers of 1 300 €, plus VAT, to cover their projected expenses. Additionally, applicants can rely on technical help throughout the submission process, as the program ensures administrative facilitators to aid gathering all the necessary documentation, in an effort to maximize enrolments (Silva 2023). It is pertinent to note that “Vale Eficiência” specifically targets economically vulnerable households, suffering from energy poverty and benefiting from the social tariff for electric energy. Hence, due to its limited applicability, this subsidy was not taken into further consideration.

## 2.7. Grid Buying Price

In order to estimate the electricity buying price for the household, nine Portuguese suppliers were examined (*Table 1*), assuming a contracted power of 6.9 kVA, befitting with the contracted power of the surveyed households in *Section 2.2.* For the base model, a simple tariff was assumed, where the price charged per kilowatt does not vary throughout the day, while at a later stage a time-of-use tariff was contemplated (*Section 4.2.*).

***Table 1 - Electricity buying prices from Portuguese suppliers***

| Supplier | Simple tariff (€/kWh) |
|---|---|
| EDP | 0.1958 € |
| Goldenergy | 0.1476 € |
| Endesa | 0.1293 € |
| Iberdrola | 0.1283 € |
| Galp | 0.1711 € |
| Repsol | 0.1395 € |
| AlfaEnergia | 0.1724 € |
| CBPower Energy | 0.1372 € |
| LogicaEnergy | 0.1679 € |
| **Average** | 0.1543 € |

The research resulted in a mean price of 0.15 €/kWh before VAT. In accordance with collected electricity bills, the first 100 kWh consumed in a period of 30 days benefit from a reduced VAT rate of 6%, while the additional consumption is taxed at 23% (ERSE 2022). Following this reasoning, and assuming a yearly consumption of 4300 kWh (as established in *Section 2.2.)*, and twelve 30-day months in a year, one reaches a quote of 0.18 €/kWh.

On top of the cost per kilowatt-hour, a standard electricity bill in Portugal is subject to additional fees regarding the installed power and taxes. Some examples comprehend the

“Taxa de Exploração DGEG”, a fixed predetermined fee paid to the State on the usage of electrical installations (CGD 2023), and the “Contribuição Audiovisual”, destined to finance public radio and television services (Goldenergy n.d.).

Consequently, due to added fixed charges, the figure obtained previously does not represent the total cost that a consumer has to pay divided by kWh used, but instead it will represent the savings per kWh with each less kWh consumed from the grid, when using power generated from solar panels.

## 2.8. Grid Selling Price

One of the major drawbacks of relying on solar energy lies in its inability to be stored without an additional device, meaning that the energy produced in each moment must be used in a 15-minute period, or it will be forfeited (Sowden 2023). What is more, energy is only being generated during solar hours, coinciding with the time that the studied family is not at home and, thus, presumably, has a lower demand of energy than the amount being produced.

Although new alternatives have emerged, currently, the most common way to address this surplus is to inject it back into the grid (Turgeon and Morse 2023) for free. Certainly, the recent possibility of selling it back to the Iberian Market Operator of Energy (OMIE) at either a fixed or indexed price is more attractive, despite the lengthy and possibly expensive bureaucratical process. Indeed, in order to celebrate a selling contract, one needs to request a bidirectional meter from E-REDES, register the solar unit in the platform, and register an activity with the Tax Authority (EZU Energia n.d.).

Even though at the moment it is possible to assure a fixed rate of 0.07 €/kWh (EZU Energia n.d.), it is projected that feed-in tariffs decline over the years (ESC 2023), which justifies the lower value of 0.03 € (EcoChoice n.d.) assumed. The indexed price option was not explored further, despite its current appeal, as it does not fit the project’s risk-free profile.

## 2.9. Financial Rates

The benchmark case consists of 75% debt and 25% equity financing. Regarding debt costs, from the major Portuguese banks offering loans on investments related to renewable energies, the lowest available interest rate of 4.50% was selected for the project, concerning a 10-year term (ActivoBank n.d.) (*see Table A6*). However, it is important to note that the quotes offered depend on the loan term and amount asked.

Knowing the interest rate (r) and maturity (n), as well as the present value of the loan (PV), it is possible to calculate the annual reimbursement for each bundle of panels, using the annuity formula (*Formula 1*).

***Formula 1 - Annuity***

$$(1)\ PV = Annual\ Repayment * \frac{1 - (1 + r)^{-n}}{r}$$

For the equity cost of capital, the 10-year EURIBOR swap rate of 3.28% (Chatham Financial 2023) was used. As for inflation, the medium-term aim of the European Central Bank (ECB n.d.) of 2% was considered. Notwithstanding the fact that recorded inflation has been above the desired target over the past cycles in the Euro Zone (euronews 2023), recent deceleration in rises in prices (Trading Economics n.d.) makes it feasible to assume that, for the lifetime of this investment, inflation will converge towards the desired figure of 2%.

## 3. Economic Analysis

After estimating each input in *Section 2*, summarized in *Table 2*, the next step involves constructing the model to ascertain the Net Present Value (NPV) of the project.

***Table 2 – Summary of main inputs for the NPV model***

| | | | |
|---|---|---|---|
| **Energy Consumption** | 4300 kWh/year | **Efficiency Losses** | 14% |
| **Electricity Buying Price** | 0.18 €/kWh | **Debt Weight** | 75% |
| **Electricity Selling Price** | 0.03 €/kWh | **Interest Rate** | 4.50% |
| **Total Peak Power** | *Section 2.4.* | **Debt Maturity** | 10 years |
| **Full Price** | *Section 2.4.* | **Government Subsidies** | 95%, max 1 100 € |
| **Duration of the Project** | 25 years | **Cost of Equity** | 3.28% |
| **Maintenance Cost Yearly** | 9 €/panel | **Inflation** | 2% |

## 3.1. Cost Savings

For each peak power per panel identified in *Section 2.4.*, for a range of one to twelve panels, photovoltaic panel generation in kWh for each hour of each day was calculated, using the system's total capacity and the captured radiation from the EC PVGIS 2022 database (*Section 2.1.*). Consumers' demand for each hour of the year was derived by multiplying the load fraction from Profile BTN C (*Section 2.3.*) by the total consumption of 4 300 kWh for the studied family (*Section 2.2.*). Afterwards, it was possible to assign the hourly amount of energy generated up to a maximum of full suppression of the consumption needs for each hour period. If existing, the remaining unutilized energy produced by the solar panels is injected back into grid, since it cannot be stored to fulfil future needs without an external device. To finalize, the household's consumption from the grid can be quantified as the energy demanded unmet by supply of solar energy.

In order to measure total yearly savings for each panel option, one should sum the hourly figures for a total year, in order to obtain the yearly values of energy generated for home use, for sale to the grid, and for consumption from the grid. Later, forecasted values are to be entered in *Formula 2* below regarding total savings.

***Formula 2 - Total Savings***

*(2) Total Savings = Yearly Electricity Cost without Panels – Yearly Cost of the Residual Load + Revenue from Selling Surplus Energy*

Dissecting this formula, the *Yearly Electricity Cost without Panels* is deemed to be the product of the total load by the estimated grid buying price of 0.18 €/kWh (*Section 2.7.*), while the *Yearly Cost of the Residual Load* is the expense undertaken when the household with panels resorted to the grid. Reasonably, fixed fees are not taken into account, since they have to be paid irrespective of the consumption registered. Finally, for the base case scenario, the surplus is sold at 0.03 €/kWh (*Section 2.8.*), which multiplied by the excess energy produced at each hour of day, returns the *Revenue from Selling Surplus Energy*.

Following these steps, one can estimate the yearly savings for 96 scenarios, each representing a unique combination of number of panels and peak power by panel. *Table 3* is an extracted version of one of the scenarios, with a system of panels totalling 2 050 Wp.

***Table 3 - Total Savings for a system of 2 050 Wp***

| | |
|---|---|
| **Total Power (Wp)** | 2 050 |
| **Yearly Electricity Cost without Panels** | 784.85 € |
| **Revenue from Selling Energy** | 32.30 € |
| **Cost of Residual Load** | 472.39 € |
| **Total Savings** | 344.76 € |

## 3.2 NPV for Benchmark Case

Considering the project duration of 25 years, the estimated inputs were inserted in the calculation of cash flows for each option of peak power and number of panels. The NPV will be the sum of all yearly discounted cash flows, which correspond to the cash flows obtained through *Formula 3*, discounted at the equity cost of capital (cash flows to equity).

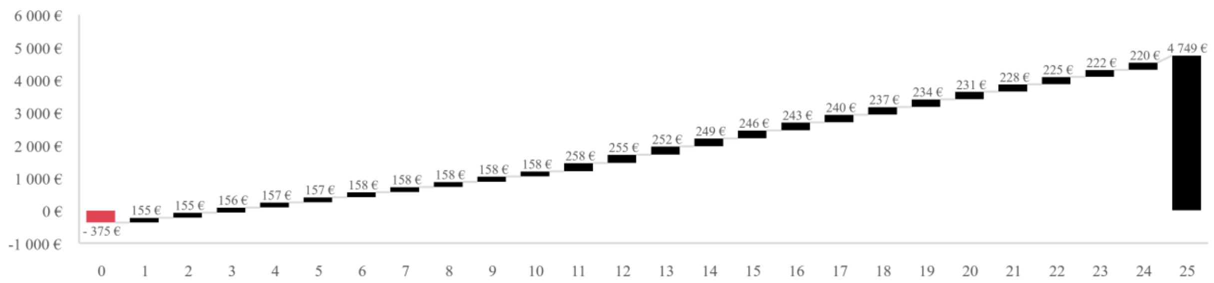
***Formula 3: Yearly Cash Flows***

$$(3)\ Cash\ Flows_t = -\ Equity\ Investment_t + Savings_t - Maintenance_t - Loan\ Repayment_t$$

It is important to note that the income related to savings, particularly the grid buying and selling price, along with the maintenance costs, were adjusted yearly to account for annual inflation of 2%, as estimated in Section 1.9. Furthermore, in this project, the capital structure is not constant, since the loan needs to be paid back. Thus, cash flows were estimated after deducting the loan instalments and, subsequently, discounted at the equity cost of capital.

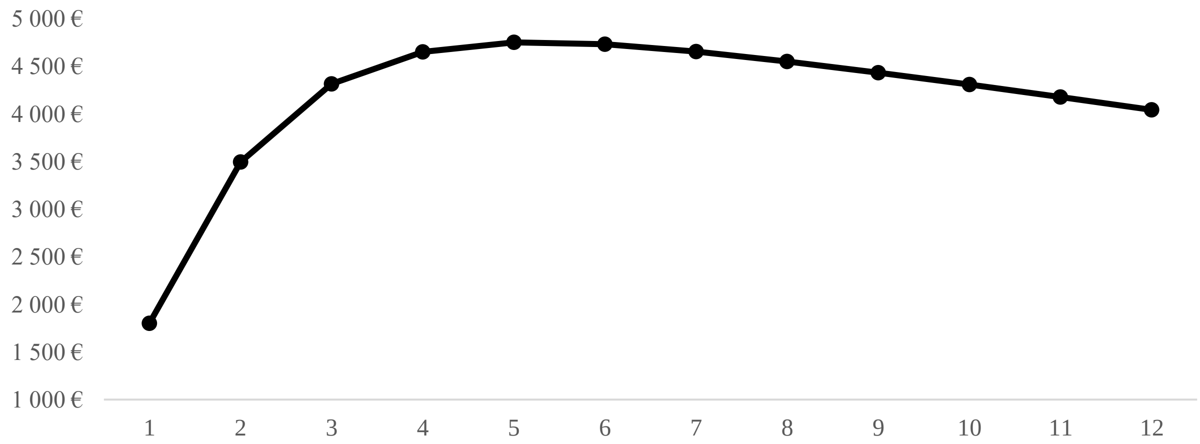
Comparing all possible scenarios, the highest rated option was found to be a system of 5 panels of 410 Wp, resulting in a present value of cash flows of 4 749 € (see *Graph 3* and *Table A7*).

***Graph 3 – Yearly Discounted Cash Flows for the optimal solution of 5 panels of 410 Wp***



A graphical depiction of Net Present Value for all options with panels of 410 Wp in *Graph 4* resembles a concave form, and reaches a maximum at five panels – the optimal solution found.

***Graph 4 - NPV of a varying number of photovoltaic panels of 410 Wp***




The optimal installation set comprises a set of five panels worth 2 600 €. Benefiting from a subsidy worth 1 100 €, the total cost for the consumer is 1 500 €. In the base case, as stated in *Section 2.9.*, 25% of the total value is paid upfront, while the remaining 75% are borrowed from the bank. Numerically, the initial equity investment is 375 €, and the loan covers the 1 125 € left.

## 3.3. Financial Metrics

To evaluate the attractiveness of the investment, one can calculate the Internal Rate of Return (IRR), which yields a rate of 47.0%, in addition to the simple payback period, which is approximately 2.3 years. This means that it would take the investor 2 years and 4 months to fully recover its initial investment with the costs savings that the project yields, with 22 years and 8 months still ahead in the project's lifespan.

The levelized cost of electricity (LCOE), a common term in the photovoltaic energy market (Kikumoto 2020), is the selling price of energy that sets the NPV to zero, after assuming that all energy generated is sold to the grid, using the same discount rate as for the NPV and having the electricity selling price growing at the inflation rate. In what regards this investment, the LCOE is 0.0392 €/kWh.

## 3.4. Other Cases

For the optimal set-up, other financing options were evaluated. First of all, in the event that no debt is undertaken, the NPV increases slightly to 4 820 € because, by paying the full investment upfront, one would not have to incur in interest payments, which are additional negative cash flows taken into consideration in the benchmark case. The payback period doubles compared to the benchmark case, now standing at 4.8 years, while the IRR falls to 21.9%.

Secondly, the possibility of not being granted any subsidy, on top of 100% equity financing, decreased the NPV to 3 720 €. The difference in the present value of cash flows of these two scenarios is exactly 1 100 €, which corresponds precisely to the subsidy available at the time of the research. Moreover, it would require 8.0 years to achieve the break-even point. This case presents an even lower IRR of 12.6%, highlighting that, understandably, the investment is less attractive without government incentives lowering its initial cost.

Thirdly, as seen in *Section 2.8.*, it is still customary that the electricity surplus is merely injected back in the grid without any sale transaction, due to both the recency and the bureaucracy involved related to this alternative. As such, that scenario was studied as well, and delivered an NPV of 4 073 €. By comparing this figure with the previously obtained in *Section 3.2.*, one can sensibly remark on the financial pertinence of establishing a contract with a local energy provider that allows the sale of the excess energy back to the grid, in case the household does not have a storage device and is therefore unable to preserve the unused produced energy.

At last, one could look into the hypothesis of relying on supplier's credit to finance the acquisition of solar panels, since a few of the studied suppliers offer 24-to-48-month credit options. However, the supplier that offers the most favourable solution found previously in *Section 3.2.* does not offer that alternative to its clients, hindering the possibility of testing it.

The main figures regarding each of the options examined so far are summarized in *Table 4* below.

*Table 4 - Summary of main results of each studied scenario for the Basic Analysis*

| Scenario | NPV | IRR | Payback Period | LCOE |
|---|---|---|---|---|
| Benchmark | 4 749 € | 47% | 2.3 years | 0.0392 € |
| No Debt | 4 820 € | 22% | 4.8 years | 0.0381 € |
| No Debt and No Subsidy | 3 720 € | 13% | 8.0 years | 0.0556 € |
| No Sale to the Grid | 4 073 € | 39% | 2.8 years | N/A |

## 4. Additional Analysis

Further research was made, and additional hypotheses were brought up and assessed as a means to complement the basic analysis from *Section 3* and determine if any deviation from the benchmark case could result in an even more attractive solution for the consumer.

### 4.1. Battery Installation

Solar batteries have been gathering momentum in the solar energy market recently. Their premise lies in the possibility of storing the excess electricity generated by the system of solar panels (Palmetto n.d.), increasing the efficiency and versatility of the setup (Crail and Tynan 2023). At the moment, the most common technologies used in residential households are lithium-ion and lead-acid, both designed to successfully handle the cyclic charging and discharging of energy (Eon Energy n.d.).

Delving deeper into the specificities of the current offer in the Portuguese market, it is observed that, most commonly, for up to around 10 panels, the battery capacity proposed is approximately 5 kWh. In addition, conventional batteries in Portugal are normally made using lithium-ion technology. These batteries have a high energy density, are more reliable and compact (Palmetto n.d.), and are generally more efficient than other options for home setups (Crail and Tynan 2023). Particularly under lithium-ion batteries, the safest option would be LFP (lithium iron phosphate) batteries, as they present a reduced risk of thermal runaway (Eon Energy n.d.).

Reflecting on the possibility of installing a solar battery, one can speculate that, on the one hand, the attractiveness of batteries lies in the fact that it solves a major shortcoming of solar energy - the intermittency in generating power. This device ensures a more consistent power supply, and allows for potential savings, since each kWh stored and then used at a time where no sunlight is available would have costed the household over 18 cents (*Section 2.7.*). On the other hand, what might deter households from relying on this alternative is the fact that it is a considerably more expensive venture, in comparison to just purchasing the solar panels. If one were to purchase a solar battery by itself, they would find that a regular 5-kWh battery, (for instance, the well-known Huawei LUNA2000 lithium battery), is generally priced above the 3 000 € mark (WccSolar n.d.), to be paid on top of the cost of the solar panels and necessary components.

To reduce the upfront cost of this option, "Fundo Ambiental", first introduced in *Section 2.6.*, subsidizes up to 95% of the total value spent in a bundle of photovoltaic panels and a battery, up to a threshold of 3 300 €, outside of Lisboa and Porto. To access the fund, similar conditions to those verified without batteries apply – the investment must be paid in full upfront, and the fund reimburses part of it afterwards. Accordingly, joint offers of panels and batteries were studied from suppliers (detailed information on *Table A8*).

Moving forward to the computation of the NPV, it is imperative to emphasize that, out of the lifetime of the project of 25 years, total savings were calculated assuming a solar battery only from the first to the tenth year of the investment. As a matter of fact, while the photovoltaic panels have a useful life of around 25 years (the considered timeline of the project), batteries face a higher degradation speed (Goldenergy 2022), becoming significantly less efficient quicker compared to panels.

As such, manufacturers issue a warranty of only 10 years for the solar batteries. In light of this, when computing the savings for this case, from year 11 onwards, the model assumes the previously computed savings without a battery (*Section 3.1.*), signalling the end of the estimated lifespan of the solar battery. For the initial ten years, total savings using batteries were estimated under the assumption that batteries were emptied out at the end of each day - the time at which the family arrives home and requires more energy, and does not have it directly from the panels since it is close to nighttime.

Further, for the purpose of calculations, it was assumed the same financing structure as in the base case (75% debt and 25% equity), as well as the same cost of debt and equity as found in *Section 2.8*.

For the same peak power per panel as in the benchmark optimal solution (410 Wp), the best option would be to acquire six panels and a battery with a 5.8 kWh capacity, yielding an NPV of 4 259 € (see *Table A9*). This option presents an IRR of 24% and an estimated payback period of 4.7 years. Yet, if instead one chooses to acquire a bundle of six panels of 380 Wp, alongside a 5-kWh battery, this option will yield a total present value of cash flows of 4 676 €, from an initial investment of 3 032 € after subsidies. Besides, it presents an IRR of 34% and a payback period of 3.2 years.

In absolute terms, it is noteworthy to mention that, even though the NPV of this alternative is close to the one obtained in the benchmark case, it not only requires a much costlier initial investment, but also has its profitability severely dependent on the subsidy attributed by the Portuguese government. In fact, without the considerable financial incentive from the government, the NPV of the project drops substantially to 803 € for the six 410 Wp panels (with an IRR of 5% and payback period of 17 years), and 1 221 € with six 380 Wp panels (with an IRR of 6% and a payback period of 15.7 years).

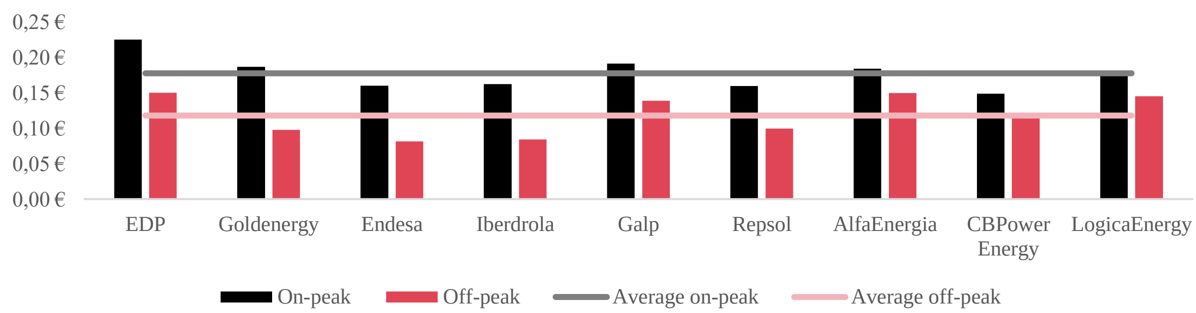
Thus, relying on the possibility of a successful application to "Fundo Ambiental" to render the investment appealing may raise concerns for a more risk-averse investor, considering that the fund is paid retroactively, requiring one to incur in the expense in full before knowing whether the application will be accepted. If denied, the investment instantly becomes significantly less attractive.

## 4.2. Time-of-use Tariff

All the suppliers benchmarked in *Section 2.7.* regarding grid buying prices also offer the option of a time-of-use tariff. Plus, out of the nine households sampled in *Section 2.2.*, two had already contracted a time-of-use tariff contract, encouraging this additional analysis section.

In a two-part tariff contract, the price charged depends on the hour of the day at which the user consumes the energy. Specifically, the interval between 8 a.m. to 10 p.m. is considered to be on-peak hours, while from 10 p.m. to 8 a.m. is off-peak hours. During on-peak hours, the average price charged reaches 0.21 €/kWh, a higher quote than with a simple tariff (0.18 €/kWh obtained in *Section 2.7.*). To counterbalance, off-peak hours charge a significantly inferior value, of approximately 0.14 €/kWh with VAT (*Graph 5*).

***Graph 5 - Electricity prices from Portuguese suppliers regarding a two-part tariff***




Another focal distinction is between the daily and weekly cycles. In a daily cycle, on- and off-peak hours are the same in every day of the year, while in a weekly cycle, time intervals are different on weekdays and weekends.

Employing a discriminated tariff might be of great value for individuals who experience flexibility in the time of the day at which they incur in energy-intensive activities in their homes. In other words, by adjusting their usage patterns to match the interval at which the grid charges a lower price, one can encounter a lower electricity bill, yet have the exact same consumption figures (Goldenergy 2023).

Once again, in the assessment of the net present value of this option, the same financing assumptions were kept, including the expected subsidy from the government, and the only change made regarded the grid buying price. The tested premise regarded a time-of-use tariff in a daily cycle. For that, each day was divided into its on- and off-peak interval, and the price paid to the grid per hour was calculated first without and then with panels. Without panels, the time-of-use tariff was determined to be adverse for the studied household, since it denoted a yearly electricity cost of 815.74 €, compared to 784.85 € from having contracted a simple tariff.

On the contrary, setting up a photovoltaic system enables the family to use less energy from the grid during on-peak periods, as these encompass the daytime hours in which the household can rely, at least partially, on the installed set of panels. What is more, at nighttime, when they cannot count on the energy being generated by solar panels, grid prices are much lower, since it is an off-peak period.

Finally, when inputting the new net savings from using a two-part tariff for each of the 25 years of the project, it is possible to conclude that this option grants an NPV of cash flows of 5 718 € (see *Table A10*). Consequently, it can be theorized that adopting a time-of-use tariff when installing solar panels constitutes a cost-effective decision for the consumer.

Switching tariffs involves contacting the current energy provider to check the feasibility of altering the current contract conditions and confirm that the existing electricity meter supports a discriminated tariff, as older meters are unable to register energy consumption by time of day (Goldenergy 2023).

## 4.3. Tracking Panel

Up until this point, photovoltaic panels were assumed to have a fixed position, installed on the roof. However, a static system of panels, even supposing optimal slope and azimuth, is constrained in its capacity to efficiently capture solar radiation, due to its inherent inability to trace the sun as it progresses over the day.

A potential approach to address this downside is through the use of a tracking solar panel system. By having the photovoltaic modules placed on a rotating structure, it is possible to maximize the amount of energy captured at each moment in time, as the set of panels follows the daily trajectory of the sun (Mibet Energy 2023), thus narrowing the angle of incidence (VR 2022). Moreover, one can distinguish between a single- and a dual-axis tracker. As the name suggests, a single-axis tracker allows the system of panels to rotate around one axis, generally the North-South route, while the latter allows the panels to move both horizontal and vertically, further optimizing exposure to sunlight (VR 2022).

This technology advancement requires several additional components, including a rotative platform, called a tracker mount, sensors, motors, and encoders, which foretell the main pitfall that this solution presents to the consumer. Indeed, a major disadvantage of this option regards the more frequent need for maintenance, on top of the already significant incremental cost to acquire the set-up parts.

In comparison to the NPV baseline model, energy production was recalculated through the EC PVGIS database (2022) for a two-axis system, thus altering total yearly savings, as well as the initial investment and the maintenance costs per annum. A total structure cost of 4 700 € (Solar Tracker Components n.d.) was added to the beginning capital invested in a system of 5 panels of 410 Wp (*Section 2.4.*), and maintenance expenses were doubled, to account for the anticipated frequent inspections. All other assumptions were kept constant, and this option was found to yield an NPV of 1 282 € (check *Table A11*), allowing the conclusion that opting for a more precise system does not constitute a more attractive venture.

## **4.4. Sensitivity and Scenario Analysis**

The applicability of this study is heavily dependent on the robustness of the data collected. Consequently, the inherent volatility of the inputs has prompted the need for a sensitivity and scenario analysis. A one-variable analysis was performed to separately assess changes in consumption, maintenance costs, the government's subsidy amount, and the project's lifetime.

Then, a two-variable analysis was executed twice, varying together first the grid buying and selling price, and then the interest and inflation rates.

Starting off with the sensitivity analysis, the household's consumption figure was tested, assuming everything else constant. Observing *Table 5*, it is possible to conclude that, the higher the family's demand of energy, the higher the NPV. If a family consumes more energy overall, it is justifiable that they will also utilize more self-produced energy, resulting in increased savings. This is due to a reduced surplus of energy, which would have been sold at a lower price than the buying price.

***Table 5 - Sensitivity analysis of the household's yearly consumption***

| Consumption (kWh) | NPV |
|---|---|
| 4000 | 4 420 € |
| 4100 | 4 531 € |
| 4200 | 4 641 € |
| **4300** | **4 749 €** |
| 4400 | 4 856 € |
| 4500 | 4 961 € |
| 4600 | 5 065 € |

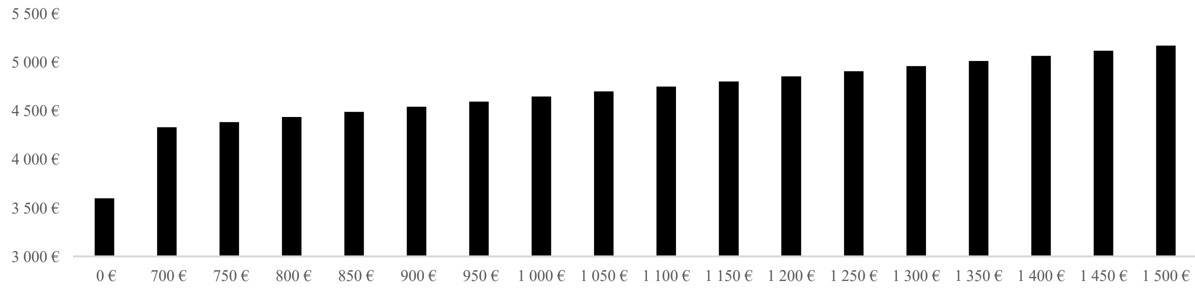
Moving forward, looking now at maintenance expenses, one can infer that a higher yearly maintenance cost will yield a lower NPV, as shown in *Table 6*. Indeed, a 50% increase in costs incurred would lead to a 9% decrease in the present value of cash flows.

***Table 6 - Sensitivity analysis of the yearly maintenance costs***

| Maintenance (€) | NPV |
|---|---|
| 35 € | 4 920 € |
| 39 € | 4 839 € |
| **43 €** | **4 749 €** |
| 47 € | 4 660 € |
| 52 € | 4 561 € |
| 57 € | 4 452 € |
| 63 € | 4 333 € |

Moreover, as seen in *Section 2.6.*, government incentives play a key role in subsidizing the installation of solar panels. As such, it is relevant to study how a change in the subsidy offered would impact the NPV. In *Graph 6*, it can be remarked that the attractiveness of the project is positively related to the value of the subsidy.

***Graph 6 - Sensitivity analysis of the value of the government's subsidy***




At last, as mentioned in *Section 2*, the panels' expected lifetime is 25 years. Any deviation from this duration considerably alters the NPV, since it represents one more (or less) year receiving a net positive cash flow. By looking at *Table 7* one can see that if the system were to last for 27 years the NPV would rise to 5 175 €.

***Table 7 - Sensitivity analysis of the project's lifetime***

| Lifetime | NPV |
|---|---|
| 21 | 3 865 € |
| 23 | 4 313 € |
| **25** | **4 749 €** |
| 27 | 5 175 € |
| 29 | 5 590 € |

Regarding the energy prices assumed in this study, it should be noted that in January of 2024, electricity prices in Portugal for the regulated market are expected to increase by 3.7% on average (Lusa 2023). Indeed, considering the fluctuations in energy prices in recent times, it also appears useful to study to what degree market prices of electricity affect the profitability of the project, by testing the effect that a change in both the buy and sell price would have on NPV.

As observable on *Table 8* below, for both variables, a slight increase in their value contributes positively to NPV, allowing the conclusion that, with all else equal, increasing electricity prices benefit the installation of solar panels, as a higher selling price translates into higher revenue for the sale of surplus energy, and a higher buying price increases the value of savings attained by producing the energy oneself instead of buying it from the grid.

*Table 8 – Scenario analysis of the electricity buying and selling price*

| | | Buying Price | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.14 € | 0.15 € | 0.16 € | 0.17 € | 0.18 € | 0.19 € | 0.20 € | 0.21 € | 0.22 € | 0.23 € |
| Selling Price | 0.005 € | 2 775 € | 3 133 € | 3 492 € | 3 850 € | 4 208 € | 4 567 € | 4 925 € | 5 283 € | 5 642 € | 6 000 € |
| | 0.010 € | 2 910 € | 3 268 € | 3 627 € | 3 985 € | 4 344 € | 4 702 € | 5 060 € | 5 419 € | 5 777 € | 6 135 € |
| | 0.015 € | 3 045 € | 3 404 € | 3 762 € | 4 120 € | 4 479 € | 4 837 € | 5 195 € | 5 554 € | 5 912 € | 6 271 € |
| | 0.020 € | 3 181 € | 3 539 € | 3 897 € | 4 256 € | 4 614 € | 4 972 € | 5 331 € | 5 689 € | 6 047 € | 6 406 € |
| | 0.025 € | 3 316 € | 3 674 € | 4 032 € | 4 391 € | **4 749 €** | 5 108 € | 5 466 € | 5 824 € | 6 183 € | 6 541 € |
| | 0.030 € | 3 451 € | 3 809 € | 4 168 € | 4 526 € | 4 884 € | 5 243 € | 5 601 € | 5 960 € | 6 318 € | 6 676 € |
| | 0.035 € | 3 586 € | 3 945 € | 4 303 € | 4 661 € | 5 020 € | 5 378 € | 5 736 € | 6 095 € | 6 453 € | 6 811 € |
| | 0.040 € | 3 721 € | 4 080 € | 4 438 € | 4 797 € | 5 155 € | 5 513 € | 5 872 € | 6 230 € | 6 588 € | 6 947 € |
| | 0.045 € | 3 857 € | 4 215 € | 4 573 € | 4 932 € | 5 290 € | 5 649 € | 6 007 € | 6 365 € | 6 724 € | 7 082 € |
| | 0.050 € | 3 992 € | 4 350 € | 4 709 € | 5 067 € | 5 425 € | 5 784 € | 6 142 € | 6 500 € | 6 859 € | 7 217 € |

Finally, by varying simultaneously the interest rate and inflation, one can conclude that the two variables affect the NPV with contrary forces – the NPV will be higher, the higher the inflation and the lower the interest rate. Further, it is possible to infer that a marginal change in inflation has a more substantial impact on the NPV in absolute terms (*Table 9*).

*Table 9 – Scenario analysis of the interest rate and inflation rate*

| | | Interest Rate | | | | |
|---|---|---|---|---|---|---|
| | | 4.00% | 4.50% | 5.00% | 6.00% | 7.00% |
| Inflation Rate | 1.50% | 4 439 € | 4 410 € | 4 380 € | 4 320 € | 4 259 € |
| | 2.00% | 4 778 € | **4 749 €** | 4 720 € | 4 659 € | 4 598 € |
| | 3.00% | 5 536 € | 5 507 € | 5 477 € | 5 417 € | 5 356 € |
| | 4.00% | 6 415 € | 6 386 € | 6 356 € | 6 296 € | 6 234 € |
| | 5.00% | 7 435 € | 7 406 € | 7 377 € | 7 316 € | 7 255 € |

## 5. Final Recommendation

Having looked for the optimal NPV in *Section 3.2.*, one can reasonably conclude that the best decision for the benchmark case would be to purchase a system of 5 solar panels of 410 Wp each, leading to a total installed power of 2 050 Wp. This investment has a payback period of 2.3 years, an IRR of 47%, and yields an NPV of 4 749 €.

To further maximize the NPV of this solution, the household should switch to a time-of-use tariff, as seen in *Section 4.2.*, which would allow the family to increase the NPV to 5 718 €, with a payback period of 1.8 years and an IRR of 59%, with the same initial investment required.

Other alternatives analysed, such as adding batteries (*Section 4.1*) and using a tracking panel (*Section 4.3.*), resulted in less attractive projects. In addition, several scenarios were studied in

*Section 4.4.*, showcasing the robustness of this investment - on all relevant variables, even under less favourable conditions than those expected, the project remains profitable to undertake. All the alternatives studied are summarized in *Table 10*.

***Table 10 – Summary and main results of analysed alternatives***

| Scenario | Section | NPV | IRR | Payback Period |
|---|---|---|---|---|
| Benchmark | *3.2.* | 4 749 € | 47% | 2.3 years |
| No Debt | *3.4.* | 4 820 € | 22% | 4.8 years |
| No Debt + No Subsidy | *3.4.* | 3 720 € | 13% | 8.0 years |
| Supplier's Credit | *3.4.* | N/A | N/A | N/A |
| No Sale to the Grid | *3.4.* | 4 073 € | 39% | 2.8 years |
| Battery Installation Subsidized | *4.1.* | 4 259 € | 24% | 4.7 years |
| Battery Installation Not Subsidized | *4.1.* | 803 € | 5% | 17.0 years |
| Time-of-use Tariff | *4.2.* | 5 718 € | 59% | 1.8 years |
| Tracking Panel | *4.3.* | 1 282 € | 6% | 17.0 years |

## 6. Limitations

A main limitation of this study lies within the low sample of household's electricity consumption data gathered, raising a concern on whether the information collected in *Section 2.2.* is representative of the region. If it had been possible to collect more answers on the survey, one could assess the statistical significance of the results.

On top of that, at the time of delivery of this thesis, the focal government subsidy incorporated in the model, PAE+S, was no longer available. Therefore, funding conditions in the next round of applications may be less favourable (in fact, it is possible that the subsidy is not renewed for another round), making the investment less profitable for the household, and possibly even leading to a modified optimal decision.

Finally, one could raise a concern regarding the fact that the NPV analysis was the methodology chosen. Complementing that analysis with the Real Options Approach (ROA) would allow to capture the characteristic uncertainty and volatility of a solar project, including the managerial flexibility to either delay the investment (Di Bari 2020), waiting to attain more information, or exercise the option (Gazheli and van den Bergh 2018). Hence, embedding uncertainty could allow one to reach a steadier and more reliable optimal investment.

## Appendix

***Table A1 – Excerpt from the questionnaire regarding household's consumption***

| **General Household Information** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Household** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **# People / Household** | 2 | 1 | 4 | 4 | 3 | 4 | 1 | 1 | 1 |
| **Short description of the household** | 2 Adults working full-time outside the house | 1 Adult working full-time outside the house | 1 Adult working full-time outside the house, 3 Elders staying at home | 2 Adults working full-time outside the house, 2 Kids studying at school | 3 Elders staying at home | 2 Adults working full-time outside the house, 2 Kids studying at school | 1 Adult working full-time outside the house | Vacation home, with large vineyard, typical of Douro region | Vacation home, with large vineyard, typical of Douro region |
| **Apartment (Apt) / Isolated House** | Apt | Apt | Apt | Isolated House | Isolated House | Isolated House | Apt | Isolated House | Isolated House |
| **Size (m2)** | 133 | 150 | 109 | 300 | 300 | 400 | 98 | 250 | 70 |
| **# Floors** | 1 | 2 | 1 | 2 | 3 | 3 | 1 | 1 | 1 |
| **Size (m2) of the garden/ terrain - if applicable** | N/A | N/A | N/A | 250 | 100 | 200 | N/A | 300 | 500 |
| **Construction Year** | 2002 | 1990 | 1995 | 2000 | 1958 | 1987 | 1967 | 2003 | 2003 |
| **Insulating Features** | Double-paned windows indoors coating | Double-paned window outdoors coating | No | Double-paned windows, thick stone walls | Double-paned windows, outdoors coating | Double-paned windows, outdoors coating | Double-paned windows | Double-paned windows, thick wood walls, roof tiles, false ceiling | Double-paned windows, thick stone walls |
| **Solar Panels** | No | No | No | No | No | No | No | No | No |
| | | | | | | | | | |
| **Major House Appliances** | | | | | | | | | |
| **Fridge** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Chest Freezer** | No | No | Yes | Yes | Yes | Yes | No | Yes | No |
| **Electric Stove** | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Electric Oven** | Yes | Yes | Yes | Yes | No | Yes | No | Yes | No |
| **Washing Machine** | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes | No |
| **Dryer** | Yes | No | No | No | Yes | Yes | No | No | No |
| **Dishwasher** | Yes | Yes | No | Yes | Yes | Yes | No | Yes | No |
| **Vacuum** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No |
| | | | | | | | | | |
| **Other Relevant Consumption** | | | | | | | | | |
| **Electric Water Heating** | Gas | Gas | Gas | Electric | Electric | Electric | Gas | Electric | Electric |
| **Space Heating** | Gas, fan heater every day | Electric oil heater | Oil heater | Oil heater | Oil heater, heat recover | Oil heater, heat recover | Oil heater | Oil heater, heat recover | No |
| **Space Cooling** | No | Yes, A/C | No | No | No | No | No | No | No |
| **General Lighting** | LED | LED | Incandescent | LED | Incandescent | Incandescent | LED | LED | Incandescent |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Others** | No | No | No | Electric car charged 2x week | Electric car | Electric car, pool | No | Pool | Pool |
| | | | | | | | | | |
| **Final Considerations** | | | | | | | | | |
| **Expected differences in monthly data** | N/A | Low in July and August | N/A | Low in August | Low in July and August | Higher summer occupancy, higher in winter | Low in July and August | Higher summer occupancy | Higher summer occupancy |
| **Energy Consumption Techniques** | Weekends to use washing machine | | | | | | | | |
| **Interest in installation of solar panels** | Yes | Yes | No | Yes | Yes | Yes | No | Yes | Yes |

***Excerpt A1 – Detailed explanation of E-REDES load profiles***

"The comparative analysis of the annual profile of different Low Voltage Tariff (BTN) classes reveals that BTN Class A has the lowest variation in energy consumption between winter months (January, February, and December) and summer months (July, August, September). In contrast, BTN Class B and C profiles show a more pronounced variation, especially with higher consumption in winter than in summer. Moreover, the amplitude of the average consumption throughout the week is higher in BTN Classes A and B when compared to the BTN Class C profile. Furthermore, while in BTN Classes A and B the average consumption is significantly higher on weekdays than on Saturdays and Sundays/holidays, in BTN Class C this variation is much smaller. These observations are expected considering the characteristics of customers in different classes, where BTN Class A customers are mainly composed of businesses with high contracted power, BTN Class B customers are mainly composed of hospitality clients and some households with high annual consumption, and BTN Class C customers are predominantly households. IP is public lighting." (E-REDES 2021)

*Table A2 – Summarized comparison of E-REDES load profiles*

| Profile | BTN A | BTN B | BTN C |
|---|---|---|---|
| **Apparent Power** | > 13.8 kVA | ≤ 13.8 kVA | ≤ 13.8 kVA |
| **Yearly Consumption** | Any consumption | > 7140 kWh | ≤ 7140 kWh |
| **Load Distribution** | Higher consumption from 9 a.m. to 6 p.m. on weekdays | Higher consumption in winter months | Higher consumption in winter months |

*Excerpt A2 – Detailed analyses of BTN C from E-REDES*

**"Analysis by type of day**:

- **Weekday**: The minimum consumption is reached between 4 a.m. and 6 a.m., increasing significantly until 8 a.m. Between 8 a.m. and 1 p.m., consumption stabilizes with a tendency to increase, reaching a local maximum at 1 p.m. and then decreasing until 4 p.m. / 5 p.m. Finally, consumption increases again until 9 p.m., reaching its daily maximum, decreasing again until the end of the day. The highest consumptions occur between 8 p.m. and 10 p.m. (dinner time) in all months of the year.

- **Saturday**: The profile is very similar to weekdays, with higher consumption throughout the day, except for the peak around 8 a.m. / 9 a.m. and the maximum value observed at 8 p.m. /9 p.m., for which consumption is slightly lower. The minimum consumption is reached between 4 a.m. and 6 a.m. from April to November, like on weekdays, but it occurs later, between 5 a.m. and 7 a.m. in January, February, March, and December. There is also a notable peak in consumption at lunchtime, which is more pronounced on Saturdays than on weekdays. Like weekdays, the highest consumptions occur between 8 p.m. and 10 p.m. (dinner time), being anticipated to the period between 7 p.m. and 9 p.m. in cold months (January, October, November, and December).

- **Sunday/holiday**: The profile is similar to Saturdays, although consumption during lunchtime has an even greater impact than observed on Saturdays. The minimum value is reached between 5 a.m. and 7 a.m." (E-REDES 2021)

*Table A3 – Photovoltaic panels quotes from studied suppliers*

| Supplier | Peak Power per Panel (Wp) | Peak Power (Wp) | # Panels | Price |
|---|---|---|---|---|
| **Contigo Energía** | 455 | 1820 | 4 | 2 788 € |
| | | 2275 | 5 | 3 024 € |
| | | 2730 | 6 | 3 286 € |
| | | 3185 | 7 | 3 521 € |
| | | 3640 | 8 | 3 809 € |
| **EDP** | 400 | 800 | 2 | 1 761 € |
| | | 1200 | 3 | 1 908 € |
| | | 2000 | 5 | 3 125 € |
| | | 3200 | 8 | 4 315 € |
| | 415 | 830 | 2 | 1 968 € |
| | | 1660 | 4 | 3 048 € |
| | | 2490 | 6 | 3 902 € |
| **Galp** | 380 | 760 | 2 | 1 600 € |
| | | 1140 | 3 | 2 030 € |
| | | 1520 | 4 | 2 360 € |
| | | 2280 | 6 | 2 960 € |
| | | 2660 | 7 | 3 300 € |
| | | 3040 | 8 | 3 630 € |
| | | 3420 | 9 | 3 910 € |
| | | 5320 | 14 | 6 580 € |
| **Gascan** | 370 | 740 | 2 | 1 992 € |
| | | 1480 | 4 | 2 632 € |
| | | 2960 | 8 | 4 188 € |
| | | 3700 | 10 | 5 200 € |
| **Goldenergy** | 405 | 810 | 2 | 1 426 € |
| | | 1215 | 3 | 1 984 € |
| | | 1620 | 4 | 2 323 € |
| | | 2025 | 5 | 3 006 € |
| | | 2430 | 6 | 3 316 € |
| | | 2835 | 7 | 3 626 € |
| | | 3240 | 8 | 4 030 € |
| | | 3645 | 9 | 4 402 € |
| | | 4050 | 10 | 4 867 € |
| **Iberdrola** | 380 | 380 | 1 | 896 € |
| | | 760 | 2 | 1 580 € |
| | | 1140 | 3 | 1 976 € |
| | | 1520 | 4 | 2 444 € |
| | | 1900 | 5 | 2 696 € |
| | | 2280 | 6 | 2 912 € |
| | | 3800 | 10 | 4 784 € |
| | | 4940 | 13 | 6 260 € |
| | | 6080 | 16 | 7 448 € |
| | | 7600 | 20 | 9 248 € |
| | | 8740 | 23 | 10 292 € |
| | | 9880 | 26 | 10 652 € |
| **IKEA + Contigo Energía (SOLSTRÅLE)** | 375 | 750 | 2 | 1 560 € |
| | | 1125 | 3 | 1 920 € |
| | | 1875 | 5 | 2 460 € |
| | | 2250 | 6 | 2 850 € |
| | | 3375 | 9 | 3 820 € |
| | | 3750 | 10 | 4 234 € |
| | | 4500 | 12 | 5 600 € |
| | 455 | 2730 | 6 | 4 079 € |
| | | 3185 | 7 | 4 492 € |
| | | 3640 | 8 | 4 974 € |
| **Sunenergy** | 410 | 1640 | 4 | 2 300 € |
| | | 2460 | 6 | 2 900 € |
| | | 3280 | 8 | 3 500 € |
| | | 4100 | 10 | 4 100 € |
| | | 4920 | 12 | 4 700 € |

***Table A4 – Maintenance providers and offered quotes per number of panels***

| #Panels | Total Cost | Cost per Panel | Provider |
|---|---|---|---|
| 1 | 119.00 € | 119 € | Leroy Merlin |
| 2 | 119.00 € | 60 € | Leroy Merlin |
| 3 | 119.00 € | 40 € | Leroy Merlin |
| 4 | 119.00 € | 30 € | Leroy Merlin |
| 5 | 119.00 € | 24 € | Leroy Merlin |
| 6 | 119.00 € | 20 € | Leroy Merlin |
| 7 | 119.99 € | 17 € | Worten |
| 8 | 119.99 € | 15 € | Worten |
| 9 | 169.99 € | 19 € | Worten |
| 10 | 169.99 € | 17 € | Worten |
| 11 | 169.99 € | 15 € | Worten |
| 12 | 169.99 € | 14 € | Worten |
| 13 | 169.99 € | 13 € | Worten |
| 14 | 169.99 € | 12 € | Worten |
| 15 | 249.99 € | 17 € | Worten |

***Table A5 – Government incentives regarding renewable energy available in Portugal***

| Name | Description |
|---|---|
| "Programa de Apoio a Edifícios + Sustentáveis"(PA+E) | "Fundo Ambiental": usually a yearly initiative by the Government and the EU.<br>Typology 1: Substitution of non-efficient windows to efficient windows (A+)<br>Typology 2: Application or substitution of insulating features in roofs, walls or floors<br>Typology 3: Water Heating systems (AQS) using renewable energy, with a minimum efficiency score of A+<br>**Typology 4: Installation of photovoltaic panels with or without batteries**<br>Typology 5: Interventions regarding water efficiency |
| Vale Eficiência | Help with improving overall energetical conditions of houses (e.g., updating major appliances, outdoor coating, indoor insulating). Owner should benefit from Social Tariff of Electric Energy. |
| Casa Eficiente 2020 | Program that provides a bank loan to improve energetic efficiency to families with little economic possibilities. Co-financed by Caixa Geral de Depósitos, Millenium BCP and Novo Banco. Commercial banks act as financial intermediaries between the European Investment Bank and the beneficiaries. |
| Article 12º of Código do IRS, Article 128º of Orçamento de Estado 2023 | Article 12º - Individuals that produce up to 1MW of energy from solar panels, and have revenue from selling excess energy of up to 1000€, have the revenue exempt from IRS |

*Table A6 – Studied offers of loans regarding renewable energies in Portugal*

| Bank | Minimum Amount | Maximum Amount | Minimum Term (months) | Maximum Term (months) | Rate |
|---|---|---|---|---|---|
| Activo Bank | 1 000 € | 75 000 € | 24 | 120 | **4.50%** |
| BPI | 1 000 € | N/A | 24 | 120 | 5.50% |
| Caixa Geral de Depósitos | 2 500 € | 75 000 € | 24 | 120 | 6.60% |
| Cetelem | 1 000 € | 50 000 € | 24 | 120 | 6.80% |
| CTT | 1 000 € | 50 000 € | 24 | 120 | 6.80% |
| Millennium BCP | 1 000 € | 75 000 € | 24 | 120 | 6.40% |
| Montepio | 2 000 € | 10 000 € | 36 | 96 | 13.40% |
| Novo Banco | 2 500 € | 30 000 € | 24 | 84 | 6.90% |
| Santander | 1 500 € | 8 000 € | 24 | 96 | 4.60% |

*Table A7 – Map of Cash Flows for a solution of 5 panels of 410 Wp, for a total of 2 050 Wp*

| Year | Equity Investment | Savings | Maintenance | Loan Repayment | Cash Flows | Present Value of Cash Flows |
|---|---|---|---|---|---|---|
| 0 | -375 € | | | | -375 € | -375 € |
| 1 | | 345 € | -43 € | -142 € | 160 € | 155 € |
| 2 | | 352 € | -44 € | -142 € | 166 € | 155 € |
| 3 | | 359 € | -45 € | -142 € | 172 € | 156 € |
| 4 | | 366 € | -45 € | -142 € | 178 € | 157 € |
| 5 | | 373 € | -46 € | -142 € | 185 € | 157 € |
| 6 | | 381 € | -47 € | -142 € | 191 € | 158 € |
| 7 | | 388 € | -48 € | -142 € | 198 € | 158 € |
| 8 | | 396 € | -49 € | -142 € | 205 € | 158 € |
| 9 | | 404 € | -50 € | -142 € | 212 € | 158 € |
| 10 | | 412 € | -51 € | -142 € | 219 € | 158 € |
| 11 | | 420 € | -52 € | | 368 € | 258 € |
| 12 | | 429 € | -53 € | | 375 € | 255 € |
| 13 | | 437 € | -54 € | | 383 € | 252 € |
| 14 | | 446 € | -55 € | | 391 € | 249 € |
| 15 | | 455 € | -57 € | | 398 € | 246 € |
| 16 | | 464 € | -58 € | | 406 € | 243 € |
| 17 | | 473 € | -59 € | | 414 € | 240 € |
| 18 | | 483 € | -60 € | | 423 € | 237 € |
| 19 | | 492 € | -61 € | | 431 € | 234 € |
| 20 | | 502 € | -62 € | | 440 € | 231 € |
| 21 | | 512 € | -64 € | | 449 € | 228 € |
| 22 | | 523 € | -65 € | | 458 € | 225 € |
| 23 | | 533 € | -66 € | | 467 € | 222 € |
| 24 | | 544 € | -68 € | | 476 € | 220 € |
| 25 | | 555 € | -69 € | | 486 € | 217 € |
| **NPV** | | | | | | **4 749 €** |

*Table A8 – Offered quotes for sets of photovoltaic panels and batteries from studied suppliers*

| Supplier | Peak Power per Panel (Wp) | Peak Power (Wp) | # Panels | Batteries' Capacity (kWh) | Price |
|---|---|---|---|---|---|
| **Iberdrola** | 380 | 2280 | 6 | 5 | 6 332 € |
| | | 3800 | 10 | 5 | 8 060 € |
| | | 4940 | 13 | 5 | 9 680 € |
| | | 6080 | 16 | 5 | 10 652 € |
| | | 7600 | 20 | 10 | 14 216 € |
| | | 8740 | 23 | 10 | 15 620 € |
| | | 9880 | 26 | 10 | 16 412 € |
| **Galp** | 380 | 1900 | 5 | 5 | 6 998 € |
| | | 2280 | 6 | 5 | 7 128 € |
| | | 2660 | 7 | 5 | 7 468 € |
| | | 3040 | 8 | 5 | 7 798 € |
| | | 3420 | 9 | 5 | 8 078 € |
| | | 4180 | 11 | 5 | 8 678 € |
| | | 4560 | 12 | 5 | 9 908 € |
| | | 4940 | 13 | 5 | 10 228 € |
| | | 7600 | 20 | 10 | 15 779 € |
| **Sunenergy** | 410 | 1640 | 4 | 3 | 6 000 € |
| | | 2460 | 6 | 5,8 | 7 500 € |
| | | 4100 | 10 | 11,6 | 12 000 € |
| | | 5740 | 14 | 17,4 | 16 000 € |
| | | 7380 | 18 | 17,4 | 17 500 € |

***Table A9 – Map of Cash Flows for a solution of 6 panels of 410 Wp, for a total of 2460 Wp, with a 5.8 kWh battery***

| **Year** | **Equity Investment** | **Savings** | **Maintenance** | **Loan Repayment** | **Cash Flows** | **Present Value of Cash Flows** |
|---|---|---|---|---|---|---|
| 0 | -1 050 € | | | | -1 050 € | -1 050 € |
| 1 | | 650 € | -51 € | -398 € | 200 € | 194 € |
| 2 | | 663 € | -52 € | -398 € | 212 € | 199 € |
| 3 | | 676 € | -54 € | -398 € | 224 € | 204 € |
| 4 | | 689 € | -55 € | -398 € | 237 € | 208 € |
| 5 | | 703 € | -56 € | -398 € | 249 € | 212 € |
| 6 | | 717 € | -57 € | -398 € | 262 € | 216 € |
| 7 | | 732 € | -58 € | -398 € | 276 € | 220 € |
| 8 | | 746 € | -59 € | -398 € | 289 € | 223 € |
| 9 | | 761 € | -60 € | -398 € | 303 € | 227 € |
| 10 | | 776 € | -61 € | -398 € | 317 € | 230 € |
| 11 | | 392 € | -63 € | | 329 € | 231 € |
| 12 | | 399 € | -64 € | | 335 € | 228 € |
| 13 | | 407 € | -65 € | | 342 € | 225 € |
| 14 | | 416 € | -67 € | | 349 € | 222 € |
| 15 | | 424 € | -68 € | | 356 € | 219 € |
| 16 | | 432 € | -69 € | | 363 € | 217 € |
| 17 | | 441 € | -71 € | | 370 € | 214 € |
| 18 | | 450 € | -72 € | | 378 € | 211 € |
| 19 | | 459 € | -73 € | | 385 € | 209 € |
| 20 | | 468 € | -75 € | | 393 € | 206 € |
| 21 | | 477 € | -76 € | | 401 € | 204 € |
| 22 | | 487 € | -78 € | | 409 € | 201 € |
| 23 | | 497 € | -80 € | | 417 € | 199 € |
| 24 | | 507 € | -81 € | | 425 € | 196 € |
| 25 | | 517 € | -83 € | | 434 € | 194 € |
| **NPV** | | | | | | **4 259 €** |

*Table A10 – Map of Cash Flows for a solution of 5 panels of 410 Wp, for a total of 2050 Wp, using a time-of-use tariff*

| Year | Equity Investment | Savings | Maintenance | Loan Repayment | Cash Flows | Present Value of Cash Flows |
|---|---|---|---|---|---|---|
| 0 | -375 € | | | | -375 € | -375 € |
| 1 | | 391 € | -43 € | -142 € | 206 € | 199 € |
| 2 | | 399 € | -44 € | -142 € | 213 € | 200 € |
| 3 | | 407 € | -45 € | -142 € | 220 € | 200 € |
| 4 | | 415 € | -45 € | -142 € | 227 € | 200 € |
| 5 | | 423 € | -46 € | -142 € | 235 € | 200 € |
| 6 | | 432 € | -47 € | -142 € | 242 € | 200 € |
| 7 | | 440 € | -48 € | -142 € | 250 € | 199 € |
| 8 | | 449 € | -49 € | -142 € | 258 € | 199 € |
| 9 | | 458 € | -50 € | -142 € | 266 € | 199 € |
| 10 | | 467 € | -51 € | -142 € | 274 € | 198 € |
| 11 | | 477 € | -52 € | | 424 € | 298 € |
| 12 | | 486 € | -53 € | | 433 € | 294 € |
| 13 | | 496 € | -54 € | | 442 € | 290 € |
| 14 | | 506 € | -55 € | | 450 € | 287 € |
| 15 | | 516 € | -57 € | | 459 € | 283 € |
| 16 | | 526 € | -58 € | | 469 € | 280 € |
| 17 | | 537 € | -59 € | | 478 € | 276 € |
| 18 | | 548 € | -60 € | | 488 € | 273 € |
| 19 | | 559 € | -61 € | | 497 € | 270 € |
| 20 | | 570 € | -62 € | | 507 € | 266 € |
| 21 | | 581 € | -64 € | | 517 € | 263 € |
| 22 | | 593 € | -65 € | | 528 € | 260 € |
| 23 | | 605 € | -66 € | | 538 € | 256 € |
| 24 | | 617 € | -68 € | | 549 € | 253 € |
| 25 | | 629 € | -69 € | | 560 € | 250 € |
| **NPV** | | | | | | **5 718 €** |

*Table A11 – Map of Cash Flows for a solution of 5 tracking panels of 410 Wp, for a total of 2050 Wp*

| Year | Equity Investment | Savings | Maintenance | Loan Repayment | Cash Flows | Present Value of Cash Flows |
|---|---|---|---|---|---|---|
| 0 | -1 550 € | | | | -1 550 € | -1 550 € |
| 1 | | 457 € | -86 € | -588 € | -216 € | -209 € |
| 2 | | 466 € | -87 € | -588 € | -209 € | -196 € |
| 3 | | 476 € | -89 € | -588 € | -201 € | -183 € |
| 4 | | 485 € | -91 € | -588 € | -194 € | -170 € |
| 5 | | 495 € | -93 € | -588 € | -186 € | -158 € |
| 6 | | 505 € | -95 € | -588 € | -178 € | -146 € |
| 7 | | 515 € | -97 € | -588 € | -169 € | -135 € |
| 8 | | 525 € | -98 € | -588 € | -161 € | -124 € |
| 9 | | 536 € | -100 € | -588 € | -153 € | -114 € |
| 10 | | 546 € | -102 € | -588 € | -144 € | -104 € |
| 11 | | 557 € | -104 € | | 453 € | 318 € |
| 12 | | 568 € | -107 € | | 462 € | 314 € |
| 13 | | 580 € | -109 € | | 471 € | 310 € |
| 14 | | 591 € | -111 € | | 480 € | 306 € |
| 15 | | 603 € | -113 € | | 490 € | 302 € |
| 16 | | 615 € | -115 € | | 500 € | 298 € |
| 17 | | 627 € | -118 € | | 510 € | 295 € |
| 18 | | 640 € | -120 € | | 520 € | 291 € |
| 19 | | 653 € | -122 € | | 530 € | 287 € |
| 20 | | 666 € | -125 € | | 541 € | 284 € |
| 21 | | 679 € | -127 € | | 552 € | 280 € |
| 22 | | 693 € | -130 € | | 563 € | 277 € |
| 23 | | 707 € | -133 € | | 574 € | 273 € |
| 24 | | 721 € | -135 € | | 586 € | 270 € |
| 25 | | 735 € | -138 € | | 597 € | 267 € |
| **NPV** | | | | | | **1 282 €** |

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