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 rooftop solar panels the case of Bordeaux in France

Jean Sulzer

Work project carried out under the supervision of:
João Pedro Pereira

17-12-2021

Table of Contents

ABSTRACT **1**

EXECUTIVE SUMMARY OF ROOFTOP SOLAR ANALYSIS **2**

INTRODUCTION **3**

1. ASSUMPTIONS **4**

1.1 Housing assumptions 4

1.2 Solar panels assumptions 4

1.3 Financing assumptions 5

1.4 External assumptions 6

2. DATA AND METHODOLOGY **7**

2.1 Solar irradiance and electricity generation 7

2.2 Electricity Consumption 8

2.3 Economic Data 10

2.4 Government subsidy 15

3. ECONOMIC ANALYSIS **17**

3.1 Cash Flow calculation 17

3.2 Net Present Value 17

3.3 Levelized Cost Of Energy 18

3.4 Payback Period 18

3.5 Internal Rate of Return 19

4. SCENARIO ANALYSIS **19**

4.1 Scenario with Debt = 75% 20

4.2 Scenario with equity = 100% 21

4.3 RECOMMENDATIONS: 21

5. OPTIONAL ADDITIONAL ANALYSIS : CHANGE IN ENERGY USAGE 22

REFERENCES 24

APPENDICES 25

Abstract

This project presents the methodology for the valuation of a photovoltaic project in the city of Bordeaux. After collecting data on solar radiation, local electricity consumption, electricity costs and the costs of purchasing and installing solar panels, an excel model was built to determine, the amount of solar panels to be installed that will generate the highest Net Present Value (NPV), as well as calculate other financial metrics (IRR, Payback Period, LCOE) that enable project analysis. The development below presents the methodology of data collection and explains the results of the excel model.

Keywords : Energy Finance, Rooftop Solar, Economic Analysis, Bordeaux

Executive Summary of rooftop solar analysis

Location: Bordeaux, France **Date of analysis**: Dec/2021

***Recommendation**: install 24 solar panels (43.008 m^2), for a net present value of 7149.72€ euros, with a payback of 15.48 Years.*

Main economic results:

Financing	NPV (EUR)	Payback (Years)	IRR Goal Seek (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% debt	6660€	16.28	4.8946%	0.123
Gov. subsidies and 100% equity	7150€	15.48	4.5241%	0.085
No gov. subsidies and 100% equity	4704€	17.53	3.3987%	0.099

Additional results:

The change of heating mode from gas to electricity and the associated increase in electricity consumption will generate an NPV of 12074.67 € and a payback period of 13.61 Years for a project with 24 solar panels.

Main inputs and assumptions:

Household and Economics

Electricity Consumption	7368	kWh/year	Inflation	1.5%	per year
Electricity price – buy	0.1605	EUR/kWh	Bank loan interest rate	2.47%	per year
Electricity price – sell	0.1	EUR/kWh	Bank loan maturity	5	years
			Equity cost of capital	1.59%	per year

PV panels chosen

Peak power	370	W/panel	System losses	15%	of output
Panel area	1.792	m^2/panel	Degradation with age	0.5%	Per year
Useful life	25	Years	Maintenance costs	5	EUR/year per SQM
		Total cost of optimal installation size		19468.94	EUR

Government subsidy:

Fix Electricity Selling Price to the Grid + "Self-Consumption Premium" depending on the power of the installation :

Less than or equal to 3 kWp	380 €/kWp
Between 3 and 9 kWp	280 €/kWp
Between 9 and 36 kWp	160 €/kWp
Between 36 and 100 kWp	80 €/kWp

Introduction

The year 2020 represents a record year for renewable energy worldwide, as according to the International Renewable Energy Agency, total renewable energy production capacity would have increased by 50% in that year alone (IRENA, 2020). China and the United States of America are now the leaders in the renewable energy race and this represents a great hope for building a resilient world.

On a smaller scale, in France, solar energy continues to develop due to two main factors:
The price of electricity has been rising in France for the last 10 years (Insunwetrust, 2021) while the price of solar panels has been falling, many people are wondering if electricity from photovoltaic production is profitable and if it is worthwhile for an individual to install solar panels at home in order to reduce their electricity bills and even generate income by selling the excess energy to the grid. In 2020 in France, the photovoltaic park maximum capacity was more than 10.39 GW, which represents an increase of 8.6% compared to 2019. (RTE, 2021) Even if the results are not up to the objectives set by the PPE (Ecologie Gouv, 2018) there are constantly improving.

In this work, we will study the level of profitability of a solar project using several financial instruments. However, other subjects than financial ones must be studied, such as ecological problems (pollutions). Indeed, even if the electrical production of the solar panels does not release CO2, the manufacture, the transport, the installation or the recycling of the solar panels can pollute the environment and impact the global warming.

1. **Assumptions**

In order to perform my model and find the best solar installation for a family of 2 parents and 2 children, I had to build a context and therefore make assumptions, the main one was specify in the detailed plan of the field lab, indeed it was asked to consider a solar panel installation with optimal production conditions, that is to say a southern exposure and a slope of 30 %. Considering this first main assumption I decided to use different ones that I classified in 4 different categories:

1.1 Housing assumptions

Family of 4 people (2 parents, 2 children) living in an 100 sqm apartment gas-heated (Data-collection) in the center of Bordeaux, I choose this assumption because, according to study published in 2007 by Carte de France (Carte de France, 2007) , the households in Bordeaux are composed by 75% of apartment whereas 25% of houses. Even if this study is old, I believe that housing structure in a middle size city doesn't change that much along time.

1.2 Solar panels assumptions

I assume that the panels used will be of the type "Q.PEAK DUO-G8+" or equivalent, as received in the quote from one of the solar panel installers. These are the monocrystalline type panels which are now very popular and mainly used in rooftop solar panels installation.

The characteristics of this product are : Peak Power Output : 370 Wp, Efficiency up to 20.4% (QCells, 2017) meaning that the solar panels are able to convert up to 20.4% of the solar radiation into electricity. Manufacturer's warranty of : At least 98 % of nominal power during first year. Thereafter max. 0.54 % degradation per year. At least 93.1 % of nominal power up to 10 years. At least 85 % of nominal power up to 25 years. (QCells, 2017) From those information, I assume the Lifespan of panels is equals to 25 years or 300 months. After this life time, the solar panel continues to produce electricity but with less consistency so it is difficult to calculate the economic value of energy produced. I also used this manufacturer's warranty to measure the loose in efficiency of the solar panels over the life of the project. (2% first year and 0.54% thereafter) As shown in some studies, energy is lost in the system through heat dissipation when electricity is passed through the cables. The performance of the system is therefore not 100% but can vary between 75% and 90% (Hellowatt, 2019) depending on the quality of the inverters, the temperature or other elements of the system. I have chosen a performance ratio of 85%, because I assume the material used to be good quality and losses to be not important. I expect the maintenance cost to be 5€ (Prix Travaux m2, 2021) per square meters every years for the cleaning of the panels, this expense would be in May, in order for the panel to be clean during summer and be the most effective.

1.3 Financing assumptions

For the basic analysis, we were asked to assume the project to be financed 75% by Debt and 25 % by equity. At the end of this report, you can also find the results as if the solar panel installation was 100% Equity financed.

After comparing different offers from several local banks, I decided to use the 5 years loan from "Crédit Agricole" which offers a low interest rate compared to it peers. This interest rate varies according to the amount of money requested, but in any case it remains lower than those of its competitors and is about 2.488% (Crédit Agricole Aquitaine, 2021).

1.4 External assumptions

According to Banque de France studies (Banque de France, 2021) the expected inflation will vary around 1.3% and 1,8%, in France during the next 3 years so I assume the inflation to be 1.5% per year during the life time of the panel (25 years).

Moreover, some other studies emphasize that the inflation in electricity price will be 2.12 % (Statista, 2017) per year for the 10 next years and then the price will remain the same. I therefore used those estimation in my model to calculate the increase in electricity price over the solar panels life time.

Regarding the taxes system in France, it exists an advantage for installation with power equals or less than 3 kWp,(Insunwetrust, 2021), indeed the surplus of electricity produced by those installation are not exposed to income taxes. So the amount collected by selling the electricity to the grid will not be taxable. However, for installation higher than 3 kWp, it exists two types of income taxations for individuals :

Either "Micro-BIC" for revenue from 0 € to 70 000 €: Addition of 29% of the revenue from the sale of electricity to the net tax, if and only if income are higher than 305 € per year. (Insunwetrust, 2021)

Or "Régime Réel d'imposition simplifié" for revenue from 70 000€ to 247 000€: Deduction of expenses and depreciation from income and possibility of recovering VAT on the investment. (Insunwetrust, 2021)

Considering the type of installation "domestic usage", I assume the revenue from the solar panel installation will not exceed 70 000€ per year before solar panels income. That is why I choose the first income taxes method in order to compute the NPV of the project. Then I had to calculate the taxation level of this family. To do so, I assumed it is a middle class family, with annual revenue around 70 000 €. For this type of family (2 adults, 2 children) we have to divide the total revenue per 3 in order to find the taxable income (70 000/3= 23

333.33€), so the tax bracket corresponds to 11% (Service Public, 2021) of the income. After the income taxes, it exists social security contributions at a level of 15.5% of the taxable income (29% of the total revenue) if and only if the amount is higher than 61€ per year.

To illustrate this tax system, here is a quick example for solar panel installation higher than 3 kWp:

Revenue from electricity selling to the grid : 500€
Taxable income = (500*29%)= 145 €
Income taxes = 145 * 11%= 15.95€
Social security contributions = 145 * 15.5% = 22.475 € < 61€
In this case there is no social security contributions.

2. Data and Methodology

2.1 Solar irradiance and electricity generation

The first step in the Data collection was to find a good measure of the the solar irradiance in Bordeaux. To do so I used the Solcast API Toolkit (Solcast, 2021) , it allowed me to download semi-hourly solar irradiance on Excel. In my case, I chose the 2019 Year as it is a normal year (Not leap year as 2020) and used the data expressed in GHI (W/sqm) to convert it in kWh. After some filtering and chronological classification of the data I used those different formulas to convert the Solar Irradiance (GHI) in kWh (Formula 1) and Electricity Generated (Formula 2) by my system in kWh (EG):

Formula 1 : $Solar\ Radiation_t = GHI_t * 0.001$

Formula 2 : $EG_t = Solar\ Radiation_t * X * PR * E$

Where

X is the solar panel surface in square meters (sqm)

PR is Performance Ratio = 85% (See assumptions)

E is Efficiency = 20.4% (See Assumptions)

I multiplied the values in GHI by 0.001 and then by the number of sqm of my installation (X). This calculation allowed me to get the hourly energy production of the solar panels for the year 2019 in kWh if performance ratio (PR) and efficiency (E) was 100%. However as stated in the assumptions, performance ratio = 85% and efficiency = 20.4 %. So I multiplied the value obtained in the last calculation by 0.85 and 0.204.

I could use it, later on, to calculate the **Energy Savings** I get from this solar installation as well as the income it generates by selling the **Excess Energy** produced to the grid.

2.2 Electricity Consumption

For the most precise analysis we were asked to get hourly consumption data for a standard household family of 4 people (2 parents, 2 children) in our project location. To do so, I asked several family and friends for their annual electricity invoices. I collected 3 invoices from families living in or close to Bordeaux with different consumption profiles. All three were heated by gas which is very common in France and in Bordeaux, but had different specificities regarding water heaters and appliances in the house. I therefore thought that the average of the three could give a good approximation of the Yearly Electricity Consumption (Formula 3) of an apartment in Bordeaux

Formula 3 :

Yearly Electricity Consumption = AVERAGE(Electricity Consumption Family 1+ Electricity Consumption Family 2 + Electricity Consumption Family 3) = ***7368 kWh /year***

Family 1 (Appendix 1) (2 parents, 1 children) lives in the suburb of Bordeaux and has a modern house more or less equals to 220sqm, with gas heating, electric stove and heated pool. The invoice collected and the associated yearly consumption (14568 kWh - Subscription 12 kVA) is probably higher than a standard family of 4 people living in an apartment in the city center of Bordeaux.

The second family (Appendix 2) (2 parents) lives in the city center of Bordeaux, in a renovated 70 sqm apartment. They use city gas for heating and water heating but they have an electric stove. I assume this family to have a yearly electric consumption (4104 kWh - Subscription 9 kVA) close to the standard or a bit below.

The third family (2 parents) lives in an old house, in Bordeaux, the superficies of the house is around 150 sqm and they use gas water heater and also a gas cooker, all the others household alliances uses electricity. I believe this family yearly electricity consumption (3432 kWh – Subscription 9 kVA) is below the standard family electricity consumption living in Bordeaux.

The three accommodations from which I received the electricity bills are heated with gas, so I assume that the average of these three accommodations corresponds to a 100 m2 accommodation in the center of Bordeaux heated with gas. In order to do my hourly calculation, I took the results of this formula and I divided it by the number of hour during the year 2019, and found the Hourly Electricity Consumption (Formula 4) for 2019.

Formula 4:

Hourly Electricity Consumption = Annual Electricity Consumption / Number of hours in 2019 = ***0.84109589 kWh***

Once I calculated the electric hourly consumption of a standard family in Bordeaux, I found on the open data platform of Enedis (subsidiary 100% owned by EDF which owns and cares about 95% of the electric grid in France), the hourly consumption coefficient for each hour of the year 2019 (Enedis, 2021) and different profiles. I choose the profile "RES11 Base" as it takes into account all the individual (Not industrial) consumers that ask for subscription power higher than 6 kVA since the 3 invoices I received where for power 9 kVA or higher. Then I multiplied the hourly consumption found previously by the static coefficient for each hours of the year. So I could find the Adjusted Hourly Electricity Consumption (Formula 5) for each hours in 2019.

Formula 5 :

$$Adjusted\ Hourly\ electricity\ consumption_{\boldsymbol{t}} = Hourly\ electricity\ consumption_{\boldsymbol{t}} * Coefficient\ \text{“}RES11\ Base\text{”}_{\boldsymbol{t}}$$

2.3 Economic Data

Electricity cost:

In France you can choose between 2 options for the electric subscriptions, either you pay your electricity at Basic tariff meaning that you pay your electricity at a fix price all day long. Or you can choose the option "Heure creuse" meaning that during 8 hours of the day, you'll pay your electricity at low cost.

The electricity prices and subscriptions depend on the distributor you choose to furnish the electricity at your household. In France, the largest electricity company remains EDF with market shares around 66% (Selectra, 2021) of the distribution and controls the entire electric grid thanks to the subsidiary RTE.

Considering EDF important market shares, I decided to use their electricity prices as benchmark for my model. For the Basic Analysis, I used the Basic tariff for subscriptions higher than 6 kVA. In 2021, this price is set at 0.1605€/ kWh (EDF, 2021).

Aside from this consumption tariffication, the users have to pay an annual subscription to be connected and use the grid. For subscription equals to 9 kVA (the one I Used for my model) the price is 171.24€ per year (EDF, 2021). The price increases for subscription to more powerful contract. Thanks to the data collected on the electrical production of the system, the average electrical consumption of a household in Bordeaux and the Inflation Adjusted Electricity Purchase Price (Formula 6), I was able to calculate the Energy Savings (Formula 7) & Excess Energy (Formula 10) during each month of the year.

Energy Savings: Represents the amount of electrical energy in euros saved by the household's thanks to the installation of solar panels.

Formula 6 :

$$Inflation\ Adjsuted\ Electrcity\ Purchase\ Price_{\boldsymbol{t}} = Electricity\ Purchase\ Price_{\boldsymbol{t}} * Electricity\ Inflation\ Rate_t$$

Formula 7 :

$$Energy\ Savings\ _t = (Electricity\ Consumption\ Before\ Rooftop\ Solar\ _t - Electricity\ Consumption\ After\ Rooftop\ Solar_t) * Inflation\ Adjsuted\ Electrcity\ Purchase\ Price_{\boldsymbol{t}}$$

I then adjusted the energy savings and maintenance costs for inflation:

Formula 8:

$$Inflation\ Adjusted\ Energy\ Savings_{\ \boldsymbol{t}} = \ Energy\ Savings_{\ \boldsymbol{t}} * \ Inflation\ Rate_{\boldsymbol{t}}$$

Formula 9:

$$Inflation\ Adjusted\ Maintenance\ Costs_t = \ Maintenance\ Costs_{\ t} * \ Inflation\ Rate_t$$

Excess Energy (Sold to the market): It is important to note that the Excess Energy (sold to the market) is only present when the electricity production from the solar panels is higher than the household consumption.

Formula 10:

$$Excess\ Energy_{\ t} = \ Electricity\ Produced\ by\ Rooftop\ Solar_{\ t} - Energy\ Consumed\ by\ the\ Household_t$$

Electricity price by selling to the grid:

In France, the government wants to favorize the electricity production from "green" & sustainable sources. Thus, they encourage responsible production and self-consumption. Depending on the type of installation and the power it produces, the government has fixed prices for the energy company to buy electricity from individuals, those price are fix for 3 months and are reviewed every semester. In our assumptions, we stated that the Solar Panel installation is destinated to a Standard family in Bordeaux which will consume the electricity produced and sell the excess production to the grid. In that case, there are two fixed selling prices. The first one corresponds to installation with production power inferior or equals to 9 kWp and is set at 0.10€ per kWh (Total, 2021) and the second one for installations between 9 kWp and 100 kWc is set at 0.06€ per kWh (Total, 2021), above 100 kWp the installation is no longer considered as individual production and therefore not protected by the government regulations. Once I found the data on the market price of electricity, I was able to calculate the Revenue from the resale of the excess energy (Revenue from FiT Formula 11) for each month of the year.

Formula 11 :

$$Revenue\ from\ FiT_t = \ Excess\ Energy_t * Electricity\ Selling\ Price_t$$

(As mentioned before, Electricity Selling Price must be adapted to the power of the rooftop solar project)

I then deducted the Income Taxes from the Taxable income (See Taxes assumption).

Formula 12:

$$Revenue\ from\ FiT\ after\ Taxes_t = Revenue\ from\ FiT_t * (1 - Taxable\ Income\ Rate_t) * (1 - Income\ Taxes\ Rate_t)$$

Installation cost of solar panels:

In order to have the most precise analysis, I contacted several Solar Panels producers and installers and managed simulations on the internet to receive different quotes and compare the prices of the solar panels installers.

For a 3 kWp installation I received 1 quote from Effy with a total investment before government subsidy of 7990 € (Appendix 4) . This offer includes the installation of 9 monocrystalline solar panels with a capacity of up to 3 kWp as well as micro-inverters that allow the system to have a minimum lifetime of 25 years.

For a 6 kWp installation I received 2 quotes from different companies. The first one was from Effy with a total cost of 14642 € and the second one from Hellio with a total cost of 15990€ before government subsidy. This offer includes the installation of 18 Monocrystalline solar panels with a capacity of up to 6 kWp as well as micro-inverters that allow the system to have a minimum lifetime of 25 years. I also did a simulation with the Insunwetrust website which gave me a price estimate of 14000 € before investment premium for the same type of installation. (Appendix 5-3)

Once I received it I made the average of the prices quoted for installation equals to 3 kWp and 6 kWp and realized a liner interpolation of the price for Solar installation from 1 solar panels to 30 solar panels in order to find the CAPEX of the project. The result of this linear interpolation is the following :

Formula 13:

$$Capex_t = 765.26x + 1102.7$$

Where x is the number of panels (From 1 to 30 panels)

Interest rate for consumer loan:

After some research on the internet to find a loan fitting to Solar Panel project, I found loans for "Sustainable projects" with 0% interest rates. At first sight, this loan seems very interesting for our project as it would allow us to finance our installation, by spreading the payments, without paying interest. However, once looking at the loans conditions I understood that Solar Panel Project doesn't respect the eligibility for those types of loans, except if you realize other modifications for your house and you change the insulation for example. It would consequently change the nature of the project and this is not what we are expecting. After doing deeper researches on the internet and comparing the offers of several major French banks (BNP Paribas, Crédit Mutuel, Caisse d' Epargne, Banque Populaire, etc.) I found that Crédit Agricole offered loans for individuals with low interest rates for a 5 year maturity and decided to use their interests on loans in order to perform my model.

To do so, I calculated 75% of the solar panels installation prices that will be financed by debt and see what interest the credit Agricole offers me, and found the following loan: **5 year maturity (M) with 2.488% (Rd) yearly interest.**

With this data, I was able to calculate the annuity factor and then the annual payment to repay the loan.

Formula 14: $Annuity\ Factor_t = \frac{(1-(1+Rd)^{-M})}{Rd}$

Formula 15:

$$Annual\ Loan\ Repayment_t = (CAPEX_t * 0.75)\ /\ Annuity\ Factor_t$$

Once I collected all these data, and divided it by 12 to calculate the Monthly Debt Repayment.

2.4 Government subsidy

In France, as I said before, the government promotes the individual production and consumption. So they fix electricity selling price to the grid, as mentioned before. Moreover, since 2017, the government offers subsidy for individuals installing solar panels at their home respecting several conditions :

The individual should auto-consume the electricity it produces and sell the excess production to the grid.

The Solar Panels should be installed on a roof or a similar support structure in parallel to it, ground-mounted photovoltaic panel installations are not eligible.

The Installations power should be less than 100 kWp.

The work should be realized by a RGE label certified company. This label was created by the Ministry of Ecological and Solidarity Transition in 2011.

Those subsidies are based on the installation power and it is distributed during 5 years after the beginning of the project.

Amount of the subsidy per installation per kWp (Ministry of Economy, Finance and Recovery, 2021)

Less than or equal to 3 kWp	380 €/kWp
Between 3 and 9 kWp	280 €/kWp
Between 9 and 36 kWp	160 €/kWp
Between 36 and 100 kWp	80 €/kWp

In order to find the appropriate government subsidy, I had to calculate the power of the solar panel installation and associate it to the right amount of subside in the table above:

Formula 16 :

*Project Power (kWp) = Peak Power per Solar panels * Number of Panels*

Formula 17:

$$Government\ Subsidy_t = Project\ Power\ (kWp) * Corresponding\ Level\ of\ Government\ Subsidy$$

After calculating the correct amount of government subsidy over 5 years, I divided it by 5 in order to find the annual amount paid by the government and assumed that it would be paid in the first month of the year for 5 years.

3. **Economic Analysis**

3.1 Cash Flow calculation

After collecting the data and calculating the different elements (Inflation adjusted Energy savings, Revenue from FiT, Inflation adjusted maintenance costs, CAPEX, Taxes, Annual loan repayment and government subsidy), I was able to calculate the monthly cash flows generated by the project depending on the number of solar panels installed.

Formula 18:

$$\begin{aligned} Cash\ Flow\ After\ Taxes\ and\ Debt\ Repayment_t \\ &= -Capex_t + Revenue\ From\ FiT\ After\ Taxes_t \\ &+ Inflation\ Adjusted\ Energy\ Savings_t \\ &- Inflation\ Adjusted\ Maintenance\ Costs_t \\ &- Monthly\ Loan\ Repayment_t + Government\ Subsidy_t \end{aligned}$$

Once the cash flows per month were established, I could start to establish the parameters of the Economic analysis.

3.2 Net Present Value

The parameter on which our analysis is based is the Net Present Value (NPV), which allows us to calculate the value that the project creates for the economic entity that implements it (The family in this case). It is calculated by discounting all cash flows by the appropriate discount rate, in this case the cost of equity for a standard household in France. As the 10 years government Bond is negative in France, I choose the 10 year swap rate r = 1.59%

Formula 19:

$$NPV = \sum_{t=1}^{n} \frac{Cash\ Flow\ After\ Taxes\ and\ Debt\ repayment}{(1+r)^t}$$

r represent the appropriate discount rate, in this case it is the cost of equity

3.3 Levelized Cost Of Energy

Levelized cost of electricity (LCOE) allows to determine the average production cost of 1 kWh, it is calculated thanks to the average total costs of building and operating the project over the total electricity production in kWh during its life time.

Formula 20:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_i + M_t}{(1+r)^t}}{\frac{E_t}{(1+r)^t}}$$

Where :

I_t Represent the total initial investment with financing

M_t Represent the maintenance costs in Month t

E_t Represent the electricity generation in Month t

r is the appropriate discount rate, in this case it is the cost of equity.

3.4 Payback Period

The payback period represents the time during which the initial investment will be covered by the revenues and the project becomes profitable. In my model, I used the cumulative free cash flows to find out which month it goes positive and thus find out in which months the income covers the investment.

3.5 Internal Rate of Return

The Internal Rate of Return (IRR) is a very used financial indicators that calculate at which discount rate the NPV of the project would be set to 0.

Formula 21:

$$0 = NPV = \sum_{t=1}^{n} \frac{Cash\ Flow\ After\ Taxes\ and\ Debt\ repayment_t}{(1 + IRR)^t}$$

4. Scenario Analysis

Despite some differences between the results of the two scenarios, there are also many similarities. Firstly, we notice that in both situations, the NPV remains positive between 2 and 24 panels, therefore it will be financially interesting for an average family living in Bordeaux to install between 2 and 24 solar panels at home, regardless of the type of financing. However, we observe some disparities in the curve, indeed, from 1 to 9 solar panels, the NPV sloap increases strongly. This is explained by the important increases in revenues from savings and surplus production resale to the grid. Between 10 and 24 solar panels, the curve continues to increase but less strongly, because the revenues coming from the savings stagnate or increase less, while the one coming from the resale of the surplus continues to increase. Also in each scenarios, the maximum NPV is reached at 24 panels, and a power slightly below 9 kWp, after which the resale price of the electricity increases from 0.1 €/ kWh to 0.06 €/ kWh. Moreover, we notice that in each scenario, the LCOE decreases with the number of solar panels installed, i.e. the larger the solar installation, the lower the production cost of 1 kWh. Finally, we notice a negative relationship between IRR and payback, indeed, the payback period decreases when the IRR increases. (Appendix Table 1 & 2)

4.1 Scenario with Debt = 75%

After collecting the data and running the model with debt financing = 75 % and equity financing = 25%, I was able to build the NPV curve.

Figure 1 : NPV Generated per number of panels with Debt financing = 75% (Without subsidy)

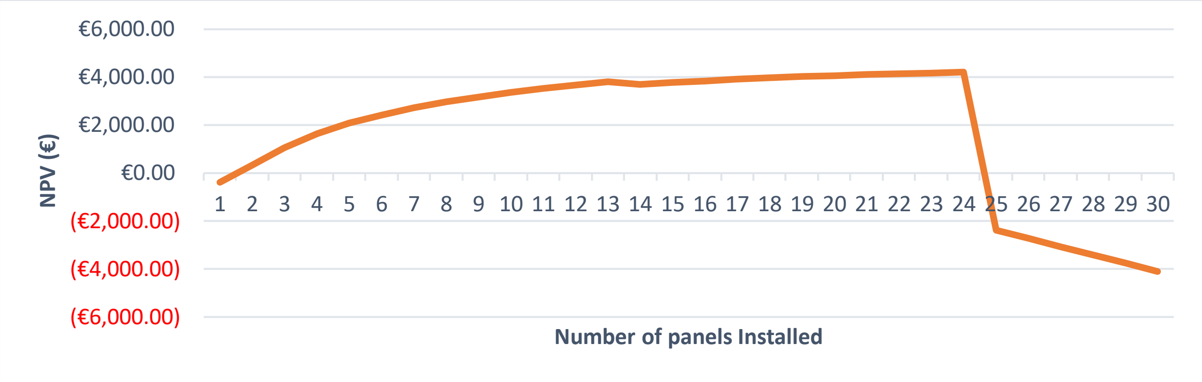


Figure 1 represent the NPV associated to the number of panels installed, without government subsidy. The most valuable project is reached at 24 panels with NPV of 4214.70 €, with a Payback Period of 219.35 Months and LCOE of 0.1230 €/kWh. For such a large installation, the majority of the incomes come from the resale of the surplus to the grid, it is thus logical that the NPV is strongly impacted by this decrease of the resale prices.

Figure 2 (Appendix) represents the NPV associated with the number of panels installed, with government subsidy we notice that the curve is very similar to the one in figure 1, however the NPV increases thanks to the subsidy. Indeed, the Maximum NPV for this scenario is reached at 24 panels with a value of 6660.47€. The Government Subsidy also reduces the payback period and LCOE of the project therefore, it allows the installation to reach the break-even point earlier.

`

4.2 Scenario with equity = 100%

After the different projects valuations with 75 % debt financed, we were asked to evaluate the same project 100% equity financed.

Figure 3 : NPV Generated per number of panels with Equity = 100% (Without subsidy)

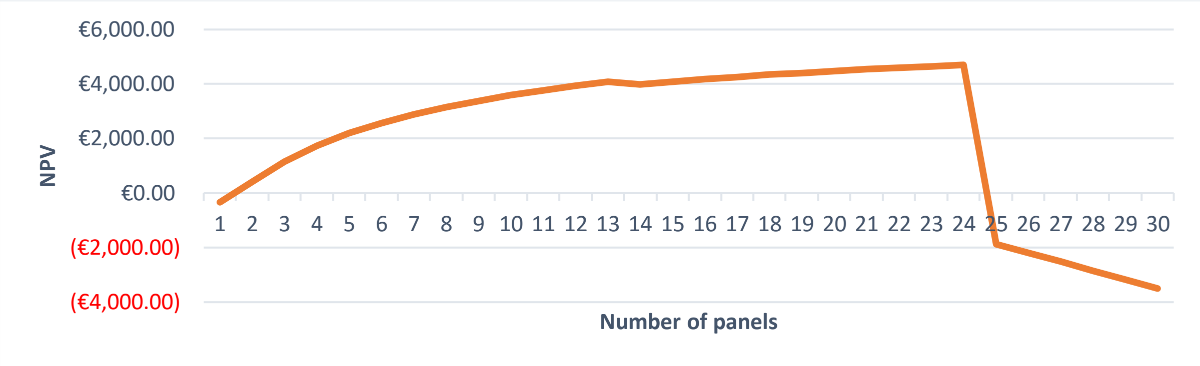


Figure 3 represent the NPV associated to the number of panels installed, if the project was 100% equity financed, without government subsidy. We note that the slope of the NPV curve is similar of the one Figure 1 however the values are slightly higher and the maximum NPV is 4703.95€. This difference comes from the fact that debt financing is more expensive than equity financing Rd (2.488%) > Re (1.59%). Therefore Payback Period and LCOE decreases with equity financing.

Figure 4 (Appendix) represent the NPV associated to the number of panels installed, if the project was 100% equity financed, with government subsidy. The maximum NPV is 7149.72€ and the government subsidy increases the NPV of the project, decrease the Payback Period and the LCOE of the project compared to Figure 3.

4.3 Recommendations:

As it is a NPV based analysis, it seem that Scenario 2 with government subsidy is most valuable project for this type of household. So my recommendation is to install 24 panels, 100% financed with equity, and ask for the government subsidy. The project would generate an NPV of 7149.72 €, with a payback of 185.75 Months, IRR of 4.5241 % and LCOE of 0.085 €/kWh.

5. Optional Additional Analysis : Change in energy usage

As I found the number of installed panels very large, I wondered how a change in heating source and increase in power consumption could influence the project NPV and payback.

As stated in the assumptions, the apartment is heated with gas, so I thought it would be interesting to compare the results if it was heated with electricity. I looked into the electrical consumption of the house and found an average of 110 kWh/sqm (Selectra, 2021) per year.

I multiplied this figure by the number of sqm in the flat, 110 kWh * 100 sqm, which means an annual increase of 11000 kWh for the household.

The final annual consumption of the household will therefore be 18368 kWh. I have then distributed this annual consumption to the 8760 hours of the year by the same procedure as in the basic analysis with the consumption coefficient “Coef RES11 Base”.

After analyzing the NPV curves (Figures 5 - 6), we can clearly see that the increase in electricity consumption justifies the installation of a large number of solar panels, in fact, the NPV reaches 12074.67 € with government subsidy for the installation of 24 solar panels 75% Debt financed which is largely superior to the 6660.47 € associated with this same project but with a lower electricity consumption as there is no electric heating. The payback decreases from 18.28 Years from the previous analysis to 13.61 Years for this type of project and electricity consumption associated and the IRR reach 7.25%.

This increase in the value of the project comes from the increase in electricity savings thanks to the project. The difference between the two types of consumption comes from the nature of the revenues, in the basic analysis with the “low” electricity consumption we notice that, with a large number of solar panels, the majority of the revenues comes from the resale of electricity to the grid at 0.1 €/kWh. In the optional analysis, the electricity consumption of the household is higher, so the revenues generated by the savings are also higher. In other words, the kWh that are not sold to the grid at 0.1€/kWh are saved from the household electricity expenses at

0.1605 €/ kWh. It should also be noted that when the resale price of electricity increases from 0.1€/kWh to 0.06 €/kWh, the NPV of the project decreases but it remains positive thanks to the important savings.

Références

Carte de France. Accessed September 4, 2021. http://www.cartesfrance.fr/Bordeaux-33300/logement-Bordeaux.html.

"Coefficients Des Profils." ENEDIS Open Data. Accessed October 5, 2021. https://data.enedis.fr/page/coefficients-des-profils/?flg=fr.

Gabriele, Florian. "Fiscalité Des Panneau Solaire: Guide Définitif (2021)." In Sun We Trust, November 5, 2021. https://www.insunwetrust.solar/blog/conso/fiscalite-de-lenergie-solaire-photovoltaique/.

"[Guide 2021] Rendement Des Panneaux Solaires." Hello Watt. Accessed September 13, 2021. https://www.hellowatt.fr/panneaux-solaires-photovoltaiques/rendement-panneaux-solaires.

Hilario, P. Godoy. "Électricité : Prix Estimé France 2040." Statista. Accessed September 25, 2021. https://fr.statista.com/statistiques/666336/prevision-prix-electricite-france/.

"Installation De Panneaux Solaires : Vous Avez Droit à Des Aides !" Accueil. Accessed October 15, 2021. https://www.economie.gouv.fr/particuliers/aides-installation-photovoltaiques.

"Prix Des Panneaux Solaires En 2021." Tous les prix des travaux au m2. Accessed October 23, 2021. https://www.prix-travaux-m2.com/prix-panneaux-solaires.php.

"Prix Rachat Du KWh Photovoltaïque En 2021." Total Spring. Accessed October 14, 2021. https://www.total-spring.fr/prix-rachat-kwh-photovoltaique-2020/.

"Production – Production Renouvelable : RTE Bilan Électrique 2020." Bilan électrique 2018. Accessed December 4, 2021. https://bilan-electrique-2020.rte-france.com/production-production-renouvelable/#.

"Projections Macroéconomiques – Septembre 2021." Banque de France, September 23, 2021. https://publications.banque-france.fr/projections-macroeconomiques-septembre-2021.

"Q Cells." Q.PEAK DUO-G8+ : Q.PEAK DUO G8 Series : SOLAR PANELS : PRODUCTS : Q CELLS. Accessed October 20, 2021. https://www.q-cells.com/en/main/products/solar_panels/G8/G8_series01.html.

"Quel Est Le Barème De L'impôt Sur Le Revenu ?" Particuliers - actif. Accessed November 15, 2021. https://www.service-public.fr/particuliers/vosdroits/F1419.

"Simulateur Crédit Travaux - Crédit Agricole D'aquitaine." Simulateur Crédit Travaux - Crédit Agricole d'Aquitaine. Accessed September 19, 2021. https://www.credit-agricole.fr/ca-aquitaine/particulier/simulation-devis/credits/simulateur-credit-travaux-deco.html.

"Solcast API Toolkit." Solcast API Toolkit. Accessed September 5, 2021. https://toolkit.solcast.com.au/.

"Tarif EDF 2021: Augmentation Prix Electricité (Explications)." In Sun We Trust, November 4, 2021. https://www.insunwetrust.solar/blog/le-solaire-et-vous/augmentation-prix-electricite/.

"Www.ecologie.gouv.fr." Accessed December 8, 2021. https://www.ecologie.gouv.fr/sites/default/files/20200422%20Programmation%20pluriannuelle%20de%20l%27e%CC%81nergie.pdf.

"Www.particulier.edf.fr." Accessed October 11, 2021. https://www.particulier.edf.fr/content/dam/2-Actifs/Documents/Offres/grille-prix-digiwatt.pdf.

Yl, Anonyme, Arnaud, and Sarah Nonfoux. "EDF (Electricité De France) : Tarifs Particuliers & Pros, Contacts." Fournisseurs, December 8, 2021. https://www.fournisseurs-electricite.com/edf.

Appendices

Table 1: Summary Scenario 1 = 75 % Debt Financed

Scenario 1 Without Subsidy

Number Of Panels Installed	1	5	10	15	20	24	30
NPV	-€390.97	€2077.53	€3369.22	€3772.46	€4068.00	€4214.70	-€4104.04
Payback Period	-	199.67	198.17	208.08	213.57	219.35	-
LCOE	0.2540	0.1446	0.1310	0.1264	0.1241	0.1230	0.1218
IRR	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Scenario 1 With Subsidy

Number Of Panels Installed	1	5	10	15	20	24	30
NPV	-€255.10	€2756.91	€4388.29	€5301.07	€6106.14	€6660.47	-€2387.71
Payback Period	-	170.42	175.20	185.02	190.63	195.35	-
LCOE	0.2540	0.1446	0.1310	0.1264	0.1241	0.1230	0.1218
IRR	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Table 2: Summary Scenario 2 = 100 % Equity Financed

Scenario 2 Without Subsidy							
Number Of Panels Installed	1	5	10	15	20	24	30
NPV	-€344.03	€2201.39	€3589.24	€4088.63	€4480.32	€4703.95	-€3499.41
Payback Period	0.00	185.01	187.01	198.03	204.64	210.39	-
LCOE	0.2055	0.1172	0.1062	0.1025	0.1007	0.0997	0.0988
IRR	0.00%	0.39%	0.38%	0.33%	0.30%	0.28%	0.08%
Scenario 2 With Subsidy							
Number Of Panels Installed	1	5	10	15	20	24	30
NPV	-€208.16	€2880.77	€4608.31	€5617.24	€6518.46	€7149.72	-€1783.08
Payback Period	0.00	161.61	166.24	175.00	181.25	185.75	-
LCOE	0.2055	0.1172	0.1062	0.1025	0.1007	0.0997	0.0988
IRR	0.05%	0.50%	0.46%	0.42%	0.39%	0.38%	0.03%

Figure 3 : NPV Generated per number of panels with Debt financing = 75% (Without subsidy)

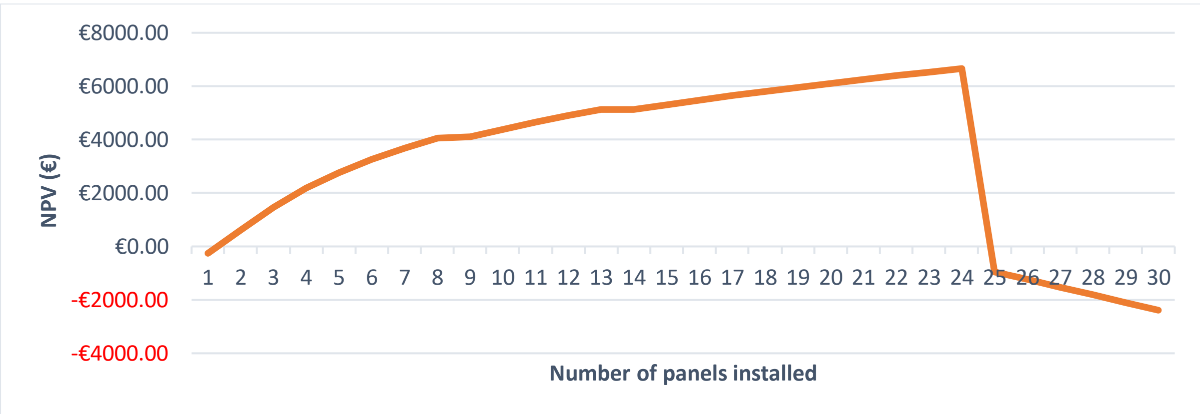


Figure 4 : NPV Generated per number of panels with Equity = 100% (Without subsidy)

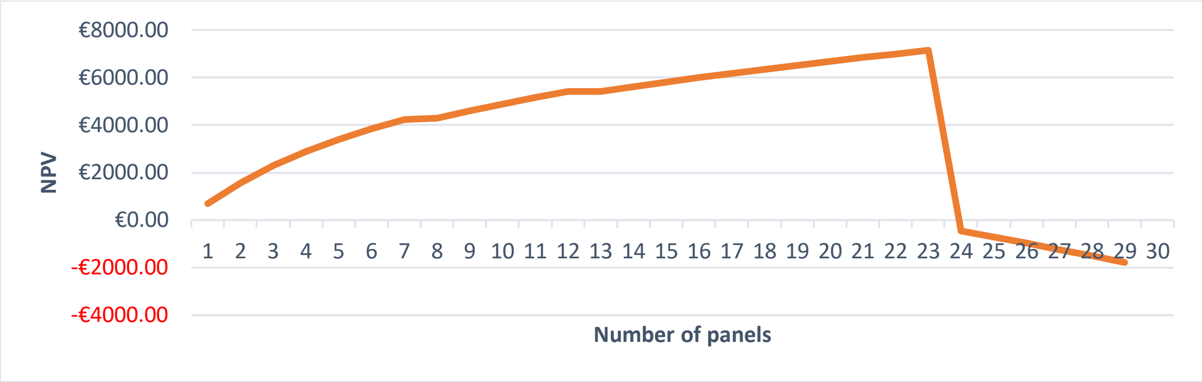


Figure 5 : Additional analysis - NPV Generated per number of panels with Debt financing = 75% (With subsidy)

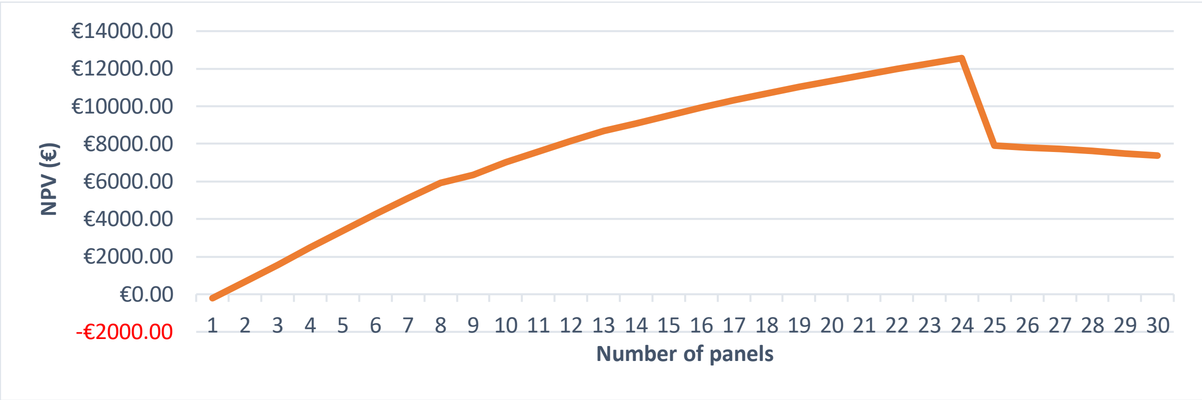
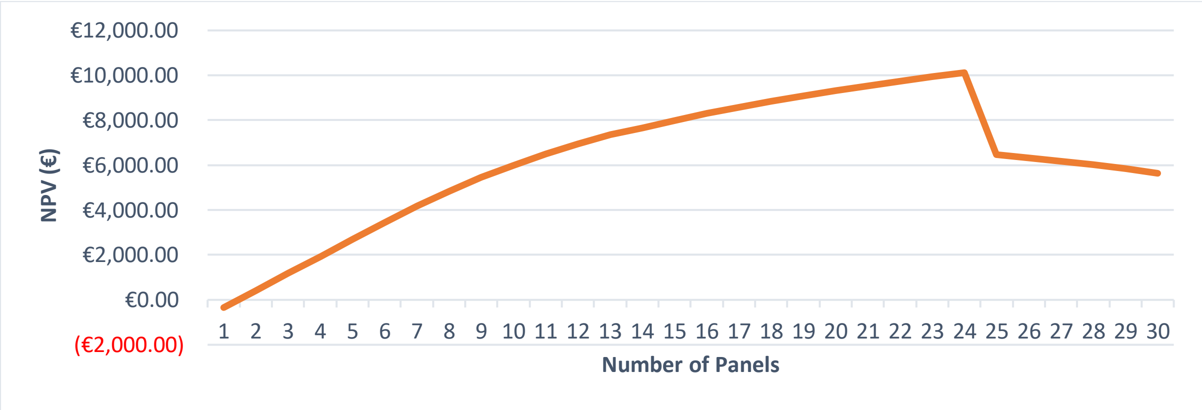


Figure 6 : Additional analysis - NPV Generated per number of panels with Debt financing = 75% (Without subsidy)



Appendix 1 : Electricity Invoice Family 1 Total yearly consumption : 14568 kWh

Document à conserver 5 ans — Page 2/4

Détail de la facture du 14/12/2020 N°31559138836

Votre contrat Electricité

"Tarif Bleu" - 12 kVA - Option Heures Creuses - Compteur communicant n°81177536009148
Horaires heures creuses - 22H36-6H36 - (peuvent varier de quelques minutes)

	Relevé début	Relevé fin	Conso kWh	Prix €HT/mois	Montant €HT	TVA
Abonnement						
Heures Creuses - 12kVA - du 14/12/19 au 31/01/20				12,17	19,55	5,5%
Heures Creuses - 12kVA - du 01/02/20 au 31/07/20				12,28	73,28	5,5%
Heures Creuses - 12kVA - du 01/08/20 au 13/12/20				12,97	57,41	5,5%
Heures Creuses - 12kVA - du 14/12/20 au 13/01/21				12,97	12,97	5,5%
Déduction - Heures Creuses - 12kVA - du 14/12/19 au 13/01/20				12,17	-12,17	5,5%
Total Abonnement (dont acheminement 120,44 €)					**151,04**	
	Relevé début	Relevé fin	Conso kWh	Prix €HT/kWh	Montant €HT	TVA
Consommation						
Heures Creuses - 12kVA - du 14/12/19 au 13/12/20	10925 (Enedis)	15950 (Enedis)	5025	0,0791 (1)	397,39	20,0%
Heures Pleines - 12kVA - du 14/12/19 au 13/12/20	22718 (Enedis)	32261 (Enedis)	9543	0,1158 (2)	1 105,20	20,0%
Total Consommation (dont acheminement 414,87 €)			14568		**1 502,59**	
			Conso kWh	Prix €HT/ kWh	Montant €HT	TVA
Taxes et Contributions						
Taxe sur la Consommation Finale d'Electricité (TCFE)			14568	0,00981 (3)(4)	142,93	20,0%
Contribution au Service Public d'Electricité (CSPE)			14568	0,02250	327,78	20,0%
Contribution Tarifaire d'Acheminement Electricité (CTA)					32,57	5,5%
Total Taxes et Contributions					**503,28**	
Total Electricité hors TVA					**2 156,91**	

Appendix 2 : Electricity Invoice Family 2 Total yearly consumption : 4104 kWh

Détail de la facture du 30/12/2020 N°34364309398

Votre contrat Electricité

"Tarif Bleu" - 09 kVA - Option Base - Compteur électronique n°526

	Relevé début	Relevé fin	Conso kWh	Prix €HT/mois	Montant €HT	TVA
Abonnement						
Base - 09kVA - du 26/12/19 au 31/01/20				9,38	11,38	5,5%
Base - 09kVA - du 01/02/20 au 31/07/20				9,50	56,69	5,5%
Base - 09kVA - du 01/08/20 au 25/12/20				10,07	48,53	5,5%
Base - 09kVA - du 26/12/20 au 25/01/21				10,07	10,07	5,5%
Déduction - Base - 09kVA - du 26/12/19 au 25/01/20				9,38	-9,38	5,5%
Total Abonnement (dont acheminement 84,92 €)					**117,29**	
	Relevé début	Relevé fin	Conso kWh	Prix €HT/kWh	Montant €HT	TVA
Consommation						
Base - 09kVA - du 26/12/19 au 25/12/20	51214 (Enedis)	55318 (Enedis)	4104	0,1000 (1)	410,49	20,0%
Total Consommation (dont acheminement 156,53 €)			4104		**410,49**	
			Conso kWh	Prix €HT/ kWh	Montant €HT	TVA
Taxes et Contributions						
Taxe sur la Consommation Finale d'Electricité (TCFE)			4104	0,00982 (2)(3)	40,29	20,0%
Contribution au Service Public d'Electricité (CSPE)			4104	0,02250	92,34	20,0%
Contribution Tarifaire d'Acheminement Electricité (CTA)					22,96	5,5%
Total Taxes et Contributions					**155,59**	
Total Electricité hors TVA					**683,37**	

Appendix 3 : Quote Effy 18 Solar panels (6kWp)

effy

DEVIS n° VTI-02010

Offre EFFY SOLAIRE

Date : 17/09/2021
Validité du devis : 1 mois

Installation photovoltaïque en autoconsommation avec vente de surplus

1. Identification du client

M/Mme :	Mr.
Nom :	Sulzer
Prénom :	Jean
N° Client:	SUN-26456
Téléphone :	0679442152
Adresse mail	jean.sulzer@hotmail.fr
Adresse d'installation	**Adresse de facturation**
Boulevard du Président Wilson	Boulevard du Président Wilson
33000	33000
Bordeaux	Bordeaux

2. Caractéristiques et prix de l'offre

Puissance de la Solution 5.9 kWc

	Montant HT		Taux TVA	Montant TVA	Montant TTC	
Fourniture de la Solution Photovoltaïque						
Puissance crête installée : 5.9kWc Panneaux : 18 modules Q-Peak DUO BLK-G9+ Onduleur : 18 micro-onduleurs Enphase IQ7+ Système de surimposition K2 Systems Coffret de protection électrique respectant les normes françaises NF 15712 Passerelle "Enphase ENVOY S METERED" pour visualiser la consommation globale de la maison et la production globale de l'installation (sous réserve d'une connexion internet)	10 088,75 €	HT	20.00%	2 017,75 €	12 106,50 €	TTC
Dont éco participation	*6,48 €*	*HT*	*20.00%*	*1,30 €*	*7,78 €*	*TTC*
Prestations (dont main d'oeuvre)						
Installation par un installateur qualifié et RGE Assurance décennale Effy Service d'assistance administrative (Déclaration Préalable, Demande de Raccordement, Consuel) Essai, paramétrage et mise en service du système de surveillance (monitoring) Nettoyage de fin de chantier SAV assuré par nos équipes dédiées	3 362,92 €	HT	20.00%	672,58 €	4 035,50 €	TTC
TOTAL	**13 451,67 €**	**HT**	**20.00%**	**2 690,33 €**	**16 142,00 €**	**TTC**
Offre promotionelle						
Remise commerciale dans le cadre de l'Offre de rentrée**	**-1250,00 €**	**HT**	**20.00%**	**-250,00 €**	**-1500,00 €**	**TTC**

Total commande à régler par le client	**14 642,00 € TTC**
Prime à l'investissement	
Estimation du montant de la prime d'investissement en vigueur à la date d'emission du devis (Voir détails en page 2 au §4)	**1652,00 € TTC**
Pour information : montant de votre investissement total (déduction faite de la prime à l'investissement)	**12 990,00 € TTC**

*Le prix de la Solution Photovoltaïque comprend une éco-participation de 0.36 HT par module selon la référence PV.11103 du barème en vigueur.
**Offre promotionnelle "Offre de rentrée" valable du 01/09/2021 au 30/09/2021

EFFY SOLAIRE, SAS au capital de 2.350.000 euros - 804 085 694 R.C.S. PARIS
Tour Montparnasse 33 avenue du Maine - BP 195 - 75755 Paris Cedex 15, France
Tél. : 0 806 70 11 11 - Mail : solaire@effy.fr
TVA intra. : FR81804085694
N° d'immatriculation ORIAS : 20006938
Contrat d'assurance n°000000144650526 - MMA IARD SAS - 14 boulevard Marie et Alexandre Oyon - 72030 Le Mans Cedex 9

Appendix 4: Quote Effy 9 Solar panels (3kWp)

E

Effy <nepasrepondre@info.effy.fr>

To: Jean; Francois Sulzer

Wednesday 3 November 2021 at 08:33

Voici un récapitulatif de
votre projet d'installation de panneaux photovoltaïques.

Puissance de l'installation :

3 kWC

- 25 m^2 de surface d'installation
- Panneaux solaires garantis 25 ans

Production annuelle :

3566 kWh

- Vous allez gagner 525 € par an en moyenne

Coût estimatif des travaux **7990 €**

<u>Appendix 5 :</u> Quote Effy 16 Solar panels (6kWp)

hellio

A Paris, le 20/10/2021

Réf du devis : D-ST-PV-6kWc-

Devis : Installation de panneaux photovoltaïques

Information client :	Adresse du chantier :
Jean Sulzer 124 Cours du Médoc 33300 Bordeaux 33679442152 jean.sulzer@hotmail.fr	124 Cours du Médoc 33300 Bordeaux

L'établissement de ce devis est gratuit.

Il est établi suite à la suite d'une simulation et d'appels auprès d'un conseiller au : 20/10/2021

Puissance de l'installation photovoltaïque : 6 kWc
Nombre de panneaux installés : 16 panneaux photovoltaïques de marque DUALSUN
Date de début des travaux estimée : dans un délai de 1 à 3 mois à partir de la réalisation des conditions suspensives.
Durée estimée des travaux : estimation en cours.

Description	Quantité	Prix Unitaire	Prix total HT*
Fourniture de la solution photovoltaïque Puissance crête installée : 6 kWc Panneaux photovoltaiques : 16 modules DUALSUN PV FLASH SHINGLE 375WC Ensemble de structure : ESDEC ClickEvo (vis. rails. étrayés et clip de montage) Micros onduleurs : 16 micros onduleurs Enphase IQ7PLUS Coffret AC : D-E COFFRET AC ENPHASE FR IQ MONO	1	8 714,72 €	8 714,72 €
Installation et pose de la solution photovoltaïque	1	4 602,28 €	4 602,28 €
Visite technique	1	250,00 €	250,00 €

- 2 -17

Eco participation	1	8,00 €	8,00 €
Visite technique offerte	1	-250,00 €	- 250,00 €
Montant total HT		**13 325,00 €**	
TVA applicable (20%) En application de l'article 278 du CGI		**2 665,00 €**	
Montant total TTC		**15 990,00 €**	