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 PV PANELS: THE CASE OF GENOA

Riccardo Verona
46262

Work project carried out under the supervision of:

Prof. JOÃO PEREIRA
20/04/2022

Acknowledgments

This work used infrastructure and resources funded by Fundação para a Ciência e a Tecnologia (UID/ECO/00124/2013, UID/ECO/00124/2019 and Social Sciences DataLab, Project 22209), POR Lisboa (LISBOA-01-0145-FEDER-007722 and Social Sciences DataLab, Project 22209) and POR Norte (Social Sciences DataLab, Project 22209). Summary of rooftop solar analysis.

Summary of rooftop solar analysis

Location: Milan, Italy **Date of analysis**: April 2022

Recommendation*: Install four solar panels (7.69 m^2), for a net present value of 3415.08 euros, with a payback of 12 years.*

Main economic results:

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% debt	3415	12	10.7%	0.070
Gov. subsidies and 100% equity	3631	11	9.4%	0.066
No gov. subsidies and 100% equity	1473	18	3.6%	0.117

Additional results:

A system of six 400 W panels, together with a 5.12 kWh battery, requires an initial investment of € 9730. If the PV system is financed with 100% equity and government subsidies, it will provide an NPV of €6071.83, with a payback of 9 years.

Main inputs and assumptions:

Household and Economics

Electricity Consumption	3561	kWh/year	Inflation	2.0%	per year
Electricity price – buy	0.22	EUR/kWh	Bank loan interest rate	5.10%	per year
Electricity price – sell	0.00	EUR/kWh	Bank loan maturity	5	years
			Equity cost of capital	1.71%	per year

PV panels chosen

Peak power	400	W/panel	System losses	14,0%	of output
Panel area	1.92	m^2/panel	Degradation with age	0.5%	per year
Useful life	25	Years	Maintenance costs	€ 32	per year

Total cost of optimal installation size (without subsidies)	5700	EUR
Total cost of optimal installation size (after subsidies)	2850	EUR

Government subsidies:

The Italian government refunds 50% of the initial investment, up to a maximum of € 96,000, to install solar panels for self-consumption. Therefore, if the energy produced exceeds the household demand, it will not be possible to sell it with a Feed-in-Tariff.

INTRODUCTION

In 2020, the global rooftop solar photovoltaic (PV) market was valued at $64.3 billion. During the period 2021-2030, it is expected to grow at a CAGR of more than 12%. The C&I segment accounted for more than 60% of capacity, driven by the rapid growth in major solar PV markets such as China, the United States, and India.

The need for energy security, stability, and independence is a major motivator for governments to promote and develop renewable energy sources such as PV. Furthermore, increasing the use of renewable energy sources is critical in order to reduce the use of fossil fuels. The latter have been identified as one of the primary contributors to greenhouse gas emissions, making climate change a top priority challenge to be addressed in the coming decades. CO2 is the gas most associated with energy-related combustion, so much effort and research has gone into developing significant reductions. Energy production from renewable sources, such as photovoltaic plants, is one technological solution for reducing CO2 emissions. The use of PV in residential applications can significantly contribute to lowering the environmental impact of household consumption. Even so, due to the high investment cost, PV installation has not always been profitable, particularly for small plants. Nonetheless, the introduction of incentives and the progressive reduction of capital costs for PV modules in Italy have boosted residential PV installation. Domestic plants generate approximately 15% of national Photovoltaic systems, and approximately 30% of total PV capacity was installed in households in 2020 (GSE).

The goal of this Field Lab is to determine the unbiased economic value of installing a rooftop PV system for a standard household through metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), payback period, and Leverage Cost of Energy (LCOE). This paper is part of an international project in which the same analysis is repeated in different cities worldwide to obtain comparable results. The location used in this model is Milan, an

Italian municipality of 1,371,285 inhabitants, the capital of the Lombardy region, and located in Northern Italy. Throughout the next chapters, we will discuss the assumptions, analysis methodology, and recommendations used to find the optimal PV system that will maximize the NPV for the standard household.

DATA AND ASSUMPTIONS

a. Property Assumptions

To properly evaluate the economic value of the installation of a rooftop solar panel implant, this workshop takes into consideration the potential household investor in Milan. The latter can be associated with the standard household, which is composed of a family of 4, two parents, and two children. With both parents going off to work during the day, and both kids going to school.

Table 1 summarizes all the assumptions used for the property and its household. It is important to underline that these assumptions are not flexible, meaning that the economic model that follows can be only applied to properties and households that comply with them.

Table 1. Assumptions of the Property and its Household

Variable	Assumption
Location	Milan
House type	Isolated
Heating fuel	Gas
Household members	4
Occupancy	Half of day
Floors	2
Active energy managment	None
Roof size (m2)	30
Roof slope	39°
Shading	None
Roof direction	South

Milan has a mix of isolated homes and apartment buildings. To make the project relevant for the highest number of houses, I decided to assume that the household lives in an isolated house instead of an apartment. The reason behind this assessment relies on the fact that in Italy apartments owners, even the ones living on the last floor of the building, cannot take advantage of the common roof for personal use making the project irrelevant for them. Furthermore, the assumptions on the heating fuel, house floors, and roof size rely on the same principles of higher applicability of the project. Gas heating is the most used in Milan for detached houses such as a two-story plan and a 30 m2 roof size. The latter is assumed to have a South orientation with no nearby obstacles, meaning it has no shade covering it during the day.

Active energy management can be conducted through the programmed use of laundry machines and dishwashing machines during the middle of the day, where the solar panels will produce a higher amount of energy. This management is typically associated with a household that lives in a "smart house" and can increase significantly the savings associated with an SP system. But in Italy, there is a low penetration of "smart houses" (12.4%) compared to the U.S. and other European countries. It is so assumed in the model that the Milan family does not have active energy management.

b. **Solar Irradiance and Potential Electricity Generation**

To obtain the most precise data available regarding solar irradiance and potential electricity generation, the EU source "Photovoltaic Geographical Information System" was used. In order to have an average of the typical solar irradiance (W/m2) for a 1 kW PV system in Milan and avoid single-year bias, the values for the most recent years available were used in the model (2018-2019-2020). An average of the power (P) generated was then computed for each hour of every year to obtain a time series of 8760 values. The 29th of February was erased from the year 2020, since is not present in 2018 and 2019. These values vary depending on the PV system peak power and take into consideration the 14% system loss and the 0.5% degradation per year of the panels.

c. **Electricity Consumption**

A key element for this workshop is the electricity consumption of the "standard household" for the full year of 2021. To calculate it various electricity bills were collected from different parts of the city so that a bigger picture could be achieved. The average yearly electricity consumption in Milan obtained was 3561 kWh. To estimate the consumption on an hourly basis, which is essential to correctly estimate the inflow and outflow of energy from the house to the grid and the other way around, a bottom-up approach was used. The German program LoadProfileGenerator gives the user the possibility to personalize the load profile based on different types of families and cities in Europe. Data on the hourly electricity consumption for a "standard household" in Milan were collected, for different types of electric equipment. Table 2. summarize all assumptions used to establish the electric equipment that are present in a family of four in Milan.

Table 2. Assumptions for electric equipment

Factor	Value
TV	2
Laptops	2
CD/DVD player	2
Hifi System	2
Nindendo Wii	2
Dishwasher	1
Wahing machine	1
Dryer	1
Kitchen equipment	12
Microwave	1
Electric stove	1
Air Conditioner	1
Bath equipment	3
Lights	8
Radio	2

The hourly values of the equipment were then summed up and calibrated to create an accurate time series of 8760 values that reflects the consumption pattern of the standard household for the entire year in Milan for a total consumption of 3561 kWh. The load profile underlines the presents of the typical three peaks in the Italian Residential Sector: between 19.30 and 22.30, in the early morning from 7.30 to 9.30, and at lunchtime between 11.30 and 13.30.

d. **Energy Price**

In Italy, the energy price can be fixed or indexed depending on the contract stipulated by the household. When the €/kWh cost is fixed, it means that the price of electricity will always be the same for the duration of the offer. On the other hand, indexed cost means that the price of electricity changes over time depending on the market cost of raw materials, such as gas and petrol, which are needed to produce energy. If you take out a fixed price electricity contract, this means that the price will not change for a contractually agreed period, usually one, two, or three years. Furthermore, the price of electricity can be mono-hourly, i.e., constant throughout the day, or bi-hourly, in which case it changes in the two consumption time bands F1(8.00-19.00 Monday to Friday) and F23(every other hour of the week), or multi-hourly, in which case all the F1, F2 (7.00-8.00 and 19.00-23.00 Monday to Friday), and F3 (23.00-7.00 Monday to Friday and Weekends) bands are distinguished (mostly used by companies).

For the model, the contract is assumed to be fixed and mono-hourly. The energy price per hour was obtained throughout the analysis of the bills by averaging the yearly cost of electricity of the different households. The price resulted in 0.22 €/kWh for the year 2021. The outcome is in line with the average Italian electricity price which, for 2021, was between 0.21 €/kWh and 0.24 €/kWh (GSE).

The possible revenue that the family can generate by selling excess electricity produced by the photovoltaic system to the grid strictly depends on the Feed-in-Tariff that the Gestore dei Servizi Eletrici (GSE) is willing to pay. The GSE is a public entity, which is exclusively authorized to exchange energy produced by renewable energy. Through deep research on their database, the average price of 0.03 €/kWh was obtained. The latter can change within a range of 0.01 €/kWh to 0.1 €/kWh depending on supply and demand theory, but various solar panels providers also suggested a fixed Feed-in-Tariff of 0,03 €/kWh based on their previous analysis. It was so assumed for the model a fixed price of 0,03 €/kWh for the duration of the investment.

It is important to underline that the Feed-in-Tariff becomes 0.00 €/kWh when the investor decides to use the government subsidies since the financial aids are provided only for self-consumption solar panels systems. A more specific explanation will be provided throughout this paper.

e. **Solar Panels Quotes**

The selection of the optimal solar panel (SP) system to optimize the financial benefits of the landlord came through primary research where panels providers were directly contacted. Out of 18, 3 provided inclusive quotes that comprehended different types of peak power, size, and quantity. Appendix 1. shows all the installation costs of the different solar panel providers, without government subsidies, and relatives' features. To select the preferred provider a comparison of different factors, which are summarized in Table 3., was conducted. Warranty length was exempt from the assessment since all the providers offered the same length of 25 years.

Table 3. Attributes of Solar Panels

Factor	Value	Unit
Peak Power	400	W
Efficiency	20.81%	W/m2
Space	1,92	m2
Size	4	panels
Total Space	7.69	m2
Cost	5700.00	€
Cost per kWp	3562.50	€/kWp

The provider Wölmann and the Trinasolar 400 W panels were chosen for the model since they had the higher panel efficiency and one of the lowest Costs per kWp. Furthermore, Wölmann provided the real quotes for almost all the sizes of solar systems that are analyzed in the workshop and the specific installing cost for a single panel of € 2800. The latter was fundamental for the linear interpolation that has been used to create an educated guess for the quotes of solar systems that are composed of 2 and 3 panels. Moreover, the choice also depended on the fact that the panels provider added a discount on the yearly maintenance costs of the SP system that the landlord will incur. In Italy, the yearly maintenance costs of a photovoltaic system vary between 0.02 and 0.1 €/W. The highest maintenance costs are incurred by systems located in remote areas and for the maintenance of generators in hybrid systems, as well as for the replacement of components damaged by extreme weather events or vandalism. Wölmann offered 0.02 €/W for occasional cleaning and preventive maintenance of the panels, to avoid the loss of efficiency over time. Appendix 2. and 3. provide, respectively, the summary table of the Wölmann quotes and the graph representing the relationship between installation price and the number of solar panels.

f. **Bank Interest Rate**

The initial capital investment for a photovoltaic system can be very expensive and some households may need a bank loan to afford it. For this reason, the model also analyzes the scenario where the landowner borrows 75% of the total cost of installation. To obtain the optimal loan interest rate and terms, 8 local and international banks were contacted. The interest rates obtained are designed for a family of 4 where both parents earn an average salary in Milan of 59,000 €/year in the Italian private sector. They fluctuate through a range that goes from 5.10% and 12.87% since some banks take into consideration how the debtor will use the credit and others don't (i.e., if the debtor uses the credit for an environmental purpose, they offer lower rates). Appendix 4. represents the list of the lenders provided and the interest rates offered.

The most advantageous rate is the one offered by Findomestic with a TAEG of 5.10% with a 5-year maturity for a maximum amount of €10000. It is assumed that the investor will choose the lowest rate at his disposal, hance the Findomestic loan terms have been selected for this scenario in the financial analysis.

g. **Government Subsidies**

The “restructuring bonus”, extended until 2024, was introduced in 1986 with Presidential Decree 917 by the Italian government and has been enhanced several times to take into consideration new technologies. This bonus is intended for all citizens who own property and who decide to renovate their home based on an objective of overall energy efficiency upgrading of the house such as the installation of a solar panel system. It gives the possibility to have a discount on the total construction cost, up to a maximum of € 96,000, translated into tax benefits distributed in 10-year spam. The main change was brought by the Relaunch Decree, published in the Official Journal on 18 July 2020. From that moment on, the taxpayer can opt, alternatively to the deduction, for a discount directly on the invoice or the transfer of the credit to a third party. The discount offered by the government subsidy was raised to 50% of the total installation cost by the 2021 Finance Bill. Furthermore, the 2022 Budget Law extended the “renovation bonus” until 31 December 2024, until the public funds committed are available.

When a taxpayer takes advantage of the government subsidies for a photovoltaic system the authority specifies that the system must be only for self-consumption. It is thereby forbidden for the landowner to sell the excess energy produced to the grid (GSE) but he must give it away for free.

ECONOMIC ANALYSIS

h. Net Inflow/Outflow

Basic Analysis

Once all the data have been gathered and the relative assumptions clarified the model can be set up. To evaluate the financial benefit of the photovoltaic system we need to establish three key elements. First, the annual amount of system generated energy that is directly consumed by the house (Self Consumption), second, the annual amount of system generated energy that is sold directly to the grid (Sold to Grid), and ultimately the amount of electricity that the household will buy directly from the grid (Residual Load).

To do so, the model initially compares the hourly time series of the household energy demand and the hourly production of the solar panel system. Since no electricity generated is expected to be wasted, for each hour we can clearly divide the energy into that sold to the grid (PV to grid) and that which the household consumes (PV to home). The latter can never exceed the value of the load profile. The last thing to establish is the hourly volume of kWh the landlord will buy directly from the grid. It can be computed by the difference between the demand and the generated energy. Table 4. summarize the annual energy net outflow of this analysis for a 1.6 kWp PV system. It is important to underline that the model can adjust the production data for different system sizes.

Table 4. Annual energy net outflow

Factor	Value	Unit
Consumption	3561	kWh
Generation	2192	kWh
Self Consumption	1285	kWh
Sold to Grid	907	kWh
Residual Load	2276	kWh

It is now possible to assess the financial revenues, costs, and savings of the flow of electricity generated by the photovoltaic system. As stated in section 2.4, the Residual Load (RL) is paid with a fixed price (0.22 €/kWh) and a mono-hourly contract. Thereby, the Residual Cost was obtained by multiplying the RL by the fixed price. As also previously mentioned in section 2.4, the landlord can create a yearly revenue by selling the excess energy to the greed at a Feed-in-Tariff of 0.00 €/kWh or 0.03 €/kWh depending on the decision to use gov. subsidies. The savings are then calculated by subtracting the Residual Cost from the Cost without panels and then adding up the Revenue. Table 5. presents the annual economic net flow for the installation of a 1.6 kWp PV system.

Table 5. Net annual economic flow

Factor	Value	Unit
Cost w/o panels	794.78	€/year
Revenue	0.00	€/year
Residual Cost	507.93	€/year
Savings due to PV system	286.85	€/year

It is important to note that, if the landowner decides to don't take advantage of government subsidies, the revenues produced by the four panels PV system will be € 27.22. Therefore, the total annual savings will rise to € 314.07.

Additional Analysis (Batteries Storage)

The battery storage system (BSS) used in the additional analysis is a lithium battery device that absorbs and releases electrical energy. Integrated with photovoltaic systems, the BSS is an important element of development in terms of energy autonomy and efficient use of the energy produced by buildings, both public and private, as they allow the energy produced by the photovoltaic system to be accumulated and used at times of greater demand. Furthermore, in Milan, where the amount of energy Self Consumed is very low in comparison to the Residual Load, a BBS could increase the yearly savings of the landlord and therefore the financial benefits of the overall PV system.

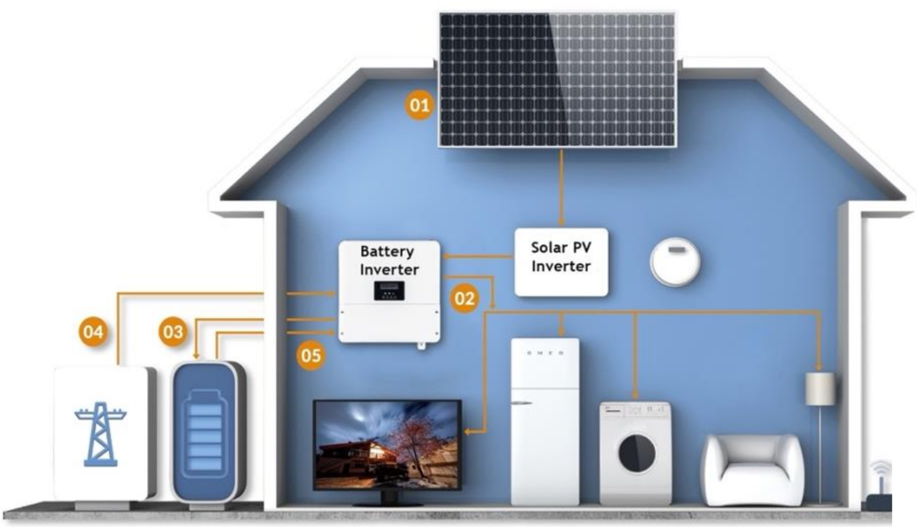
At the end of 2020, just under 40,000 storage systems were installed in Italy, with a nominal capacity of 189 MW, corresponding to an installed capacity of plants connected to storage systems of 231 MW. Since 2015, the trend in BSS installations has been one of strong growth. In 2020, in particular, the number and the installed capacity of BSSs increased by 50% compared to the previous year. This section will try to prove if, by adding a battery to the PV system, there will be an increase in financial benefits for the landlord. Table 6. summarizes the technical statistics of the battery chosen for this additional analysis, a BYD HVS 5.1 provided directly from the panel provider.

Table 6. Battery storage system characteristics

Factor	Value	Unit
Useful years	10	Years
Max Storage Capacity	5.12	kWh
Max Discharge	96%	%
Initial State of Charge	1.54	kW
Losses	0.036	%
Max charging power	2.56	kW
Cost	3090	€

Based on these characteristics the model can now calculate the net outflow of energy between the PV system, the battery, the household, and the grid. Figure 1 shows the logic behind this analysis.

Figure 1. Logics of a BSS



Source: The Solar People, *Solar panel battery storage*. (https://www.thesolarpeople.co.uk/tech-details/solar-panel-battery-storage/)

If the household consumption of energy during the day is met by the one simultaneously generated by the PV system, the household will directly consume it (2). On the other hand, if the demand is inferior, the excess energy is either stored in the battery (3) or sold to the grid

(4). The latter occurs in two occasions: when the surplus of electricity exceeds the hourly battery storage ceiling of 2.56 kW, or when the battery is already at 100% of capacity. The self-consumption from the battery has the same logic, when the household consumption exceeds the energy supplied by the panels, the battery can discharge electricity (5) to a maximum of 2.56 kW per hour. Furthermore, the storage system has a maximum discharge of 96% meaning it can never go under 4% of charge.

When the demand for energy is higher than the combination of energy generated by the PV system and discharged by the BSS, the household will buy energy from the grid through a fixed price (0.22 €/kWh) and mono-hourly contract. It is important to underline that the battery has an expected loss of 0.036% per cycle (charge and discharge). A 10-year term warranty is also in place. The latter guarantees that the battery will be at 60% of the top performance at the end of the term and that, in case it will degrade more than 40%, the battery producer will provide new parts for free in order to restore its 100% efficiency. Table 7. shows the annual energy net outflow for a 1.6 kWp PV system with the integration of the BYD HVS 5.1 battery.

Table 7. Annual energy net outflow with battery

Factor	Value	Unit
Consumption	3561	kWh
Generation	2192	kWh
Self Consumption	1285	kWh
Self Consumption from Battery	902	kWh
Sold to Grid	5	kWh
Residual Load	1374	kWh

The model can finally calculate the corresponding annual cost, revenue, and savings associated with the use of a BSS. The savings are calculated as the Cost without panels minus the Residual Cost plus the Revenue obtained by selling the energy to the grid. Table 8. summarize the annual economic net flow four panels PV system with a battery.

Table 8. Net annual economic flow with battery

Factor	Value	Unit
Cost w/o panels	794.78	€/year
Revenue	00.00	€/year
Residual Cost	306.55	€/year
Savings due to PV system	286.85	€/year
Savings due to battery	201.38	€/year

The savings obtained with the use of a BSS are € 488.23, corresponding to an increase of € 201.38 if related to the same PV system without the battery.

i. **Financial Analysis**

The objective of this section is to establish which is the optimal economic decision the landowner should take to optimize its Net Present Value (NPV).

The first element to establish is the optimal quantity of solar panels to install. To do so a financing option based on 75% debt and 25% equity, with government subsidies has been used as the benchmark for a primary NPV financial performance analysis. The latter is computed by the sum of cash inflows and outflows over a 25-year span, which is the expected lifetime of the PV system. Table 9. shows the economic variables used as input in the model.

Table 9. Economic variables

Factor	Value	Unit
Inflation Rate	2%	%
Equity Cost of Capital	1.713%	%
Maintenance Costs	0.02	€/W
Debt Intrest Rate	5.10	%
Debt Annuity Factor	4.32	n.a.
Debt Term	5	years

The yearly cash inflows are assumed to be the savings (due to PV system and due to battery) the landowner expects to encounter thanks to the installations, estimated as stated in section 3.1.

The cash outflows, on the other hand, are composed of three expenses:

1) The initial investment expenditure for the installation of the panels (and battery).
2) The maintenance costs, which were measured as € 0.02 times the total peak power (W) of the entire system, as mentioned in section 2.5
3) The loan repayment, which applies only if the financing is done by debt

The savings and the maintenance costs are assumed to grow yearly based on an inflation rate of 2%. The latter is the BCE's long-term objective for the eurozone and does not take into consideration the 2022 events (Ukrainian war and COVID-19 economic recovery) which are assumed to be temporary. The annual loan repayment is calculated as a 5-year annuity and is deducted before the estimation of the cash flow (CF). The discount rate used is therefore the equity cost of capital that is assumed to be the 10-year euro swap rate. Table 10. represent the financial outputs obtained for different photovoltaic systems sizes (2-18).

Table 10. Financial outputs for different numbers of panels installed

Number of panels	NPV [EUR]
2	2.811,15 €
3	3.414,32 €
4	**3.415,08 €**
5	3.315,04 €
6	3.148,28 €
7	2.912,40 €
8	2.621,51 €
9	2.238,13 €
10	1.918,06 €
11	1.604,58 €
12	1.210,05 €
15	49,83 €
18	-1.443,84 €

By looking at the results, we can state that the optimal quantity of solar panels to install is 4. Hence, the household should invest in a 1.6 kW photovoltaic system to maximize the NPV. Once the optimal size is established the economic analysis of the model is completed with the following metrics: Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period and Leverage Cost of Energy (LCOE).

This analysis has been applied to six different photovoltaic systems scenarios:

a) No battery financed by 75% debt and 25% equity with government subsidies

b) No battery financed with 100% equity financing and government subsidies

c) No battery financed with no bank debt and no government subsidies

d) 5.12 kWh battery financed by 75% debt and 25% equity with government subsidies

e) 5.12 kWh battery financed with 100% equity and government subsidies

f) 5.12 kWh battery financed with no bank debt and no government subsidies

The NPVs were computed with the same inputs used for the benchmark scenario but, to take into consideration the losses per cycle and the warranty of the battery throughout the 25 years life span of the PV system, a supplementary analysis was conducted for scenario d), e) and f). The model first calculated the expected cycles for a year of battery usage by dividing the kWh self-consumed from the battery and the maximum storage capacity. For the four panels PV system, the result is 176 cycles per year, which multiplied by the losses (0.036%) gives an expected yearly degradation of 6.34%. It follows that the kWh self-consumed by the battery is going to be reduced every year and the savings due to the battery will decrease systematically since they are calculated every year as the price of energy (taking into consideration inflation) times the kWh self-consumed. At this rate, the battery will be under the 60% threshold after 9 years, the provider will thereby deliver new parts for the battery in that year, restoring the efficiency of the BSS at 100%. The battery is then assumed to degrade 6.35% per year till the end of its capacity. The supplementary analysis is summarized in appendix 5.

The Leveraged Cost of Energy (LCOE) is the selling price of energy (€/kWh) that sets the NPV to zero, assuming all energy generated by the panels is sold to the grid. It is significant since it enables us to compare alternative methods of energy production consistently. To estimate the LCOE the model re-performs an NPV analysis where the household’s revenues are calculated by multiplying the entire generation of the PV system by the selling price. The latter is expected to grow at the inflation rate of 2%. The CFs generated take into consideration the initial investment expenditures, the maintenance costs, and the loan repayment. CFs are discounted by the equity cost of capital and summed up. Once the analysis is set the model uses a Goal Seek function to find the exact LCOE that fixes the NPV to zero. Table 11. compares the financial results obtained for every scenario, this passage is essential to give the best recommendation in the final section.

Table 11. Financial results for the six scenarios

Scenario	NPV [EUR]	IRR	Payback [years]	LCOE [EUR/kWh]
a)	3415 €	10.7%	12	0.070
b)	3631 €	9.4%	11	0.066
c)	1473 €	3.6%	18	0.117
d)	5222 €	11.4%	11	0.099
e)	5555 €	9.8%	10	0.093
f)	1825 €	3.3%	18	0.172

FINAL RECOMMENDATIONS

Based on the output of table 12., the best financing option for a standard household, without any storage battery, is scenario b). The latter is a 1.6 kWp photovoltaic system composed of four 400W Trinasolar panels which are fully financed with equity and by government subsidies. It guarantees savings of € 286.85 per year for a final NPV of € 3631 with an IRR of 9.4%. The payback period of the project is 11 years and the LCOE is 0.066 €/kWh.

This report also demonstrates the economic benefits that the landlord could obtain by additionally investing in a storage battery system. As a matter of fact, the highest NPV is provided by scenario e). The latter implements a BYD HVS 5.1 battery to a 1.6 kW solar panels system increasing the annual savings to € 488.23 generating a far higher NPV of € 5555. The IRR is 9.8% with a payback period of 10 years and an LCOE of 0.093.

Appendix n. 6 and n. 7 shows respectfully the complete financial analysis for the best scenario without a BBS (b) and with a BBS (e).

It is thereby recommended to invest in a photovoltaic system, especially in this period when the government subsidies in Italy cut by 50% the initial investments. Furthermore, the use of a battery storage system can highly increase the economic benefits of the investment since it enables the household to have an average extra savings of € 169.31 every year.

ITALY: MAIN ASSUMPTIONS, DATA & OUTPUT (MILANO, GENOA, ROME, PORTO EMPEDOCLE)

In this chapter, the main differences between the analyses of the Italian cities are described, to understand why and in what the results vary from city to city.

There are many differences over the input data of the model depending on the city of focus.

- Cities are slightly different in total consumption. In particular, the total annual consumption, which measures the electricity consumed by the standard household during the year ranges from: (Milano 3561 kWh) (Porto Empedocle 3550 kWh) (Rome 3600 kWh) (Genova 3153 kWh).
- Electricity prices vary among cities. In fact, prices range from (Milano: 0.22 €/kWh) (Porto Empedocle: 0.25 €/kWh) (Rome:0.23 €/kWh) (Genova: 0.27 €/kWh). On the other hand, the selling price of energy which results from excess production from the panels has a fixed value of 0.03 €/kWh. However, this value only matters if the standard household decides to forgo the governmental subsidies associated with photovoltaic systems. If the household exercise the subsidy the excess production is transferred to the grid for free.
- Panels differ in terms of brand and Peak Power (Milan: 400 W) (Rome: 400W) (Genoa: 385W) (Porto Empedocle: 375W). The highest quote for an operative system of 5 panels is 6900€ (Roma), then Milan 6220€, Genova 5983€, and the lowest is 4500€ (Porto Empedocle). This price does not include governmental subsidies.
- Differences in panel capacity (W) and solar irradiance will impact the generation capacity (kWh produced by the PV system) for a system of equal size. Generation values (5 panels): (Milan: 2740 kWh) (Genoa: 2555 kWh) (Rome: 3297 kWh) (Porto Empedocle: 3216 kWh).

- Bank loan rates are slightly different as well. Rates range from (Milano: 5.10%) (Porto Empedocle: 6.15%) (Rome: 6.03%) (Genoa: 5.50%). Maturity for Milan, Rome, Genoa is 5 years while for Porto Empedocle is 4 years.

These differences in input data are expected to generate differences in the economic outcome. Therefore, to assess the economic outcome, we have compared results for a fixed scenario. A PV system of 5 panels partially financed by governmental subsidies.

- Porto Empedocle: NPV: 7552€ ; 18.7% IRR ; Payback 5.6 years; LCOE: 0.043
- Genoa: NPV: 4654€ ; 11% IRR ; Payback 9.16 years; LCOE: 0.060
- Rome: NPV 3941€ ; 8.7% IRR ; Payback 11 years; LCOE: 0.056
- Milan: NPV 3550€ ; 8.7% IRR ; Payback 11 years LCOE: 0.059

As expected, results vary greatly among cities. This is a result of differences in the total annual consumption; cost of energy; panels quote; peak power; generation capacity; solar irradiance. Moreover, this result confirms that the South is more suitable than the North for solar panels due to favorable sun exposure and climate.

The following table resumes the differences in the main assumptions and outputs for an easier confrontation:

	Milan	Genoa	Rome	Porto Empedocle
Consumption [kWh]	3561	3153	3600	3550
Electricity cost [€/kWh]	0.22	0.27	0.23	0.25
Electricity selling price [€/kWh]	0.03			
Peak power of 1 panel [W]	400	385	400	375
Price for 5 panels [EUR]	6220	5983	6900	4,5
Generation [kWh]	2740	2555	3297	3216
NPV [EUR]	3550	4654	3941	7552
IRR	8.70%	11%	8.67%	18.70%
Payback [years]	11.0	9.16	10.8	5.6

Table 12: assumptions and output table

Furthermore, to explain the difference in the outputs, a weight on the different inputs has been calculated and can be sum up in the table below:

	Cost of panels (with subsidies)	Mainteinance cost	Savings	NPV
Porto Empedocle [EUR]	-2,250.00	-1,269.00	11,048.00	7,552.00 €
Milan [EUR]	-3,110.00	-1,015.00	7,660.00	3,550.00 €
Differences (PE-MI) [EUR]	860.00	- 254.00 €	3,388.00 €	4,002.00 €
Weights	21.49%	-6.35%	84.66%	-

Table 13: weights allocation

To calculate the weights, the difference in inputs between the two extreme cases (Porto Empedocle and Milan) have been calculated and weighted over the difference in NPVs.

$$Weight_i = \frac{I_{PE} - I_{MI}}{NPV_{PE} - NPV_{MI}} \quad (1)$$

Where: I_{PE} = *Input factor Porto Empedocle*

I_{MI} = *Input factor Milan*

NPV_{PE} = *NPV Porto Empedocle*

NPV_{MI} = *NPV Milan*

It can be noted that most of the weight allocation is on the savings since they represent the biggest part of the final NPV. The savings are calculated as the electricity expense that there would be without the solar panels system, minus the electricity expense with the solar panels system, plus the revenues from selling electricity to the grid.

Summary of rooftop solar analysis

Location: Rome, Italy **Date of analysis**: January 2022

Recommendation*: install 4 solar panels (5.76 m^2), for a net present value of 3664 euros, with a payback period of 12 years.*

Main economic results

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
[Gov. subsidies and] 75% debt	3664	12	9.78%	0.070
[Gov. subsidies and] 100% equity	3990	11	8.94%	0.065
[No gov. subsidies and] 100% equity	2897	16	3.96%	0.051

Additional results

Moreover, a system consisting of 15 panels together with a battery of 5 kWh, requires an initial net investment of 7570€ (considering gov. subsides, 50% off the gross cost), but provides an NPV of 9207€, with a payback period of 10 years.

Main inputs and assumptions

Household and Economics					
Electricity Consumption	3600	kWh/year	Inflation	2.0%	per year
Electricity price – buy	0.23	EUR/kWh	Bank loan interest rate	6.03%	per year
Electricity price – sell	0.03	EUR/kWh	Bank loan maturity	5	years
			Equity cost of capital	1.713%	per year

PV panels					
Peak power	400	W/panel	System losses	14.0%	of output
Panel area	1.92	m^2/panel	Degradation (max)	0.5%	per year
Useful life	25	Years	Maintenance costs	10	EUR/year per panel

Total cost of optimal installation size (without subsidies)	6720	EUR
Total cost of optimal installation size (after subsidies)	3360	EUR

Government subsidies

Since 2019 the Italian Government introduced a subside which, in the form of a direct discount on invoice, refunds immediately 50% of the initial investment in solar panels for own consumption. However, being the installation strictly intended for the sole own consumption, a clause of the subside is the ban of selling with a feed-in-tariff the electricity produced in excess.

INTRODUCTION

The goal of this project is to make available to the general public, in a simple and effective way, an analysis of the installation of a solar system on a single-family house in the city of Rome, Italy's capital and most populous city, with 2.9 million inhabitants.

The result of the study will be a recommendation on the optimal number of panels to be installed along with the main economic results of such an installation (Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Leverage Cost of Energy (LCOE)). This analysis will then be included in a larger project, from whose website (https://www.pvpayback.com/) it will be possible to compare it with other analyses carried out by other students on different locations around the world.

This project may prove to be particularly useful in view of the growth in yields and development of PV in recent years, but above all because of the ever-increasing attention that needs to be paid to renewable energies in order to ensure a future for our planet by breaking our dependence on fossil fuels.

DATA AND ASSUMPTIONS

Since the objective of the project is to give an economic assessment of the financial viability of installing a solar panel system in the selected geographical area, it is important to carefully introduce the data and assumptions used in the model. Some of them as number of panels, financing form and type of solar system (with or without battery) will be user selectable inputs in the model (although their optimal values in order to give the best possible recommendation are pre-selected). Different combinations of inputs will generate different configurations of economic costs and energy generations, resulting in different values of metrics used in the economic analysis, such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period and Levelized Cost of Electricity (LCOE).

Property and household characteristics

The City of Rome is composed by an equal mix of isolated houses and apartment buildings. To the extent of the project, the analysis is assumed to consider a standard family living in an detached house, since the tenants of an apartment have not the permission to install personal solar panels on the shared roof of their apartment building. The house is ideally located in the residential area of Casal Palocco, in the southwestern part of Rome. The rooftop of the detached house is assumed to be facing South and having a 37° inclination (which is also the optimal slope for panels installation in the area). Direction and slope of the rooftop are optimal characteristics for the location in terms of solar irradiance. During the calendar year no shadow is assumed to cover it.

The standard household is made up of 4 family members, the 2 parents which both go to work during the day and the 2 kids which go to school during the same time slot. To make the analysis being as much realistic as possible, it was decided not to take into consideration the possibility of an active energy management being adopted by the family. It is because evidence shows how, the population of central and southern Italy is the least prone to such behaviours countrywide. This is mostly caused by the lack, in an average household, of the necessary machinery equipped with technology for the programming of such use.

Table 1 summarizes all the characteristics assumed for the property and its household. They are non-flexible, meaning that the model and the subsequent economic analysis applies only to properties located in the same area and following the same structural characteristics of the property described.

Table 1. Property and household characteristics

Variable	Assumption
City	Rome
Neighborhood	Casal Palocco
House structure	Detached
Roof size (m2)	40
Roof slope	37°
Roof shading	None
Roof direction	South
Houseold members	4
Active energy management	None

Solar system characteristics

Table 2 summarizes the attributes of the panels composing the solar system selected as best project.

The panels selected are Trina Solar Vertex S. The technology used by the panels is the monocrystalline, in which the wafer composing the panel cell, is made from single-crystal silicon. Under this technology the electrons that generate the electricity current have more room to move, making monocrystalline solar panels more efficient.

The efficiency, which is the most commonly used parameter to compare the performance of one solar cell to another, is defined as the ratio of energy output from the solar cell to input energy from the sun.

The hypothetical useful life of the selected solar panels is of 25 years. It is based on the guarantee offered by the producer on the performance of the cells. The guarantee concerning the manufacturing defects is of 15 years instead. In addiction a maintenance cost of 10 euros/year per panel based on most recent market research is obtained and introduced in the costs calculations.

The number of panels multiplied by the peak power of one panel (W) results in the overall system size (kWh).

Table 2. Solar system characteristics

Variable	Value
Model	Trina Solar Vertex S
Peak power of 1 panel	400 W
Number of panels	3
System size	1.20 kWh
Panel size	1.92 m2
Efficency	20.80%
Useful life	25 years
Mainteniance cost	10 €/year per panel

The selection of this model resulted from the comparison of different quotes given by different providers contacted in the Rome area.

Out of 12 contacted, 3 providers gave a precise and complete quote. It was necessary to obtain not only a comprehensive overall quote, but in addition to it also a differentiation between the cost of labour (fixed) and the cost of the panels (relative to quantity), in order to be able to subsequently, through a linear interpolation estimate, have a greater range of solutions (number of panels, space occupied and system size) that could be analysed with their own relative costs. Appendixes 1 and 2 illustrate respectively a comprehensive overview of all the quotes obtained, and the quote from the selected provider interpolated in order to provide a full range of system size solutions (from 2 to 15 panels).

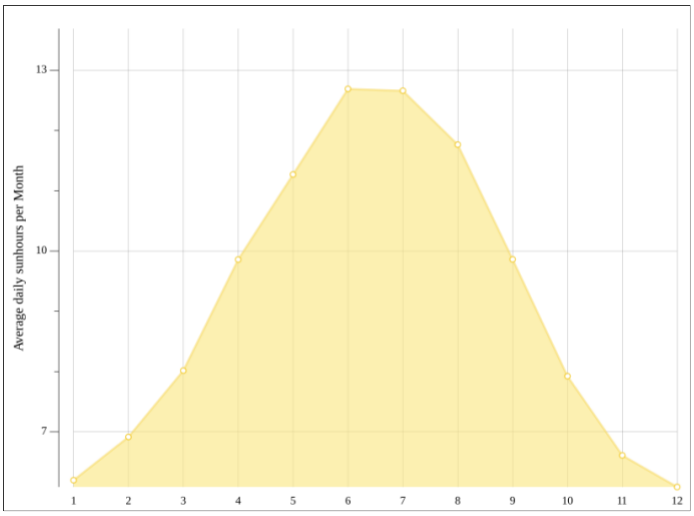
The price per kW was calculated for each model, and by relating this to the efficiency of the panel it was possible to derive the efficiency/price per kW ratio, which was the metric used in order to choose the model with the highest value for money.

2.3 Solar irradiance and potential electricity generation

The data regarding the specific solar irradiance and potential electricity generation for the location of Rome was obtained through the "Photovoltaic Geographical Information System", an opensource database offered by the European Commission (https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP).

The selected datasets are those of the two most recent years in the database, 2019 and 2020 respectively. A time series of 8760 values is therefore obtained for every year, each indicating the solar irradiance (W/m2) and potential electricity generation (W) of a standard 1 kWh solar system for each hour of the year. The two datasets are then combined, and the obtained average is the one which will be used in the analysis. Figure 1 highlights the average daily sun hours per month in Rome during 2019 (a peak sun hour is defined as one hour in which the intensity of solar irradiance (sunlight) reaches an average of 1,000 watts (W) of energy per square meter).

Figure 1. Average daily sun hours per month in Rome



Electricity consumption

In order to estimate the electricity consumption of the assumed standard household, 4 real utility bills of different kind of households located in Rome have been collected. After a careful analysis, by taking into consideration the household size (number of people), the building dimension (m2) and the consumption habits of the real households whose bills were collected, an educated guess was made in order to evaluate the total annual consumption of the standard household of the project. It resulted in an estimated yearly consumption of 3600 kWh.

Subsequently, a top-down approach is used, meaning that a consumption profile was used in order to allocate the amount of annual consumption to each hour of the day (8760 values per year). To this end, the load profile of a European location with similar weather conditions and consumption habits to the territory of Rome was obtained and used, since for reasons of commercial competition all the Italian entities contacted in order to receive this kind of dataset did not have the possibility to provide it. The corresponding location chosen was Portugal and the dataset used is the one of E-REDES, an electricity distributor of the Portuguese utility group EDP (https://www.e-redes.pt/pt-pt/perfis-de-consumo). Table 3 shows a comparison between the average annual temperatures (min, max, and average) from 1991 to 2020 in Rome and Lisbon. It confirms how the weather conditions among the two locations are quite similar, giving grounds to conclude that electricity consumption habits are as well similar, also given the same levels of socio-economic and technological advancement between the two countries.

Table 3. Average temperatures (1991-2020) in Rome and Lisbon

City	Min (°C)	Max (°C)	Average (°C)
Rome	11.1	21	16
Lisbon	13.7	21.4	17.55

Government subsidy

The 2022 Budget Law has confirmed the effort of Italian Government through energy transition by inducing householders to invest in renewables through guaranteeing a direct 50% discount on invoice directly offered from providers. It is very easy to obtain and has the only limit of a maximum price of €2400 per kilowatt installed for solar systems, €1000/kWh for the storage systems and up to a maximum total cost threshold settled at €96000 (leading to a maximum obtainable discount of €48000). A limit of the subside is the ban of selling with a feed-in-tariff the electricity produced in excess. Despite this, in the following economic analysis the summarized subsidy will play a crucial role in reaching a high investment NPV.

Economic data

Given the 4 real utility bills collected for the estimation of the electricity consumption at point 2.4, another valuable information retrieved by the analysis of the above was the final consumer electricity cost. It was made by averaging the slightly different costs (given different furniture contracts) indicated on each of the 4 bills, which ended in an outcome of 0.23 €/kWh. This result was carried for the forthcoming economic analysis.

A second important economic metric necessary, especially in order to find out how much future revenue a household would receive from selling excess electricity produced by solar panels on the market, is the feed-in-tariff. It is a price value set by the Italian Service Provider which averaged at 0.03 €/kWh during the 2021. Although the revenues from the sale of the excess electricity may be attractive to users, it is necessary to consider in the analysis that these revenues cannot be realized when using the government subsidy to finance 50% of the investment. This is because the government has specified that the discount on the invoice is only offered to households that install such solar systems for the sole purpose of domestic self-consumption, thus preventing them from the reselling of excess production. It means that, for instance, following the best project proposed in this paper which takes benefits from the government subsidy, the amount of possible revenues realized by selling excess production to the grid amounts to zero.

Subsequently, in order to make the following economic analysis of the project as complete as possible, the possibility of financing part of it through a private loan was also taken into account. With regards to loan providers, out of 9 local and international credit institutions and banks contacted, a list of 6 quotes was obtained (Appendix 3) and out of them the one with the fixed annual lower rate (in Italian called TAEG) for an assumed loan maturity of 5 years was selected. It was Findomestic with a fixed annual rate of 6.03%. Although the rate is competitive, during the course of the analysis it was observed that adding a private loan with a subsequent interest rate to the government subsidy (which comes for free) would only tend to reduce the financial attractiveness of the project. In fact, the best project proposed uses the government grant but finances the remaining project costs through 100% equity, without the need for a loan contract to be set.

Finally, the last two main economic data used in the project analysis are the 10-year Swap rate (Euro) used to discount the equity cash flows (as equity cost of capital), which averaged to 1.713% annually and the inflation rate used to inflate the cash flows in the yearly analysis which was set to 2% per year.

Table 4 gives a summary of all economic data used in performing the analysis.

Table 4. Economic data

Variable	Value
Electricity cost	0.23 €/kWh
Electricity selling price	0.03 €/kWh
Bank loan interest rate	6.03%.
Bank loan maturity	5 years
Equity cost of capital	1.713% per year

ANALYSIS

The following section describes in more detail the flow of electricity and money generated through the installation of the solar system.

Although the production data can be adjusted to account for different system sizes, the results reported here will take into account a system (identified as best project) consisting of 4 panels, each with a capacity of 400 W, for a total of 1.6 kWh.

3.1 Electricity flow (in/out)

Given the hourly annual production and consumption data described respectively in sections 2.3 and 2.4, it is possible to determine:

- The total quantity of electricity generated by the system (production)
- The quantity of electricity generated by the system used by the household (self-consumption)
- The quantity of electricity generated by the system (ideally, if no gov. subsidy is used) sold to the grid (outflow to grid)
- The quantity of electricity bought from the grid (residual load)

Table 5 shows the annual totals for the above-described quantities (assuming a 1.6 kWh system).

Table 5. Annual electricity flows for a 1.6 kWh system

Variable	Value
Consumption	3600 kWh
Production	2637 kWh
Self-consumption	1431 kWh
Outflow to grid	1206 kWh
Residual load	2169 kWh

Financial flow (in/out)

By matching the Electricity flow results described in section 3.1 with the Economic data in section 2.6 it is possible to derive yearly:

- The cost that would have occurred without the project (cost w/o project)
- The revenue obtained by selling electricity to the grid at the feed-in-tariff, only possible if no gov. subsides are used (revenue)
- The cost still occurred even with the project (residual cost)
- The savings obtained thanks to the project (savings due to the project)

Table 6 shows the annual totals for the above-described quantities (assuming a 1.6 kWh system).

Table 6. Annual financial flows for a 1.6 kWh system

Variable	Value
Cost w/o project	828 €
Revenue	36 €
Residual cost	499 €
Savings due to the project	365 €

Additional analysis (battery)

A further interesting analysis to be made on the topic is the one regarding the inclusion of a battery to store the excess electricity produced by the system.

In grid connect systems as the one analysed in this project, where batteries are not inherently required, they may be beneficially included for load matching or power conditioning. This is even more important when seen in the case of the use of government subsides, which do not allow excess electricity to be sold for a feed-in-tariff to the grid and thus amplify the economic advantages of integrating this technology into the project.

As for the choice of panels, a comparison of different quotes received from 3 installers in the Rome area (Appendix 4) was the baseline to determine the best model under a value for money ratio.

Given the technical characteristics of the chosen battery, the way in which it could be linked with the production of electricity generated by the panels during the 8760 hours of the year was analysed, in order to obtain data on the benefits in terms of cost reduction that it could provide. The subsequent economic results will be better explained and compared in the next section.

It will be interesting to note that, with the introduction of the battery, the optimal number of panels generating the system increases (almost threefold). This is rational since the possibility of storing excess electricity favors a greater number of panels, capable of generating more electricity.

What should be emphasized is the fact that the analysis did not predict any degradation of the battery over time as the manufacturer provides a performance guarantee that eliminates the need for such a calculation given the free replacement offered as soon as the battery loses storage capacity.

Table 7 recaps the main characteristics of the battery chosen.

Table 7. Battery characteristics

Variable	Value
Model	Huawei LUNA2000
Storage useful life	15 years
Max. Loading Capacity	5 kWh
Cost	3,000 €

Economic results

At this stage, with the data and analysis proposed in the previous parts, the purpose of this section is to describe the outcomes of the model. These include economic benefits, costs and a final recommendation on the ideal number of solar panels to install.

In order to be able to choose on a consistent basis the best solution for the household, the model was set up in such a way as to be able to propose different outcomes depending on the selection of certain variables. The different inputs generate 3 different scenarios for the model without battery and 3 for the one with the storage capability.

The resulting 6 different scenarios are described below:

a) [Gov. subsidies and] 75% debt (without battery)

b) [Gov. subsidies and] 100% equity (without battery)

c) [No gov. subsidies and] 100% equity (without battery)

d) [Gov. subsidies and] 75% debt (with battery)

e) [Gov. subsidies and] 100% equity (with battery)

f) [No gov. subsidies and] 100% equity (with battery)

Given these model-generated scenarios, a range of possible numbers of panels to be installed (from 2 to 15) was obtained, and for each the relevant key economic indicators (Appendix 5 and 6). Thanks to the latter, it was possible to identify for each setting the best project, and finally the two scenarios with the absolute best projects (one without and one with the battery). Table 8 summarizes the best projects for each scenario, together with the respective economic indicators, which will be described more specifically in the following lines.

Table 8. Best project for each scenario

	(a)	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**
Number of panels	4	4	15	10	10	15
NPV	3,664 €	3,990 €	2,897 €	9,711 €	10,101 €	10,936 €
IRR	10%	9%	4%	11%	10%	7%
Payback (years)	12	11	16	10	10	12

From the table above it is possible to figure out which are the two best projects.

For the one without battery, the optimal is scenario b), financed by Gov. subsidies and 100% equity, with an ideal number of 4 panels offering a total project NPV of 3990 €, an IRR of 8.94% and a payback period of 11 years.

For the project including the battery, the best scenario is the e), again financed through Gov. subsidies and 100% equity, with an ideal number of 15 panels, a battery of 5 kWh, an NPV of 9207 €, an IRR of 9.09% and a payback period of 10 years.

What may seem strange from the above results is that it is recommended to install more panels in the two cases (without and with battery) where no gov. subsides are present. This can be explained by the fact that, as previously pointed out, Italian law does not allow electricity produced using a system financed through gov. subsides to be sold to the market, therefore only in the scenario without such subsidies was the possibility to sell excess electricity introduced, generating in the model the output of a greater number of panels (which generates an higher NPV if compared to systems with fewer number of panels) in order to take full advantage of this form of profit.

In order to make the economic results clearer, a very brief explanation of the economic metrics used is necessary:

NPV: the Net Present Value is used to calculate the current total value of a future stream of payments. If the NPV of a project or investment is positive, it means that the discounted present value of all future cash flows related to that project or investment will be positive, and therefore attractive.

IRR: the Internal Rate of Return is a metric used in financial analysis to estimate the profitability of potential investments. IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. Generally speaking, the higher an internal rate of return, the more desirable an investment is to undertake.

Payback: the Payback Period is the length of time it takes to recover the cost of an investment or the length of time an investor needs to reach a breakeven point. Shorter paybacks mean more attractive investments, while longer payback periods are less desirable. It is calculated by dividing the amount of the investment by the annual cash flow.

LCOE: one last metric used to get a clearer view of the benefits of installing such systems is the LCOE. The Levelized Cost of Energy (LCOE) represents the average revenue per unit of electricity generated needed to recover the construction and operating costs of a generation facility over an assumed financial and operating life cycle. The LCOE is often cited as a summary measure of the overall competitiveness of different generation technologies.

Its formula is:

$$\text{LCOE}=\frac{\text{Total Lifetime Cost}}{\text{Total Lifetime Output}} \quad \text{or} \quad \text{LCOE}=\frac{\sum_{t=1}^{n}\frac{I_t+M_t}{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}}$$

Where:

It = Investment and costs for the year t

Mt = O&M for the year t

Et = Electrical output for the year t

r = Discount rate

n = The (expected) lifetime of the power system

The lower the result, the greater the economic attractiveness of a project.

In the case of our two best projects, the LCOE of the project without battery is 0.083 while that with battery is 0.071. This also reflects the better position of the second project (with battery) in a comparison on the sole NPV base.

A comparison with other results found in Italy (Milan, Genoa, Rome, Porto Empedocle)

In this chapter, the main difference between the analyses of the Italian cities are described, to understand why and in what the results vary from city to city.

There are many differences over the input data of the model depending on the city of focus.

- Cities are slightly different in total consumption. In particular, the total annual consumption, which measures the electricity consumed by the standard household during the year ranges from: (Milano 3561 kWh) (Porto Empedocle 3550 kWh) (Rome 3600 kWh) (Genova 3153 kWh).
- Electricity prices vary among cities. In fact, prices range from (Milano: 0,22 €/kWh) (Porto Empedocle: 0,25 €/kWh) (Rome:0,23 €/kWh) (Genova: 0,27 €/kWh). On the other hand, the selling price of energy which results from excess production from the panels has a fixed value of 0,03 €/kWh. However, this value only matters if the standard

household decides to forgo the governmental subsidies associated with photovoltaic systems. If the household exercise the subsidy the excess production is transferred to the grid for free.

- Panels differ in terms of brand and Peak Power (Milan: 400 W) (Rome: 400W) (Genoa: 385W) (Porto Empedocle: 375W). The highest quote for an operative system of 5 panels is 6900€ (Roma), then Milan 6220€, Genova 5983€, and the lowest is 4500€ (Porto Empedocle). This price does not include governmental subsidies.
- Differences in panel capacity (W) and solar irradiance will impact the generation capacity (kWh produced by the PV system) for a system of equal size. Generation values (5 panels): (Milan: 2740 kWh) (Genoa: 2555 kWh) (Rome: 3297 kWh) (Porto Empedocle: 3216 kWh).
- Bank loan rates are slightly different as well. Rates range from (Milano: 5.1%) (Porto Empedocle: 6,15%) (Rome: 6,03%) (Genoa: 5,50%). Maturity for Milan, Rome, Genoa is 5 years while for Porto Empedocle is 4 years.

These differences in input data are expected to generate differences in the economic outcome. Therefore, to assess the economic outcome, we have compared results for a fixed scenario.

A PV system of 5 panels partially financed by governmental subsidies.

- Porto Empedocle: NPV: 7552€ ; 18.7% IRR ; Payback 5.6 years; LCOE: 0.043
- Genoa: NPV: 4654€ ; 11% IRR ; Payback 9.1 years; LCOE: 0.06
- Rome: NPV 3941€ ; 8.7% IRR ; Payback 11 years; LCOE: 0.056
- Milan: NPV 3550€ ; 8.7% IRR ; Payback 11 years LCOE: 0.059

As expected results vary greatly among cities. This is a result of differences in the total annual consumption; cost of energy; panels quote; peak power; generation capacity; solar irradiance. Moreover, this result confirms that the South is more suitable than the North for solar panels due to favorable sun exposure and climate.

The following table resumes the differences in the main assumptions and outputs for an easier confrontation:

Table 9: Assumptions and output table

	Milan	Genoa	Rome	Porto Empedocle
Consumption [kWh]	3,561	3,153	3,600	3,550
Electricity cost [€/kWh]	0.22	0.27	0.23	0.25
Electricity selling price [€/kWh]	0.03			
Peak power of 1 panel [W]	400	385	400	375
Price for 5 panels [EUR]	6,220	5,983	6,900	4,500
Generation [kWh]	2,740	2,555	3,297	3,216
NPV [EUR]	3,550	4,654	3,941	7,552
IRR	8.70%	11%	8.67%	18.70%
Payback [years]	11.0	9.1	10.8	5.6

Furthermore, to explain the difference in the outputs, a weight on the different inputs has been calculated and can be sum up in the table below:

Table 10: Weights allocation

	Cost of panels (with subsidies)	Maintenance cost	Savings	NPV
Porto Empedocle [EUR]	-2,250.00	-1,269.00	11,048.00	7,552.00 €
Milan [EUR]	-3,110.00	-1,015.00	7,660.00	3,550.00 €
Differences (PE-MI) [EUR]	860.00	- 254.00 €	3,388.00 €	4,002.00 €
Weights	21.49%	-6.35%	84.66%	-

To calculate the weights, the difference in inputs between the two extreme cases (Porto Empedocle and Milan) have been calculated and weighted over the difference in NPVs.

$$Weight_i = \frac{I_{PE} - I_{MI}}{NPV_{PE} - NPV_{MI}}$$

Where: I_{PE} = *Input factor Porto Empedocle*

I_{MI} = *Input factor Milan*

NPV_{PE} = *NPV Porto Empedocle*

NPV_{MI} = *NPV Milan*

It can be noted that most of the weight allocation is on the savings since they represent the biggest part of the final NPV. The savings are calculated as the electricity expense that there would be without the solar panels system, minus the electricity expense with the solar panels system, plus the revenues from selling electricity to the grid.

4. FINAL RECCOMANDATION

The aim of this project was to make the economic benefits of installing photovoltaic panels on a domestic unit quantitatively tangible. It was possible to conclude which two projects are optimal, with the number of panels for each and the relative economic results.

However, something that should definitely be added is a remark on how these forms of renewable energy are nowadays increasingly necessary not only to limit costs or make a financial gain, but to protect the fragile natural environment as much as possible.

Particularly in Italy, a fairly sunny country, in many areas the development of investment in solar energy is not at the level it could be. I hope that projects such as this one can encourage this development in an increasingly green direction.

Summary of rooftop solar analysis

Location: Porto Empedocle (AG), Italy **Date of analysis**: April/2022
Recommendation*: install 3 solar panels (7.92 m^2), for a net present value of 7863€, with a payback of 4 years.*

Main economic results:

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% debt	7863	4.0	45.9	0.0453
Gov. subsidies and 100% equity	7975	3.6	29.1	0.0431
No gov. subsidies and 100% equity	7059	6.6	15.6	0.0706

Additional results:

However, a system of 5 panels, together with a battery of 5 kWh (5000€ battery price), requires an initial total investment of 9500€ of which only 1188€ are of equity, but provides an NPV of 9143€, with a payback period of 7.6 years and an IRR of 17.5%. This considering government subsidies (50% off the initial price).

Main inputs and assumptions:

Household and Economics

Electricity Consumption	3550	kWh/year	Inflation	2%	per year
Electricity price – buy	0.25	EUR/kWh	Bank loan interest rate	6.15%	per year
Electricity price – sell	0.03	EUR/kWh	Bank loan maturity	4	years
			Equity cost of capital	1.71%	per year

PV panels chosen

Peak power	375	W/panel	System losses	14%	of output
Panel area	2.64	m^2/panel	Degradation with age	0.5%	per year
Useful life	25	Years	Maintenance costs	10	EUR/year

Total cost of optimal installation size (without subsidies) 2700 EUR

Government subsidies:

The government subsidies as March 2022 entail a discount of 50% on the invoice price. However, by using the government subsidies it is not possible to sell the energy back to the grid, but this problem might be overcome with the use of a battery, depending on the implant size.

INTRODUCTION

In this paper we are going to analyze the economic value of the installation of rooftop solar panels system in an average residential house's roof. This paper takes part in a bigger project, in which the same analysis is carried forward for various locations all over the world. The aim of the project is to make a more conscious decision on whether or not shift to solar energy source and sensibilize people toward a more reasonable energy consumption.

The location of our analysis is Porto Empedocle (AG), a town of 18000 inhabitants, situated in the south cost of Sicily, Italy, right in the middle of the Strait of Sicily. The area of the city is spread over 25 km^2 and the population density is 616.17 ab./km^2. The average annual income is 14798€ (Comuni Italiani, 2022)[i], the average annual temperature is 16.8°C and the average annual rainfall is 535mm (Climate data, 2022)[ii].

As it is located in Sicily, a Special Administrative Region, it might follow special laws and results might vary from other similar investments. However, every specific difference at regional level is going to be commented in the paper below.

The reader of this paper should keep in mind that the economic value of the investment is very dependent on factors that are variable over time, such as government subsidies, bank loan interest rate and raw material price. However, the analysis is set up to be as accurate as possible and can be considered accurate as S1 2022 and reasonably for the following year.

In order to make a final decision on the investment to undertake, multiple economic factors such as NPV, IRR, Payback period, LCOE, etc. have been considered; however, the reader should not underestimate the environmental impact that a project like this can provide. With the recent shift toward green energy and sustainability everyone has a different exposure to the matter, though, being it a variable that is purely personal, it is not considered in our analysis, but we recommend the reader to take it into account when making a final decision.

DATA AND ASSUMPTIONS

Standard local household

The first thing to consider in this analysis is the typical investor. All the cashflows have to be considered from the side of the household. Given the demography data of the town we can assume that the typical local household is composed by four people, two parents and two children. Both parents are off to work during the day and both kids at school. Therefore, most of the consumption is during the evening, at night, and in the early morning. The family lives in a house with the roof fully exposed to the sun and we will assume unlimited roof area for the solar system installation. Average annual income of the household is 30000€, composed by the salary of the two parents.

Consumption

The annual consumption for the local household has been calculated referring to energy bills collected from the different households in the area. The average annual value for total consumption is 3550 kWh. However, an hourly consumption profile for our sample household was not publicly available, thus the analysis in based on an educated guess of the hourly consumption of the family over the year. The approach for the educated guess has been finding a city with very similar characteristics to Porto Empedocle, with available data. The closest city with data available is Lisbon. The two cities are indeed at similar latitudes (Porto Empedocle 37° 17' and Lisbon 38° 43'), with similar average temperature (Porto Empedocle 16.8°C and Lisbon 17.4°C)(See Table 1), average solar irradiation (PV system power (Porto Empedocle 187.6W and Lisbon 182.9W)) and lastly similar Zero Degree-Day. A Zero Degree-Day in energy monitoring and targeting is when either heating or cooling consumption is at a minimum, which is useful with power utility companies in predicting seasonal low points in energy demand. (Wikipedia, 2022)[iii]

	LISBON			PORTO EMPEDOCLE		
Month	Min (°C)	Max (°C)	Average (°C)	Min (°C)	Max (°C)	Average (°C)
January	8	15	12	9	12	11
February	9	16	13	10	13	12
March	10	18	14	11	15	13
April	12	20	16	13	18	16
May	14	22	18	14	19	17
June	16	25	21	18	24	21
July	18	28	23	21	28	25
August	18	28	23	22	28	25
September	17	26	22	19	26	23
October	15	23	19	16	23	20
November	12	18	15	16	17	17
December	9	15	12	12	14	13

Table 1: Average temperature (1991-2020) in Porto Empedocle and Lisbon

In practice, most of the electricity consumption is generated by machines such as dishwasher or washing machine or hot water boiler. Heating devices are mainly gas sourced, therefore not considered in our study.

Energy Price

To find an energy price, several energy bills of households around the area have been collected. The most common contract types are the single fixed price and three time slots price. For the aim of our analysis, we are going to use the varying price to achieve a more accurate result. For the provider UBroker, the prices inclusive of 10% VAT are divided as follows:

- From 8am to 7pm the price is 0.2948€/kWh (F1);
- From 7pm to midnight the price is 0.2560€/kWh (F2);
- From midnight to 8am the price is 0.2111€/kwh (F3).

Furthermore, with a solar panels system it is possible to sell the excess of electricity to the grid that in the case of Italy is “Gestore Servizi Energetici” (GSE) at a variable price that on average is 0.03 €/kWh. This means that with the solar panels system, every kWh that is produced and not used for internal consumption is going to be sold to the grid for 0.03€. However, if at some point the system does not produce enough energy to supply the household’s energy consumption, they would need to buy it from GSE at an higher price dependent on the hour of the day, according to the previous price plan. Lastly, it has to be mentioned that the energy can be sold to the grid only if the investor does not take advantage of the government subsidy, that is going to be described later in the text. If he does, the energy is going to be inserted in the grid for free and there is going to be no return on the excess of energy (Nicora, 2022)[iv]. This problem can be solved with the use of a battery, but this option is also going to be analyzed later in the paper.

Solar Irradiance

Another key factor to consider in our analysis is the solar irradiance in our location. To retrieve this data, it is possible to use the PVGIS European Union website that provides hourly solar irradiance for every day of the year. (European Commission Database, 2016)[v] To have less bias on a single year, the average of the solar irradiance between 2018, 2019 and 2020 was computed and used in the calculations.

Solar Panels Prices

Important for an accurate study's result was contacting three local solar panels providers to decide the best option in the market. Starting in January 2022, the Italian government imposed a maximum price for each kW of energy of solar panel system of 2400€ and thanks to the "ecobonus" ("Legge di bilancio 2022"), one of the latest Italian laws aimed at an increase of the housing sustainability, the investor gets an immediate 50% discount on the final value of the invoice. Even though all the suppliers are more or less on the same line with the prices of the panels, the company that would provide the best service is "energit", a company based in Sardinia that operates all over the national territory. They would provide 60-cells monocrystalline panels integrated with power optimizers and Solarage inverter and peak power of one panel of 375W. Monocrystalline solar panels have solar cells made from a single crystal of silicon while polycrystalline solar panels have solar cells made from several fragments of silicon melted together. The former type is the most used in the market and has a higher efficiency on average, at the expenses of the price; it is indeed slightly more expensive, but with the price capped by law the difference is negligible. Furthermore, thanks to the Solarage inverter, the system they provide is composed by autonomous panels, therefore if one has a damage or a decrease in power, it will not affect the efficiency of the other panels, thus always maximizing the energy production. Moreover, 10€ per panel a year are to be accounted as maintenance costs, related to the cleaning of the panels, since they are going to be exposed to a big amount of sand coming from the Sahara desert with southern wind and extra dust. Lastly for the panels we are considering a 0.5% degradation per year. (European Commission Database, 2016)[vi] The following is a table to recap the cost, area and power of the system based on the number of panels:

Number of panels	Cost		kW	Sq meters	
1	900	EUR	0.375	2.64	Linear interpolation
2	1800	EUR	0.75	5.28	Linear interpolation
3	2700	EUR	1.125	7.92	Linear interpolation
4	**3600**	**EUR**	**1.5**	**10.56**	**Real quote**
5	4500	EUR	1.875	13.2	Linear interpolation
6	**5400**	**EUR**	**2.25**	**15.84**	**Real quote**
7	6300	EUR	2.625	18.48	Linear interpolation
8	**7200**	**EUR**	**3**	**21.12**	**Real quote**
10	9000	EUR	3.75	26.4	Linear interpolation
11	**9900**	**EUR**	**4.125**	**29.04**	**Real quote**
13	**11700**	**EUR**	**4.875**	**34.32**	**Real quote**
14	12600	EUR	5.25	36.96	Linear interpolation
16	**14400**	**EUR**	**6**	**42.24**	**Real quote**
17	15300	EUR	6.375	44.88	Linear interpolation
18	16200	EUR	6.75	47.52	Linear interpolation
19	17100	EUR	7.125	50.16	Linear interpolation
20	18000	EUR	7.5	52.8	Linear interpolation
100	90000	EUR	37.5	264	Linear interpolation

Table 2: cost, area and power of the system. In bolt the real quotes from energit.

Battery

In a more advanced analysis, the system can include a battery. This is an interesting option because the energy that is produced in excess can be stored and used when needed instead of buying it from the grid.

There are batteries of several sizes, but the one the panels' provider could install is a WEKO battery of 5kWh for a price of 5000€, the battery has 10 years guarantee and an expected life of 15 years. The DoD (depth of discharge), the percentage of discharge that the battery can reach, is 100% and the degradation with cycle is of 0.048% of the peak power of the battery. The provider takes care of dismantling the battery, therefore that cost is not taken into consideration in our analysis.

To consider the degradation, the yearly degradation percentage is calculated by multiplying the loss per cycle times the number of cycles. Therefore multiplying the yearly degradation percentage per residual efficiency, the yearly degradation is derived. After the battery degrades till the efficiency goes below 60% of the peak efficiency, it gets substituted within the 10 years warranty for free, therefore the peak power goes back to 100%. After the 10 years of warranty expire, the battery is left to degrade till its life end.

Funding

In this analysis we also consider different ways of funding the system:

- 100% equity would entail the household to pay for the full amount of the project.
- A mix of debt and equity would require the household to apply for a bank loan and use it to finance 75% of the project, using private source for the remaining 25%. To have a real-world estimation of the loan interest rate, various local banks have been contacted and the one providing the best loan rate is Banca Intesa San Paolo in Realmonte (AG). They would give a 6.15% interest rate for a 4-year maturity loan

with monthly installments in the case of a private employee, however it has to be considered that if the household is employed by the government, they would give a much lower interest rate (around 4%), thanks to some law incentives. The debt is amortized using the French amortization plan with equal installments every period.

ECONOMIC ANALYSIS

The study has been carried forward analyzing various aspects of the investment. The key KPIs used are the NPV of the project, the IRR, the Payback period and the LCOE. Other minor KPIs have been included in these 4 major figures.

Levelized Cost of Energy

The Levelized Cost of Energy (LCOE) is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. In practice, it represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle and is calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered. (Lai, Chun Sing, McCulloch, Malcolm D., 2017)[vii] The formula is the following:

$$LCOE = \frac{Sum\ of\ costs\ over\ life\ time}{Sum\ of\ electrical\ energy\ produced\ over\ life\ time} = \sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t} \Big/ \sum_{t=1}^{n} \frac{E_t}{(1+r)^t} \quad (1)$$

Where: I_t = *investment expenditures in the year t*

M_t = *operations and maintenance expenditures in the year t*

F_t = *electricity expenses in the year t*

E_t = *electrical energy generated in the year t*

r = discount rate

n = expected lifetime of the system

In our study we calculate the LCOE by setting the NPV of the investment to zero, since, as previously mentioned, it has to be the break-even of the cost for the financial life of the project. The lower it is the better because means that we would need to buy electricity for less to break even the investment.

Payback Period

The payback period of an investment is the time needed to repay the investment (arrive at break-even) and start making profits. In our case it is the time the investor has to wait before getting a positive income from the solar system. The formula used for the calculation is the following:

$$Payback\ Period = \frac{Cost\ of\ the\ investment}{Average\ annual\ cash\ flow} \tag{2}$$

For this value, the lowest the better since it means that the investor is able to generate return quickly.

IRR

The internal rate of return (IRR) is a metric used in financial analysis to estimate the profitability of potential investments. The IRR in practice is the discount rate that makes the NPV of all the cashflows of a project equal to zero. Generally speaking, the higher an internal rate of return, the more desirable an investment is to undertake. (Fernando J., 2022)[viii] In this project the IRR is used to compare the profitability of systems with different number of panels and different characteristics and is one of the main KPIs taken into consideration. The formula for the IRR is the following:

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0 \tag{3}$$

Where: C_t = *Net cash inflow during the period t*

C_0 = *Total initial investment costs*

IRR = Internal Rate of Return

t = number of time periods

In our analysis we IRR is very variable in all our scenarios, it goes indeed from 5% to 35% circa, making it easier to select a project based only on this metric.

NPV

The Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. It is used to analyze the profitability of an investment and in practice represents today's values of a future stream of payments. NPV accounts for the time value of money and can be used to compare similar investment alternatives, it relies however on a discount rate that is derived from the cost of capital of the investment. (CFA Institute, 2021)[ix] It is safe to assume that with the right manutention, unless there are extreme and unpredictable events, the cashflow of a solar panels system are relatively safe and predictable. The formula for the calculation of the NPV is the following:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \tag{4}$$

Where: R_t = *Net cash inflow - outflows during a single period t*

i = Discount rate that could be earned in alternative investment

t = Number of time periods

In our study, the NPV is the main KPI used to make the final investment decision, as it is the one, we assume, would be mostly considered by a standard household.

From energy to financials

To end up with the results for the different metrics, the values on energy production have to be transformed into economic figures.

We calculate the energy generation multiplying the peak power of the system by the radiation for 1kW for each hour of the year and we therefore sum them up to find a total generation over one year. Second step was to find the consumption in one year that comes from the hourly load profile that was previously described multiplied by the consumption derived from the electricity bills. From there, it is straightforward to derive how much energy is coming from the solar panels, how much energy is bought from the grid and how much energy is sold to the grid (in absence of battery). From this, applying the different prices of energy for buying and selling positions it is derived the cost without panels, the revenues from the sale to the grid, the residual cost of the energy that has to be bought from the grid and finally the savings due to the implementation of the project.

Financial figures

To find the best NPV outcome different analysis scenarios have been considered.

A first scenario, that can be considered as basic analysis, considers the price of the panels without subsidies, without the use of a bank loan and without a battery. It is clear that it will mainly be the least profitable investment. The results are presented in the table below:

Number of panels	**NPV [EUR]**	**IRR**	**Payback [years]**	**LCOE [EUR/kWh]**
1	3,632.06	21.56%	4.9	0.0706
2	6,412.34	19.61%	5.3	0.0706
3	**7,059.25**	**15.59%**	**6.6**	**0.0706**
4	6,955.46	12.54%	8.1	0.0706
5	6,612.60	10.35%	9.5	0.0706
6	6,155.08	8.70%	10.8	0.0706
7	5,620.40	7.38%	12	0.0706
8	5,050.89	6.32%	13.2	0.0706
10	3,860.69	4.68%	15.4	0.0706
11	3,247.27	4.04%	16.4	0.0706
13	2,000.57	2.97%	18.2	0.0706
14	1,367.96	2.53%	19.1	0.0706
16	94.46	1.76%	20.7	0.0706

Table 3: Main figures of the basic analysis

A second scenario considers only the price of panels discounted by the government subsidies offered. A table that summarizes all the data is presented.

Number of panels	NPV [EUR]	IRR	Payback [years]	LCOE [EUR/kWh]
1	4,082.06	41.59%	2.5	0.0431
2	7,215.84	37.44%	2.8	0.0431
3	**7,974.55**	**29.09%**	**3.6**	**0.0431**
4	7,897.10	22.99%	4.6	0.0431
5	7,552.19	18.75%	5.6	0.0431
6	7,078.71	15.62%	6.6	0.0431
7	6,519.02	13.17%	7.7	0.0431
8	5,920.37	11.20%	8.9	0.0431
10	4,665.82	8.16%	11.3	0.0431
11	4,018.04	6.94%	12.5	0.0431
13	2,700.17	4.89%	15.1	0.0431
14	2,030.77	4.00%	16.4	0.0431
16	682.60	2.43%	19.3	0.0431

Table 4: Main figures of a system paid using 100% equity

Here it can be seen that the NPV as well as the IRR are decreasing with the increase in the number of panels, the LCOE is fixed at 0.0431 €/kWh and the payback is proportional to the number of panels installed. This leads to a single best choice of installing 3 panels for a power of 1.125kW.

However, this scenario does not consider the case of financing the project by equity and debt. The next table describes the results for the above-mentioned scenario:

Number of panels	NPV [EUR]	IRR	Payback [years]	LCOE [EUR/kWh]
1	4,044.81	83.17%	1.4	0.0453
2	7,141.33	69.65%	1.8	0.0453
3	**7,862.79**	**45.89%**	**4.0**	**0.0453**
4	7,748.09	31.99%	5.1	0.0453
5	7,365.93	24.03%	6.2	0.0453
6	6,855.19	18.91%	7.4	0.0453
7	6,258.25	15.27%	8.6	0.0453
8	5,622.35	12.54%	9.8	0.0453
10	4,293.29	8.61%	12.4	0.0453
11	3,608.27	7.11%	13.8	0.0453
13	2,215.89	4.65%	16.6	0.0453
14	1,509.23	3.62%	18.1	0.0453
16	86.56	1.81%	21.1	0.0453

Table 5: Main figures of a system paid using 75% debt

Here it can be noted that even though the NPV is lower compared to the basic scenario the IRR is higher in most of the cases. Payback period and LCOE are both higher. Therefore, also in this case the choice on the best investment is on 3 panels for 1.125kW, however in this case the equity investment would be 337.5€.

Lastly, a scenario in which the investment is paid by debt and equity and the use of a battery is considered is analyzed and the following table sums up the main results:

Number of panels	NPV [EUR]	IRR	Payback [years]	LCOE [EUR/kWh]
1	1,429.88	5.41%	15.6	0.2108
2	4,842.05	11.80%	10.2	0.1281
3	6,982.21	15.16%	8.5	0.1005
4	8,641.70	17.66%	7.5	0.0867
5	**9,143.08**	**17.48%**	**7.6**	**0.0784**
6	9,088.97	16.27%	7.9	0.0729
7	8,759.81	14.78%	8.4	0.0690
8	8,268.52	13.25%	8.9	0.0660
10	6,992.33	10.38%	10.2	0.0619
11	6,300.64	9.13%	10.9	0.0604
13	4,879.21	6.96%	12.6	0.0581
14	4,153.54	6.01%	13.5	0.0572
16	2,693.79	4.31%	15.6	0.0557

Table 6: Main figures of a system using 75% debt and a battery

In this last scenario we can find contradicting results - even though we find on average a much higher NPV, the IRR is lower and the payback period higher, as well as the LCOE. Based on the NPV, our key metric in the investment choice, installing 7 panels for 2.63kW would be the best choice.

The following graph is instead a comparison of all the three different scenarios' NPVs:

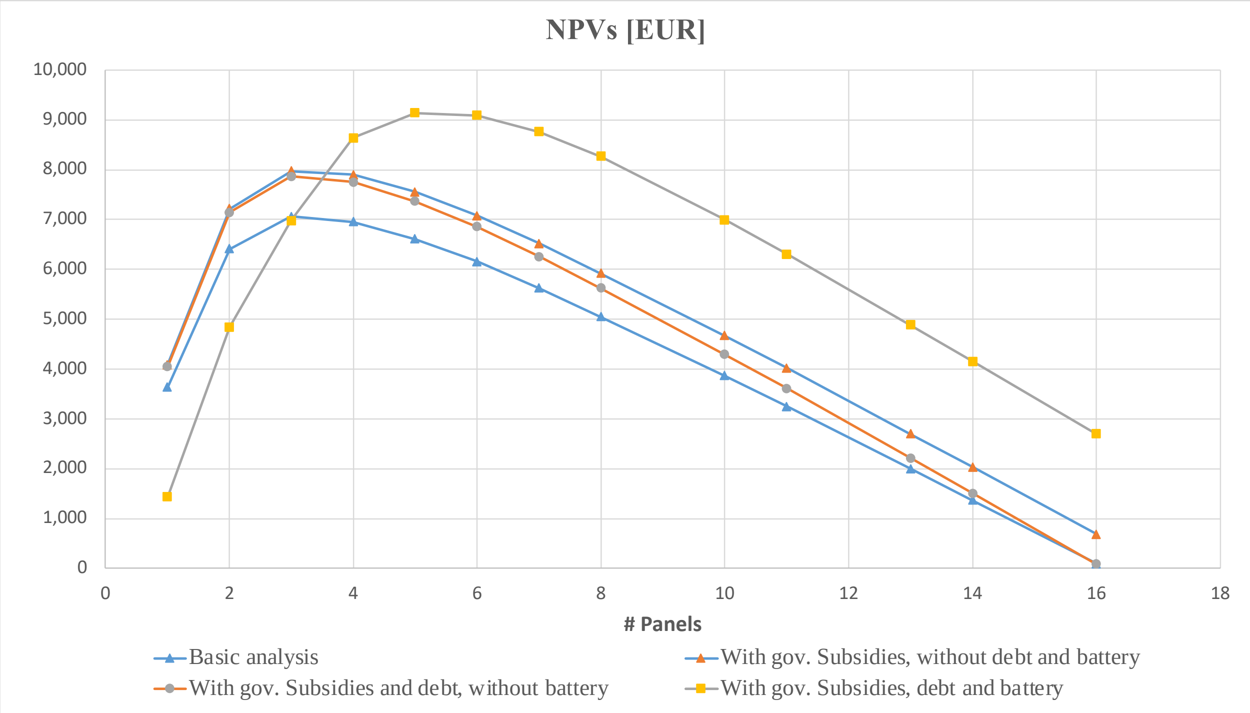


Figure 1: comparison of the NPVs of the projects

ITALY: MAIN ASSUMPTIONS, DATA & OUTPUT (MILANO, GENOA, ROME, PORTO EMPEDOCLE)

In this chapter, the main difference between the analyses of the Italian cities are described, to understand why and in what the results vary from city to city.

There are many differences over the input data of the model depending on the city of focus.

- Cities are slightly different in total consumption. In particular, the total annual consumption, which measures the electricity consumed by the standard household during the year ranges from: (Milano 3561 kWh) (Porto Empedocle 3550 kWh) (Rome 3600 kWh) (Genova 3153 kWh).
- Electricity prices vary among cities. In fact, prices range from (Milano: 0,22 €/kWh) (Porto Empedocle: 0,25 €/kWh) (Rome:0,23 €/kWh) (Genova: 0,27 €/kWh). On the other hand, the selling price of energy which results from excess production from the panels has a fixed value of 0,03 €/kWh. However, this value only matters if the standard household decides to forgo the governmental subsidies associated with photovoltaic

systems. If the household exercise the subsidy the excess production is transferred to the grid for free.

- Panels differ in terms of brand and Peak Power (Milan: 400 W) (Rome: 400W) (Genoa: 385W) (Porto Empedocle: 375W). The highest quote for an operative system of 5 panels is 6900€ (Roma), then Milan 6220€, Genova 5983€, and the lowest is 4500€ (Porto Empedocle). This price does not include governmental subsidies.
- Differences in panel capacity (W) and solar irradiance will impact the generation capacity (kWh produced by the PV system) for a system of equal size. Generation values (5 panels): (Milan: 2740 kWh) (Genoa: 2555 kWh) (Rome: 3297 kWh) (Porto Empedocle: 3216 kWh).
- Bank loan rates are slightly different as well. Rates range from (Milano: 5.1%) (Porto Empedocle: 6,15%) (Rome: 6,03%) (Genoa: 5,50%). Maturity for Milan, Rome, Genoa is 5 years while for Porto Empedocle is 4 years.

These differences in input data are expected to generate differences in the economic outcome. Therefore, to assess the economic outcome, we have compared results for a fixed scenario.

A PV system of 5 panels partially financed by governmental subsidies.

- Porto Empedocle: NPV: 7552€ ; 18.7% IRR ; Payback 5.6 years; LCOE: 0.043
- Genoa: NPV: 4654€ ; 11% IRR ; Payback 9.2 years; LCOE: 0.060
- Rome: NPV 3941€ ; 8.7% IRR ; Payback 11 years; LCOE: 0.056
- Milan: NPV 3550€ ; 8.7% IRR ; Payback 11 years LCOE: 0.059

As expected results vary greatly among cities. This is a result of differences in the total annual consumption; cost of energy; panels quote; peak power; generation capacity; solar irradiance. Moreover, this result confirms that the South is more suitable than the North for solar panels due to favorable sun exposure and climate.

The following table resumes the differences in the main assumptions and outputs for an easier confrontation:

	Milan	Genoa	Rome	Porto Empedocle
Consumption [kWh]	3,561	3,153	3,600	3,550
Electricity cost [€/kWh]	0.22	0.27	0.23	0.25
Electricity selling price [€/kWh]	0.03			
Peak power of 1 panel [W]	400	385	400	375
Price for 5 panels [EUR]	6,220	5,983	6,900	4,500
Generation [kWh]	2,740	2,555	3,297	3,216
NPV [EUR]	3,550	4,654	3,941	7,552
IRR	8.70%	11%	8.67%	18.70%
Payback [years]	11.0	9.2	10.8	5.6

Table 7: assumptions and output table

Furthermore, to explain the difference in the outputs, a weight on the different inputs has been calculated and can be sum up in the table below:

	Cost of panels (with subsidies)	Mainteinance cost	Savings	NPV
Porto Empedocle [EUR]	-2,250.00	-1,269.00	11,048.00	7,552.00 €
Milan [EUR]	-3,110.00	-1,015.00	7,660.00	3,550.00 €
Differences (PE-MI) [EUR]	860.00	- 254.00 €	3,388.00 €	4,002.00 €
Weights	21.49%	-6.35%	84.66%	-

Table 8: weights allocation

To calculate the weights, the difference in inputs between the two extreme cases (Porto Empedocle and Milan) have been calculated and weighted over the difference in NPVs.

$$Weight_i = \frac{I_{PE} - I_{MI}}{NPV_{PE} - NPV_{MI}} \quad (5)$$

Where: I_{PE} *= Input factor Porto Empedocle*

I_{MI} *= Input factor Milan*

NPV_{PE} *= NPV Porto Empedocle*

NPV_{MI} = *NPV Milan*

It can be noted that most of the weight allocation is on the savings since they represent the biggest part of the final NPV. The savings are calculated as the electricity expense that there would be without the solar panels system, minus the electricity expense with the solar panels system, plus the revenues from selling electricity to the grid.

FINAL RECOMMENDATION

It is important to consider that the project is based on an average household from Porto Empedocle, that, due to a sociocultural context, distrusts institutions. From this point of view, contextually to a low level of financial education, there is a translation into distrust in keeping money in a bank account preferring the use of cash, which, therefore would prevent from asking for a bank loan. Therefore, even though it does not translate in the best NVP, the household might have enough cash availability to start a project fully financing it by equity. This situation makes the project more complex since the aim of the investment itself is to generate economic profit besides of the environmental impact that would come along with an autonomous solar power system in the long term. It should also be considered that the advantageous price of using government subsidies is offset by the impossibility to sell the excess electricity to the grid, that makes desirable the use of a battery, to both store electricity during daytime and not buy it during nighttime.

Anyway, based on the analysis, without a battery, with 100% equity and using the government subsidies, the best option would be to install a 3 panels' system for a total price of 2700€ and a power of 1.125kW. This would result in a levelized cost of energy (LCOE), a measure of the average net present cost of electricity generation for a generating plant over its lifetime, of 0.043€/kWh, a payback period of 3.6 years, saving per years of 396.68€ and a total NPV of

7975€ with a 29.1% IRR, even though sometimes it contradicts the results we find on the other metrics, making therefore the choice harder. If, however there is no financial availability to invest in such a project, the choice of opening a bank loan is feasible and would still deliver a positive NPV. If the financial availability also allows the investor to install a battery to the system, the NPV would rise by almost 100% with 6800€ more of investment and go to a best project of 5 panels system for a total price of 9500€ and a power of 1.875kW. This would result in a levelized cost of energy (LCOE), a measure of the average net present cost of electricity generation for a generating plant over its lifetime, of 0.0784€/kWh, a payback period of 7.6 years, saving per years of 435.47€ and a total NPV of 9143€ with a 17.5% IRR, this considering also a bank loan to finance the project.

As a conclusion, according to the analysis, installing solar panels around Porto Empedocle seems to be a profitable investment and is highly recommended to all the household that have the possibility to do it.

Executive Summary

Location: Genoa, Italy **Date of analysis**: April 2022

Recommendation: Install four solar panels (7.44 m^2), for a Net Present Value of 4586 €, with a Payback period of 9.49 years.

Main economic results:

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh
[Gov. subsidies and] 75% debt	4586€	9.49	14%	0.07
[Gov. subsidies and] 100% equity	4816€	8.50	12%	0.06
[No gov. subsidies and] 100% equity	2826€	14.57	5%	0.11

Additional results: A system of five panels, together with a battery of 5.12 kWh, requires an initial investment before subsidies of 9073 €, but provides an NPV of 7889 €, with a payback of 7.75 years.

Main inputs and assumptions

Household and Economics					
Electricity Consumption	3153.44	kWh/year	Inflation	2%	per year
Electricity price – buy	0.27	EUR/kWh	Bank loan interest rate	5.50%	per year
Electricity price – sell	0.00-0.03	EUR/kWh	Bank loan maturity	5	years
			Equity cost of capital	1.71%	per year

PV panels					
Peak power	385	W/panel	System losses	13.5%	of output
Panel area	1.86	m^2/panel	Degradation with age	0.5%	Per year
Useful life	25	Years	Maintenance costs	9.38	EUR/year per panel
Total cost of optimal installation size (without subsidies)				5432	EUR
Total cost of optimal installation size (after subsidies)				2716	EUR

Government subsidies: The incentive program Ecobonus was established through the law Decreto Rilancio. Italian citizens can save up to 50% of their investment to install photovoltaic systems which occurred before 31/12/2024.

Introduction

This Field Lab provides an unbiased explanation of the economic potential of photovoltaic systems for a "standard household" in Italy. The model assesses the financial viability over 25 years through financial outcomes such as Net Present Value (NPV), Internal rate of return (IRR), Payback period, and Leveraged cost of energy (LCOE). Cities covered by the Field Lab are spread throughout Italy, from North to South. This wide range allows comparing results regionally while also providing a definitive recommendation for the whole country.

Nevertheless, before digging into the model's assumptions, inputs, and outputs, it is necessary to conduct a brief literature review of the Italian photovoltaic market. The first solar panel installed in Italy dates to 1979; however, its mainstream adoption occurred between the 1990' and 2000' because of the first governmental incentive program, "Conto Energia" (RegalGrid, 2020). This incentive was the first step toward nurturing the Italian renewable energy sector. Those two decades were crucial in familiarizing citizens with alternative and sustainable ways of producing and consuming energy. Since then, the trend has been positive, and its trajectory keeps on growing. According to "Gestore Servizi Energetici" (GSE), the average clean electricity consumption in Italy was marked at 33.9%, with photovoltaic accounting for roughly 20%. Moreover, Italy is the world leader in electricity consumption derived from solar panels and has the second biggest photovoltaic market infrastructure in Europe (Statista, 2021).

According to Statista, between 2009 and 2020, photovoltaic systems increased from 76593 units to 935938 units. The standard household sector is the dominant one, with 756916 units, accounting for 80.87% installed systems. The accumulated capacity from these systems in 2020 was marked at 20.85 GW. Nevertheless, self-consumption accounted for 38% of the total energy generated by panels, while the remaining 62% was transferred to the grid through a mechanism called "scambio sul posto" (RegalGrid, 2020). This mechanism ensures no energy is being wasted as it collects excess production from panels and redirects it towards the grid.

Furthermore, Italy's unique shape and sun exposure suggest that Southern regions should be the leading force in this sector; however, the highest systems concentration is in the North (55%) while the South only accounts for 28%. The remaining 17% accounts for regions in the Center (Statista, 2021). Located in the Center is the city of Genova, a beautiful, chaotic, hard-working town by the Mediterranean Sea. A city of 566.410 inhabitants, situated on the west coast of Italy, in the Liguria region. The area of the city is spread over 240.26 km2 with a population density of 2357 inhabitants per km² and an average annual salary of 37193€ (UrbiStat, 2020). Genoa's climate is Mediterranean, with mild, rainy winters and warm to hot, sunny summers. The average temperature of the coldest month (January) is 9.1 °C that of the warmest month (August) is 25.1 °C (Climates to Travel, 2022). Nevertheless, Liguria is ranked 17th for residential photovoltaic systems realized, with a capacity of 37MW derived from 8919 systems (Nicora, 2022). These systems account for only 3.4% of buildings, meaning that photovoltaic systems have produced only 1.8% of electricity consumed. Consequently, the city of Genoa is far from entirely ripping its opportunities in this sector.

Modeling Assumptions

Assumption a): This project is based on a household of 4, with working parents and two children. This implies that the house would be empty most of the day as both parents are off to work while the kids are at school. Hence, most weekly electricity consumption will occur during the night and early morning.

Assumption b): Genova's apartment buildings are predominant; therefore, the family is expected to live in an apartment building. We assume that the roof has total sun exposure and no size restrictions, which means that we can install a photovoltaic panel of any size. Panels can be mounted in a fixed position which guarantees that they are installed at the optimal slope and azimuth.

Assumption c): Smart Homes Penetration rate in Italy lies at 12.4%, which stands well below other European countries such as Germany and France (Statista, 2022). Considered by this measure are devices that are connected directly or indirectly via a so-called gateway to the Internet. Their primary purposes are controlling, monitoring, and regulating functions in a private household. This finding implies that the Load profile reflects the inability to run machines at will when energy demand is lower as the average standard household does not have adequate means to complete such a task.

Input Data

Solar Irradiance and Generation

Solar irradiation is a valuable and abundant source of power, enough to supply on its own the needs of the entire planet (Vidal, 2014). To boost the average solar irradiation collected, the angle (β), which is the angle between any tilted surface and the horizon, should be optimized. The optimum tilt angle is calculated using the Photovoltaic Geographical Information System. Hence, using irradiation data collected from satellite photos, the PVGIS calculates the PV's radiation and energy production (Photovoltaic Geographical Information System, 2022). Input values for the model are the three most recent years available in the database; 2018, 2019, and 2020. However, 2020 included the 29th of February, which is not present in 2018 and 2019. Therefore, the hourly values for the 29th of February were erased. The dataset is a time series composed of 8760 values; this means that values are gathered on an hourly basis for the entire year. These values already account for overall system losses (14%). This constant number accounts for both system losses 13.5% and 0.5% degradation per year. These values are based on crystalline silicon PV technology mounted at optimal slope and azimuth. Power (P) from the three years is averaged and will be used for the "Generation" estimate. This value estimates the quantity of energy produced by the PV system in kilowatts. This measure varies depending on the number of panels and their respective power (Watt). Hence, if Irradiance is kept as a constant, the higher the peak power (number of panels * Watt of single panel), the higher the "Generation" achieved.

Load Profile, Annual Total Consumption and Electricity Price

Table 1. Genoa's Input Values for Total Annual Consumption and Price per kW

Variables	Cerutti Family (2)	Pini Family (3)	Pini Family (4)
Heating	Natural Gas	Natural Gas	Natural Gas
Tariff	F0	F1, F2, F3	F1, F2, F3
AC	No	No	No
Annual Consumption kWh	3274*	3133.33*	3053
Price per kWh	0.29 €	0.31€	0.21€

Table 2. Genoa's Annual Consumption and Price per kW

Variable	Value	Unit
Total Annual Consumption	3153.44	kWh
Price per kWh	0.27	€ per kWh

The standard household's total annual consumption (kWh) has been calculated using energy bills collected from three homes, mainly friends and family residing in Genova. The average annual value for consumption is 3153.44 kWh which is slightly lower than the average range for Italian families of 3300-3600 kWh (Facile.it, 2022). Once the total annual consumption has been established, it needs to be allocated to the "Load Profile," obtained with a Top-Down approach. This process allocates the total yearly consumption to each hour of the year. This section is a time series of 8760 values, and it reflects the consumption pattern of the standard household for the entire year in hourly values. Nevertheless, Italian providers do not share this kind of information, both private and public. Hence, the "Load Profile" used in the model is based on E-Redes estimate for Portugal (E-REDES, 2021). In Portugal (Lisbon Region), the climate is Mediterranean, with mild, rainy winters and warm, sunny summers. The average temperature of the coldest month (January) is 11.8 °C, and that of the warmest month (August) is 23.6 °C (Climates to Travel, 2022).

Hence, Portugal's values share similarities in peaks and patterns with those highlighted for Genova in the introduction. Furthermore, 70.9% of Italian systems for heating needs rely on natural gas (Statista, 2021), while heating consumption in Portugal is mainly provided by biomass (68%) (Gouveia, 2021). Therefore, the impact on the "Load profile" caused by heating needs is barely significant as the Italian market mainly relies on Natural gas and the Portuguese one on biomass. Moreover, air-conditioning systems in both countries are alimented with electricity. AC systems were found in 15.7% of Portuguese households, while Italy's air-conditioning systems were 7% (Gouveia, 2021). Such similarities in climate and consumption patterns allow us to base Genoa's "Load profile" on Portugal's. Consequently, the main difference is the total annual consumption of kilowatts. To adapt the "Load profile" to fit the yearly consumption for Genova, the difference was divided by the 8760 values of the time series. The result was then subtracted from every value of the time series. Therefore, the updated load profile has the same consumption pattern while matching the annual total consumption of 3153.44 kWh estimated for Genova. Hence, by matching the "Load profile" with the "Generation" it is possible to observe hourly periods when production is just enough or more than enough to satisfy demand and periods of shortage when the standard household relies on standard electricity consumption.

The electricity cost (€/kWh) was obtained by averaging monthly bills collected from friends and family over 2021. Nevertheless, prices are subject to fluctuations generated by the type of contract and by providers' offerings. Hence, depending on the provider, a standard household can pay a fixed rate *(F0)* regardless of the hour of the day in which energy is consumed or a two-rate/three-rate tariff (*F2, F3)* which relies on different prices based on the time of the day. Electricity bills include taxes and reflect the ratio between kWh consumed and the price paid. In Italy, electricity bills include the Italian public television service called "Canone Rai." This rate has been deducted from every bill to have a fair analysis of the actual energy cost. This resulted in Genova's 0.27 €/kWh price, slightly higher than the national average for 2021 of 0.24 €/kWh (S. Alessandro, 2022). Moreover, to estimate the revenue received by selling excess electricity to the "Grid," the model uses the average price indicated by the PV system provider Otovo. The selling price lies at 0.03 €/kWh (Nicora, 2022). However, once a customer decides to rely on government subsidies, they give up the right to profit from selling the excess. This might come at a financial cost considering the spike in electricity prices. The first trimester of 2022 was characterized by a peak of 0.308 €/kWh as "Prezzo Unico Nazionale" in March (Luce-Gas, 2022), with prices expected to grow further because of political and economic turmoil.

Panel Quotes

Table 3. Panel Characteristics

Factor	Value	Unit
Peak Power	385	Watt
Efficiency	19.3%	-
Space	1.86	m^2
Size	8	panels
Totals Space	14.88	m^2
Installation Cost	7334	€

The chosen panel provider is Ja Solar, the Cypress series. Ja Solar's offerings outperform most of its mid-range competitors regarding efficiency. The monocrystalline Cypress series was selected for the project; it has a rated maximum power of 385 Watts, a module efficiency of 19.3%. A singular panel comprises 72 cells and covers an area of 1.86 m^2. The peak power warranty is 25 years. The installation cost is not reflected in this price. For example, Otovo offers to install an operating system of 8 Ja Solar Cypress 385 W for a fee of 7334€ before subsidies. This quote by Otovo was then used to estimate the price for smaller and larger PV systems. According to Go Solar Quotes, the yearly professional maintenance cost is estimated to be 9.375€ per panel. Hence, the bigger the PV system, the higher the maintenance cost. Panels' choice is a critical component in maximizing returns. Hence, if instead of Ja Solar, we had chosen Solstrale IKEA panels, the economic outcome would have been less attractive. A PV system of 4 IKEA Solstrale plus (400W) panels installed by Wölmann has a cost before subsidies of 6230 € and achieves an NPV of 4486 € and an IRR of 10%. These returns stand slightly below the results obtained with Ja Solar panels shown in the Executive Summary for the scenario which considers government subsidies only.

Bank Loan

Table 4. Bank Loan

Amount of Debt	75%
Annual Interest rate	5.50%
Maturity	5 years
Financing Provider	Gruppo Findomestic

Photovoltaic projects can be expensive for a standard household, and it might take years to pay back the investment. However, if the household cannot fully sustain the gross investment in the short term, there is always the possibility to rely on bank loan financing. In this case, the percentage of debt to finance the gross investment is 75%. Interest rates were gathered by submitting requests based on a fixed set of criteria for a standard household of 4. Both parents earn an average wage in the private sector (37,193€) with at least 20 years of working experience. Results varied greatly among banks. Hence, some financing providers valued the environmental cause of installing PV systems and offered lower rates. Other providers did not consider that and charged rates as high as 12.27% (Figure 7). Consequently, the most suitable provider was Gruppo Findomestic (BNP Paribas), a financing provider which has developed a type of loan called "Green Loan" to facilitate and incentivize renewables choices (Gruppo Findomestic, 2022). The fixed yearly rate offered is 5.50% for investments up to 10,000 € within a 5-year maturity.

Government Subsidies

Table 5. Government Subsidies

Amount of Subsidy	50%
Maximum amount	48,000€
Deadline	31/12/2024

The Italian government has been implementing incentives for solar panels since the early 90s, with the first one being "Conto Energia." However, other incentive programs have been set up throughout the year. The incentive program "Ecobonus" covers 50 percent of expenses which occurred before 31/12/2024 (Gazzetta Ufficiale, 2020). It used to work by deducting savings from customers' IRPEF (taxes) in a time window of 10 years by a fixed yearly amount. Nevertheless, since the 1st of July 2020, the "Decreto Rilancio" has introduced an easier way to utilize this bonus. As a result, providers already consider this incentive in their offers. This new method dramatically simplifies customers' experiences while transitioning to clean energy. However, if the incentive is used, it will not be possible to sell excess energy to the grid to generate profits.

Calculations & Main Result

Net Outflow Basic Analysis & Savings

Table 6. Net Outflow

Variable	Value	Unit
Total Annual Consumption	3153.44	kWh
Generation	2189.54	kWh
Self-Consumption	1237.79	kWh
Transferred to Grid	951.75	kWh
Residual Amount	1915.65	kWh

Once all input data was gathered, the model was set up to estimate savings associated with the PV system through the Net Outflow. The Net Outflow is a time series of 8760 hourly values, and it calculates whether the energy produced by the system is being self-consumed or transferred to the grid. In other words, it matches production with consumption. No energy must be wasted in an operational and efficient PV system. Therefore, for every hour of the year, we can calculate the difference between the power generated by panels (kWh) and the demand by the standard household. If the "Generation" is higher than demand excess energy is transferred to the "Grid"; if "Generation" is lower than demand, the household buys the "Residual Amount" through a standard electricity provider.

Savings from the PV system depend on various factors, such as the capacity of panels to generate Power (P) from solar Irradiance (W/m^2). Furthermore, it is possible to profit from excess production by selling it for a price of 0.03€/kWh to the grid. However, this opportunity is only available for those who did not take advantage of incentive programs. According to the hourly analysis, a system of 4 panels based on the average of Power generated by solar irradiance in Genova for 2018,2019,2020, generates 2189.54 kWh in one year. However, of the energy generated by the system, only 1237.79 kWh are used for "Self-consumption". The remaining 951.75 kWh are transferred to the "Grid." This means that the "Residual Amount" needed to satisfy demand is 1915.65 kWh.

Table 7. PV Savings

Variable	Value	Unit
Cost of electricity w/out panels	850.23	€ per year
Revenue transferring excess to Grid	0 or 28.55	€ per year
Residual cost to satisfy annual demand	561.50	€ per year
Savings due to PV	333.73 or 362.29	€ per year

This "Residual Amount" is being paid through a standard contract based on a fixed rate *(F0)* of 0.27€/kWh, which gives us a residual cost of 516.50 € per year. Hence, to assess the financial viability of the PV system, the annual consumption cost without solar panels was calculated and used as a benchmark. In this case, due to a "Total Annual Consumption" of 3153.44 kWh and a price of 0.27€/kWh, the energy cost for the whole year amounted to 850.23€.

Therefore, if government subsidies are in place (no revenues from selling to the grid), the yearly saving will be the difference between the benchmark cost of 850.23€ and the residual cost of 516.50 €. In this case, the standard household saves up to 333.73 € per year. If no incentive is used, the 951.75 kWh, which were previously given away for free to the grid, generates revenue of 28.55 €, increasing savings to 362.29€ per year.

Lastly, two checks are in place to ensure that the model is operating at maximum efficiency. The first one works by subtracting from the "Generation" (2189.54 kWh) the sum of "Self-consumption" (1237.79 kWh) and energy transferred to the "Grid" (951.75 kWh). This value needs to be 0.00 for the check to be valid. The second check ensures that the "Total Annual Consumption" has been completely satisfied. Therefore, the sum of the "Residual Amount"

(1915.65kWh) and “Self-consumption” (1237.79 kWh) needs to be equal to the “Total Annual Consumption” (3513.44 kWh) for the check to be valid.

Financial Viability Basic Analysis

The outcome will be measured through economic parameters such as: Net Present Value of the investment (NPV), Internal Rate of Return (IRR), Payback years, Leveraged cost of energy (LCOE). The financial viability is assessed over a period of 25 years. Cashflows are estimated through a variety of factors. Firstly, the equity investment by the household depends on governmental subsidies and bank loans according to the chosen scenario. Secondly, electricity savings (savings obtained by installing a PV system compared to the price paid for electricity consumption without) are expected to grow based on the ECB’s inflation goal for the foreseeable future of 2% (European Central Bank, 2022). Cashflows also include the yearly maintenance cost for the system. This value is estimated to be 9.38€ per panel, and it is expected to increase yearly due to 2% inflation. Lastly, CFs will consider the loan repayment over the loan’s maturity (5 years) if the debt is used. The annual loan repayment is calculated as an annuity. Hence, once cashflows have been estimated, they are discounted by the equity cost of capital; this happens as the project is risk-free, and therefore CFs are discounted by the 10-year swap rate of 1.71% (Chatham Financial, 2022). The present value of cashflows is then summed up over the project’s duration to determine the Net Present Value. This measure reflects the profitability of the project. If the NPV is positive, the discounted present value of all future cash flows related to the project will be positive, making it attractive. Hence, once the NPV is generated, we can determine the Internal rate of return (IRR). This discount rate makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. Generally speaking, the higher an internal rate of return, the more desirable an investment is to undertake.

The payback period is the length of time it takes to recover the cost of an investment or the length of time an investor needs to reach a breakeven point. Shorter paybacks reflect more attractive investments, while more extended payback periods are less desirable. Hence, to calculate the payback time of the investment, we need to estimate accumulated cash flows. The first accumulated CFs is the equity investment by the household. Then cashflows from the previous year are added to cashflows of the upcoming year for the whole range of the project. The first value showing a positive accumulated CF implies that the investment is fully recovered within the respective payback year.

Lastly, the LCOE is estimated through a Goal Seek function. LCOE is the selling price of energy that sets the NPV to zero, assuming all energy generated by the panel is sold to the grid. The sale price is expected to grow according to the 2% inflation rate. Multiplying the sale price by the yearly Generation gives us the revenue from selling to the grid. LCOE's cashflows also consider the equity investment, maintenance cost, and loan repayment. Once CFs are estimated, the present value of cashflows is computed by discounting them by the 10-year interest swap rate of 1.71%. The PVCFs are then summed up to generate the NPV, which will be offset to zero by the LCOE.

The model compares outcomes for three different scenarios:

[1] Governmental subsidies

[2] Debt (75%) and Governmental subsidies

[3] Pure Equity (no subsidies & no debt)

Figure 1. Basic NPV as a function of panels - Scenario 1 (Best project)

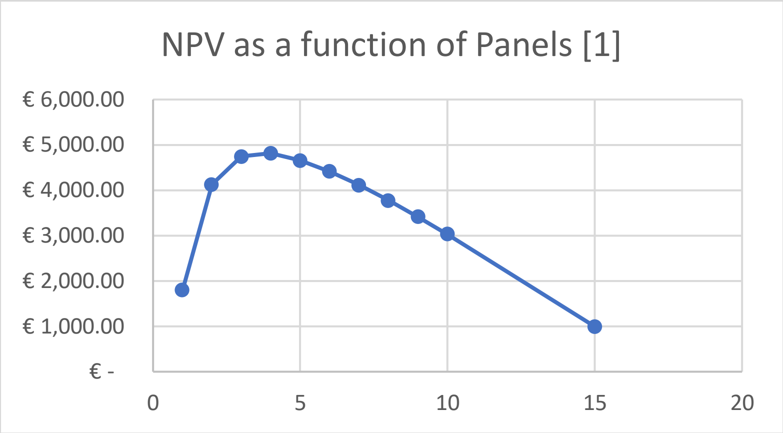


Figure 2. Basic NPV as a function of panels - Scenario 2

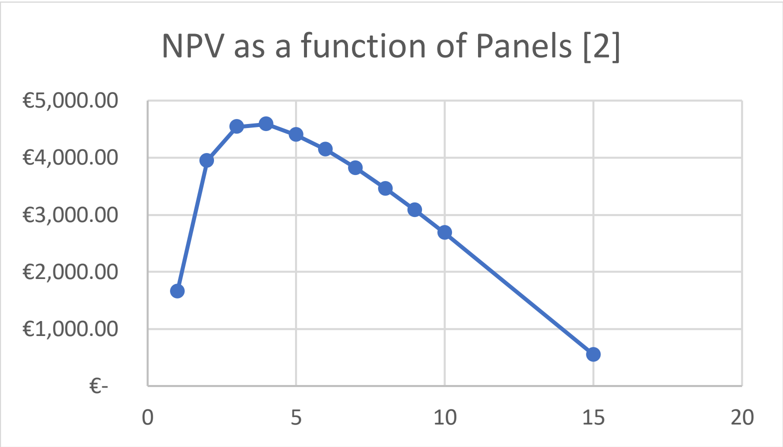
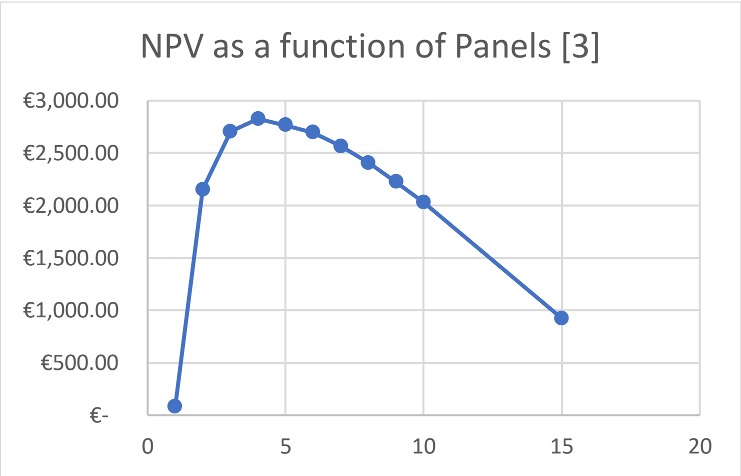


Figure 3. Basic NPV as a function of panels - Scenario 3



As shown in the Figures 1,2,3 every project scenario for the Basic analysis of Genoa generates a positive NPV. The highest NPV is associated with scenario one, only including governmental subsidies. In this scenario, 50% of the investment is deducted, and energy transferred to the grid cannot be sold for a profit. The highest NPV is achieved with a PV system made of 4 Ja Solar panels which guarantee yearly savings of 333.73€. The NPV of the project is 4816€ with an IRR of 12%, a payback period of 8.50 years, and a LCOE of 0.066 €/kWh. Lastly, according to figures 1,2,3 the NPV as a function of panels show a concave pattern, with peaks when the size of the PV system is of 4 panels in all scenarios.

Additional Analysis: Lithium-ion Battery

Table 8. Lithium-ion Battery

Variable	Value	Unit
Power Warranty (60%)	10	years
Max Storage Capacity	5.12	kWh
Max Discharge	96%	%
Initial State of Charge	1.33	kWh
Losses per cycle	0.036 %	%
Max Charging/ Discharging Power	2.56	kW
Cost	3090	€

By 2030, the worldwide lithium-ion battery market is expected to have grown from USD 41.1 billion in 2021 to USD 116.6 billion (Markets and Markets, 2022). The surge in demand for continuous power in critical infrastructures such as the renewable energy industry propels the market forward. Adding a lithium battery to the system significantly improves the percentage of energy produced by panels that the household can consume. On average, a PV system without an accumulation system enables users to deploy only a constrained percentage of the energy generated. Therefore, we expect this value to increase significantly with the addition of an external storage system. The Net Outflow of a PV system, including an accumulation system, follows the same logic as one without. The critical difference is that we can allocate energy produced more efficiently through the battery. Therefore, once the panel generates kilowatts, those kWh are allocated to self-consumption, the battery, and the grid.

The chosen battery is BYD HVS 5.*1*, and it has a cost of 3090€ and a 60% peak power warranty within the first 10 years of usage—the “Usable capacity” peaks at 5.12 kWh with a “Maximum discharge” of 96%. The maximum discharge reflects the ability of the battery to discharge up to 96% of the energy stored. Hence, the “Available storing capacity” will be given by the “Usable capacity” (5.12 kWh) minus 4% of the “Usable capacity” (0.2048 kWh). This results in an “Available storing capacity” of 4.92 kWh. Capacity is further reduced by the losses happening in every charging and discharging cycle. “Losses” fluctuate between 0.025% and 0.048% depending on the state of charge of the battery, hence, on average 0.036% per cycle (Spotniz, 2003). Moreover, the higher the size of the PV system, the higher the higher the annual losses per cycle.

In example, a system of 5 panels paired with a battery generates capacity losses of 7.87% in the first year, while a system of 10 panels generates capacity losses of 10.19%. This percentage is found by dividing the “Self-Consumption due to battery” by the maximum storing capacity of the battery of 5.12 kWh and multiplying the result by the average losses per cycle of 0.036%. Therefore, within the first 10 years of usage, if the battery does not guarantee a minimum performance of 60% of the available capacity, the client can exercise its warranty and replace the battery with a new one without incurring into additional expenses. In example, a PV system of 5 panels paired with a BYD battery generates 2408.32 kWh of overall “Self-Consumption” with 1119.23 kWh attributed to the battery. Hence, with losses of 7.87% in the first year, the following year maximum capacity is given by: Self-Consumption due to battery of year one 1119.23 kWh – (7.87% of losses times 1119.23 kWh). This results in 1031.15 kWh of maximum Self-Consumption from the battery in year 2. In this case, a new battery is provided for free in the beginning of year 8 when the percentage of power warranty goes below the 60%

performance threshold. Hence, from year 8 onwards, the new battery will continue to suffer losses and will end up with only 25% of capacity in the 25th year. The "Maximum charge power" for lithium batteries is 50% of the "Usable capacity"; this means the battery cannot recover more than 2.56 kWh per hour (MasterVolt, 2022). The same constriction applies to the "Discharge power", meaning that the battery discharges accumulated power up to 2.56 kWh per hour. Lastly, according to regulations regarding the safety of the transportation of lithium, the "Initial state of charge" cannot be more than 30% of the "Usable capacity" (Recharge, 2022). Therefore, the first value of the "Available storing capacity" of the model is 30% of the "Available storing capacity" (4.92 kWh) which results in 1.33 kWh.

The battery charges itself using excess production during hours when the "Generation" is higher than demand ("Load profile"). It is important to remember that the charging capacity has an hourly ceiling of 2.56 kWh and an overall charging capacity of 5.12 kWh. Hence, the model calculates the charging percentage of the battery for every hour and the percentage difference from the hour before. The battery's maximum charge is 100%; however, since we can only discharge 96%, the battery will have a bottom ceiling of 4%.

Table 9. Net Outflow Storage Battery

Variable	Value	Unit
Total Annual Consumption	3153.44	kWh
Generation	2736.93	kWh
Self-consumption PV	1289.09	kWh
Self-Consumption Battery	1119.23	kWh
Transferred to Grid	328.93	kWh
Residual Amount	745.09	kWh

On the one hand, grid connection is still relevant as the combination between excessive solar irradiance and limited re-charging power generates hours in which production will be higher than the consumption and storing capacity. Therefore, in the case in which "Generation" is higher than demand and the battery's capacity is already full, excess production will be transferred to the "Grid". On the other hand, when the sum of "Generation" and the amount of energy stored in the battery is insufficient to meet demand, the household will consume the "Residual Amount" through a standard energy provider.

A system of 5 panels with an additional storage system has a "Generation" of 2736.93 kWh, "Self-Consumption PV" of 1289.09 kWh, "Self-Consumption due to battery" of 1119.23 kWh and "Transferred to Grid" of 328.93 kWh. This implies that the "Residual Amount", which is the amount of energy that needs to be purchased through a standard provider to meet the total annual demand, has a value of 745.09 kWh.

Table 10. Savings Storage Battery

Variable	Value	Unit
Yearly electricity Cost w/out panels and battery	850.23	€ per year
Revenue selling excess to Grid	0 or 9.87	€ per year
Residual cost of energy to satisfy Annual demand	200.89	€ per year
Savings due to PV & Battery	649.34 or 659.21	€ per year

In this case, savings due to the PV and the battery amount to 649.34€ per year if the household relies on governmental subsidies. However, if that is not the case, savings are enhanced by the 9.87 € revenue obtained by transferring energy to the grid which results in total annual savings of 659.21€. As for the Basic analysis two checks are in place. The first one ensures that all energy generated is being correctly allocated. It works by deducting from the "Generation" the sum of "Self-consumption," "Self-consumption due to battery," and energy "Transferred to the Grid."

The check must be 0.00 to be true. The second check checks that the “Total Annual Consumption” equals the sum of “Self-consumption,” “Self-Consumption due to battery,” and the “Residual Amount.” Lastly, the financial viability of a PV system with a lithium battery follows the same pattern as one without. The acquisition cost of the battery also benefits from the incentive “Ecobonus.” Various providers such as Otovo offer a PV system that includes an accumulation system. Hence, the customer enjoys a discount over all the elements of the PV system, significantly reducing the equity investment. Therefore, the equity investment, governmental subsidies, yearly electricity savings from the PV, yearly electricity savings form the battery, bank loans, and maintenance costs will be the founding element of cashflows which are discounted by interest swap rate of 1.71% and grow by an inflation rate of 2%.

The model compares outcomes for three different scenarios:

[1] Governmental subsidies

[2] Debt (75%) and Governmental subsidies

[3] Pure Equity (no subsidies & no debt)

Figure 4. NPV as a function of panels & accumulation system- Scenario 1 (Best project)

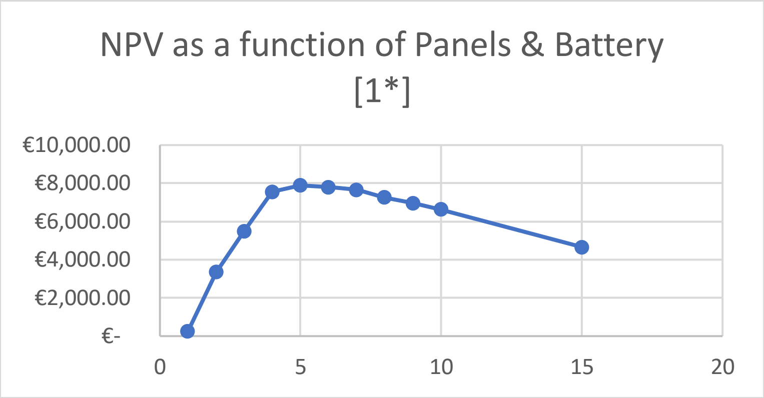


Figure 5. NPV as a function of panels & accumulation system- Scenario 2

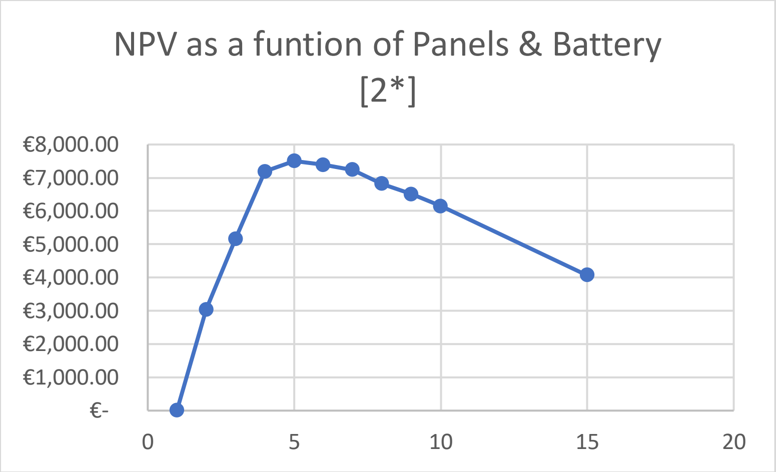
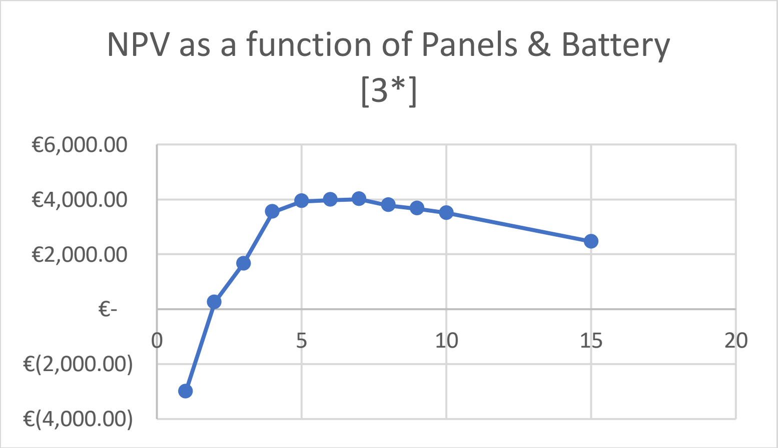


Figure 6. NPV as a function of panels & accumulation system- Scenario 3



The additional analysis with the introduction of a lithium-iron storage system has strengthened the economic outcome of the PV system. When a battery is considered, the maximum NPV increases significantly in every scenario. The best project is within the scenario [1]. A PV system made of 5 panels paired with a lithium-ion battery achieves an NPV of 7889 €, an IRR of 13%, a payback period of 7.75 years, and an LCOE of 0.082€/kWh. All Scenarios follow the same concave pattern meaning that the NPV gradually rises and then slowly decreases as the number of panels increases. Peaks are at 5 panels for scenario [1] and [2] and 7 panels for scenario [3]. The main difference in scenario [3] is the possibility to sell excess production to the Grid for 0.03 € per kilowatt as no incentives are being used. Moreover, in scenario [3] the NPV associated with installing 1 panel paired with a lithium-ion battery has a negative NPV. This results from the combination of a high equity investment and a scarce generation. Nevertheless, as soon as the number of panels increases, the NPV increases accordingly up to 4002 € for a system of 7 panels.

In conclusion, a standards household in Genoa should install a PV system (with or without an accumulation system) to provide financial returns and a sustainable way of producing and consuming energy.

Summary of Input & Output for Italy

In this chapter, to understand why and in what the results vary from city to city, the main differences between the analyses of the Italian cities are described.

There are many differences over the input data of the model depending on the city of focus.

- Cities are slightly different in total annual consumption. In particular, the total annual consumption, which measures the electricity consumed by the standard household during the year ranges from: (Milano 3561 kWh) (Porto Empedocle 3550 kWh) (Rome 3600 kWh) (Genova 3153 kWh).
- Electricity prices vary among cities. In fact, prices range from (Milano: 0.22 €/kWh) (Porto Empedocle: 0.25 €/kWh) (Rome:0.23 €/kWh) (Genova: 0.27 €/kWh). On the other hand, the selling price of energy which results from excess production from the panels has a fixed value of 0.03 €/kWh. However, this value only matters if the standard

household decides to forgo the governmental subsidies associated with photovoltaic systems. If the household exercise the subsidy the excess production is transferred to the grid for free.

- Panels differ in terms of brand and Peak Power (Milan: 400 W) (Rome: 400W) (Genoa: 385W) (Porto Empedocle: 375W). The highest quote for an operative system of 5 panels is 6900€ for Rome, then Milan 6220€, Genova 5983€, and the lowest is 4500€ Porto Empedocle. This price does not include governmental subsidies.
- Differences in panel capacity (W) and solar irradiance will impact the generation capacity (kWh produced by the PV system) for a system of equal size.

  Generation values for 5 panels: (Milan: 2740 kWh) (Genoa: 2555 kWh) (Rome: 3297 kWh) (Porto Empedocle: 3216 kWh).
- Bank loan rates are slightly different as well. Rates range from (Milano: 5.10%) (Porto Empedocle: 6.15%) (Rome: 6.03%) (Genoa: 5.50%). Maturity for Milan, Rome, Genoa is 5 years while for Porto Empedocle is 4 years.

These differences in input data are expected to generate differences in the economic outcome. Therefore, to assess the economic outcome, we have compared results for a fixed scenario.

A PV system of 5 panels partially financed by governmental subsidies.

- Porto Empedocle: NPV: 7552€ ; 18.7% IRR ; Payback 5.6 years; LCOE: 0.043
- Genoa: NPV: 4654€ ; 11% IRR ; Payback 9.16 years; LCOE: 0.060
- Rome: NPV 3941€ ; 8.7% IRR ; Payback 11 years; LCOE: 0.056
- Milan: NPV 3550€ ; 8.7% IRR ; Payback 11 years LCOE: 0.059

As expected results vary greatly among cities. This is a result of differences in the total annual consumption; cost of energy; panels quote; peak power; generation capacity; solar irradiance. Moreover, this result confirms that the South is more suitable than the North for solar panels due to favorable sun exposure and climate.

The following table resumes the differences in the main assumptions and outputs for an easier confrontation:

Table 11. Assumptions and output table

	Milan	Genoa	Rome	Porto Empedocle
Consumption [kWh]	3561	3153	3600	3550
Electricity cost [€/kWh]	0.22	0.27	0.23	0.25
Electricity selling price [€/kWh]	0.03			
Peak power of 1 panel [W]	400	385	400	375
Price for 5 panels [EUR]	6220	5983	6900	4500
Generation [kWh]	2740	2555	3297	3216
NPV [EUR]	3550	4654	3941	7552
IRR	8.70%	11%	8.67%	18.70%
Payback [years]	11.0	9.16	10.8	5.6

Furthermore, to explain the difference in the outputs, a weight on the different inputs has been calculated and can be sum up in the table below:

Table 12. Weights allocation

	Cost of panels (with subsidies)	Mainteinance cost	Savings	NPV
Porto Empedocle [EUR]	-2250.00	-1269.00	11048.00	7552.00 €
Milan [EUR]	-3110.00	-1015.00	7660.00	3550.00 €
Differences (PE-MI) [EUR]	860.00	- 254.00 €	3388.00 €	4002.00 €
Weights	21.49%	-6.35%	84.66%	-

To calculate the weights, the difference in inputs between the two extreme cases (Porto Empedocle and Milan) have been calculated and weighted over the difference in NPVs.

$$Weight_i = \frac{I_{PE} - I_{MI}}{NPV_{PE} - NPV_{MI}} \quad (5)$$

Where: I_{PE} = *Input factor Porto Empedocle*

I_{MI} = *Input factor Milan*

NPV_{PE} = *NPV Porto Empedocle*

$$NPV_{MI} = NPV\ Milan$$

It can be noted that most of the weight allocation is on the savings since they represent the biggest percentage of the final NPV. The savings are calculated as the electricity expense that there would be without a PV system, minus the electricity expense with the solar panels system, plus the revenues from selling electricity to the grid if no governmental incentive is being used.

APPENDIX

Milan:

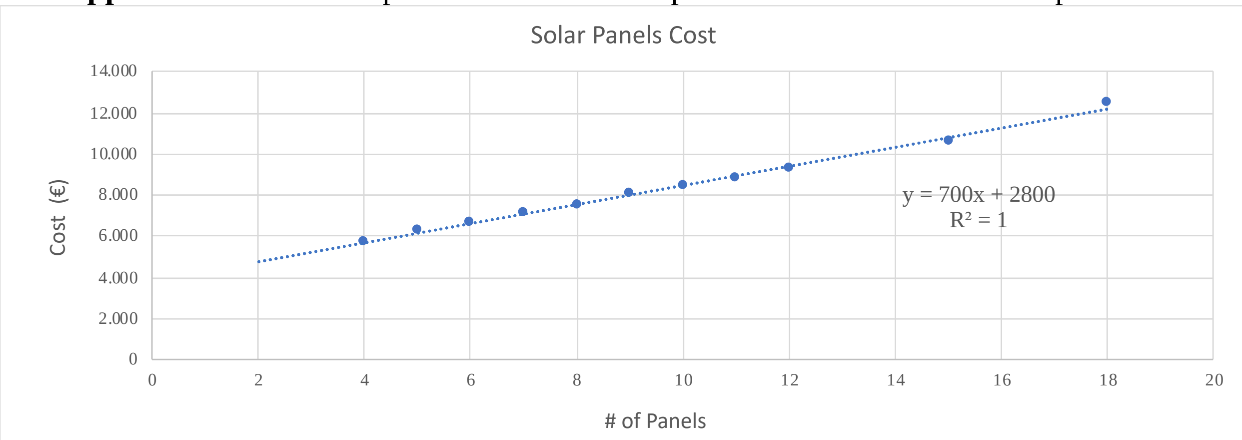
Appendix 1. Solar panel providers quotes

Solar Panels								
Company	**Brand**	**Peak Power**	**Efficiency**	**Space (m2)**	**Size**	**Total Space (m2)**	**Cost (€)**	**Cost per kWp**
Otovo	JA Solar	380	20,34%	1,87	8	14,95	6861	2256,91
Otovo	JA Solar	380	20,34%	1,87	15	28,03	9614	1686,67
Otovo	JA Solar	380	20,34%	1,87	18	33,63	10838	1584,50
Otovo	JA Solar	385	20,70%	1,86	5	9,3	4494	2334,77
Otovo	JA Solar	385	20,70%	1,86	9	16,74	8090	2334,78
Otovo	JA Solar	385	20,70%	1,86	10	18,6	8989	2334,81
Otovo	JA Solar	385	20,70%	1,86	12	22,32	10787	2334,78
Otovo	FuturaSun	400	19,88%	2,01	8	16,10	7288	2277,50
Otovo	FuturaSun	400	19,88%	2,01	15	30,18	10618	1769,67
Otovo	FuturaSun	400	19,88%	2,01	18	36,22	14658	2035,83
Sorgenia	Longi	375	20,59%	1,82	8	14,57	7050	2350,00
Sorgenia	Longi	375	20,59%	1,82	14	25,50	9610	1830,48
Sorgenia	Longi	375	20,59%	1,82	16	29,15	10360	1726,67
Sorgenia	Longi	385	19,46%	1,98	8	15,82	10990	3568,18
Sorgenia	Longi	385	19,46%	1,98	12	23,74	13940	3017,32
Sorgenia	Longi	385	19,46%	1,98	16	31,65	17370	2819,81
Wolmann	Trinasolar	375	20,45%	1,83	8	14,67	6190	2063,33
Wolmann	Trinasolar	375	20,45%	1,83	16	29,34	8950	1491,67
Wolmann	Trinasolar	375	20,45%	1,83	18	33,00	9519	1410,22
Wolmann	Trinasolar	400	20,81%	1,92	8	15,38	7480	2337,50
Wolmann	Trinasolar	400	20,81%	1,92	15	28,84	10570	1761,67
Wolmann	Trinasolar	400	20,81%	1,92	18	34,60	12440	1727,78

Appendix 2. Summary table of the Wölmann quotes

Selected Solar Panels									
Company	**Brand**	**Peak Power**	**Efficiency**	**Space (m2)**	**Size**	**Total Space (m2)**	**Quoted Cost (€)**	**Cost (€)**	**Cost per kWp**
Wolmann	Trinasolar	400	20,81%	1,92	2	3,84		4200	5250,00
Wolmann	Trinasolar	400	20,81%	1,92	3	5,77		4900	4083,33
Wolmann	Trinasolar	400	20,81%	1,92	4	7,69	5700	5700	3562,50
Wolmann	Trinasolar	400	20,81%	1,92	5	9,61	6220	6220	3110,00
Wolmann	Trinasolar	400	20,81%	1,92	6	11,53	6640	6640	2766,67
Wolmann	Trinasolar	400	20,81%	1,92	7	13,46	7050	7050	2517,86
Wolmann	Trinasolar	400	20,81%	1,92	8	15,38	7480	7480	2337,50
Wolmann	Trinasolar	400	20,81%	1,92	9	17,30	8030	8030	2230,56
Wolmann	Trinasolar	400	20,81%	1,92	10	19,22	8420	8420	2105,00
Wolmann	Trinasolar	400	20,81%	1,92	11	21,15	8770	8770	1993,18
Wolmann	Trinasolar	400	20,81%	1,92	12	23,07	9250	9250	1927,08
Wolmann	Trinasolar	400	20,81%	1,92	15	28,84	10570	10570	1761,67
Wolmann	Trinasolar	400	20,81%	1,92	18	34,60	12440	12440	1727,78

Appendix 3. Relationship between installation price and the number of solar panels



Appendix 4. List of the lenders provided

Debt Interest Rate	
Younited Credit	5.60%
BNL	8.50%
Compass	12.87%
Findomestic	**5.10%**
Unicredit	6.16%
Sella	7.60%
Agos	7.50%
Cofidis	6.70%

Appendix 5. Supplementary battery analysis to take in consideration losses and warranty

Year	1	2	3	4	5	6	7	8	9
Self consumption due to battery	902,17	844,94	791,34	741,15	694,13	650,10	608,86	570,24	902,17
Savings Battery [€]	201,38	192,38	183,78	175,57	167,72	160,22	153,06	146,22	235,95
Battery Capacity	100%	94%	88%	82%	77%	72%	67%	63%	100%
Energy price [€]	0,22	0,23	0,23	0,24	0,24	0,25	0,25	0,26	0,26
Savings Battery	*902,171*	*844,94253*	*791,34455*	*741,1465*	*694,1327*	*650,10117*	*608,86273*	*570,24021*	*534,06766*
Battery Capacity	*100%*	*94%*	*88%*	*82%*	*77%*	*72%*	*67%*	*63%*	*59%*

11	12	13	14	15	16	17	18	19	20	21	22	2
791,34	741,15	694,13	650,10	608,86	570,24	534,07	500,19	468,46	438,74	410,91	384,85	360,4
215,33	205,70	196,51	187,72	179,33	171,32	163,66	156,34	149,35	142,68	136,30	130,21	124,3
88%	82%	77%	72%	67%	63%	59%	55%	52%	49%	46%	43%	40%
0,27	0,28	0,28	0,29	0,29	0,30	0,31	0,31	0,32	0,33	0,33	0,34	0,3
468,4607	*438,74442*	*410,91316*	*384,84735*	*360,43499*	*337,5712*	*316,15775*	*296,10264*	*277,3197*	*259,72823*	*243,25266*	*227,8222*	*213,3705*
52%	*49%*	*46%*	*43%*	*40%*	*37%*	*35%*	*33%*	*31%*	*29%*	*27%*	*25%*	*24%*

Appendix 6. (b) Financial Analysis Project – No battery financed with 100% equity (Gov. Sub.)

Incremental Cash Flows										Payback		LCOE	0,06571823	
Year	(Equity) Investment	Electricity savings (w/ inflation)	Maintenance costs (w/ inf)	Battery savings (w/infaltion)	Loan repayment	CF	PV(CF)	NPV	IRR	Accum CF	Payback year	Panel Generation [kWh]	Sale price with inflation [eur/kWh]	Revenue from sale [eur]
0	-2850					-2850	-2850	3631	9,38%	-2850				
1		287	-32	0	0	255	251			-2595		2192	0,0657	144
2		293	-33	0	0	260	251			-2335		2192	0,0670	147
3		298	-33	0	0	265	252			-2070		2192	0,0684	150
4		304	-34	0	0	270	253			-1800		2192	0,0697	153
5		310	-35	0	0	276	253			-1524		2192	0,0711	156
6		317	-35	0	0	281	254			-1242		2192	0,0726	159
7		323	-36	0	0	287	255			-955		2192	0,0740	162
8		329	-37	0	0	293	256			-663		2192	0,0755	165
9		336	-37	0	0	299	256			-364		2192	0,0770	169
10		343	-38	0	0	305	257			-59		2192	0,0785	172
11		350	-39	0	0	311	258			251	11	2192	0,0801	176
12		357	-40	0	0	317	258			568	12	2192	0,0817	179
13		364	-41	0	0	323	259			891	13	2192	0,0833	183
14		371	-41	0	0	330	260			1221	14	2192	0,0850	186
15		378	-42	0	0	336	261			1557	15	2192	0,0867	190
16		386	-43	0	0	343	261			1900	16	2192	0,0884	194
17		394	-44	0	0	350	262			2250	17	2192	0,0902	198
18		402	-45	0	0	357	263			2607	18	2192	0,0920	202
19		410	-46	0	0	364	264			2971	19	2192	0,0939	206
20		418	-47	0	0	371	264			3342	20	2192	0,0957	210
21		426	-48	0	0	379	265			3721	21	2192	0,0977	214
22		435	-49	0	0	386	266			4107	22	2192	0,0996	218
23		443	-49	0	0	394	267			4501	23	2192	0,1016	223
24		452	-50	0	0	402	267			4903	24	2192	0,1036	227
25		461	-51	0	0	410	268			5313	25	2192	0,1057	232

Appendix 7. (e) Financial Analysis Project – 5.12 kWh battery financed with 100% equity (Gov. Sub.)

Incremental Cash Flows										Payback		LCOE	0,093431594	
Year	(Equity) Investment	Electricity savings (w/ inflation)	Maintenance costs (w/ inf)	Battery savings (w/infaltion)	Loan repayment	CF	PV(CF)	NPV	IRR	Accum CF	Payback year	Panel Generation [kWh]	Sale price with inflation [eur/kWh]	Revenue fro sale [eur]
0	-4395					-4395	-4395	5555	9,83%	-4395				
1		287	-32	201	0	456	449			-3939		2192	0,0934	205
2		293	-33	192	0	452	437			-3486		2192	0,0953	209
3		298	-33	184	0	449	427			-3038		2192	0,0972	213
4		304	-34	176	0	446	417			-2592		2192	0,0992	217
5		310	-35	168	0	444	407			-2148		2192	0,1011	222
6		317	-35	160	0	442	399			-1706		2192	0,1032	226
7		323	-36	153	0	440	391			-1266		2192	0,1052	231
8		329	-37	146	0	439	383			-827		2192	0,1073	235
9		336	-37	236	0	535	459			-293		2192	0,1095	240
10		343	-38	225	0	530	447			237	10	2192	0,1117	245
11		350	-39	215	0	526	436			763	11	2192	0,1139	250
12		357	-40	206	0	523	426			1286	12	2192	0,1162	255
13		364	-41	197	0	520	417			1805	13	2192	0,1185	260
14		371	-41	188	0	517	408			2323	14	2192	0,1209	265
15		378	-42	179	0	516	400			2838	15	2192	0,1233	270
16		386	-43	171	0	514	392			3353	16	2192	0,1257	276
17		394	-44	164	0	514	385			3866	17	2192	0,1283	281
18		402	-45	156	0	513	378			4379	18	2192	0,1308	287
19		410	-46	149	0	513	372			4893	19	2192	0,1334	293
20		418	-47	143	0	514	366			5407	20	2192	0,1361	298
21		426	-48	136	0	515	360			5922	21	2192	0,1388	304
22		435	-49	130	0	516	355			6438	22	2192	0,1416	310
23		443	-49	124	0	518	351			6957	23	2192	0,1444	317
24		452	-50	119	0	521	346			7477	24	2192	0,1473	323
25		461	-51	114	0	523	342			8001	25	2192	0,1503	329

Rome:

Appendix 1. Solar panels quotes obtained by contacted providers (best in grey)

Provider	Brand	Panel Size (W)	Efficiency (%)	Space (m2)	Quantity	Total Space (m2)	System Size (kWh)	Cost (€)	Price per kW (€)	Eff./€kW
Ingegneria Fotovoltaica	Hyundai HiE-S410VG	410	20.90%	1.96	8	15.7	3.28	10900	3323	0.63
					12	23.5	4.92	12900	2622	0.80
Be Next	Trina Solar Vertex S	400	20.80%	1.92	8	15.4	3.20	7600	2375	0.88
	Viessmann Vitovolt 300	400	20.40%	1.96	12	23.5	4.80	12300	2563	0.80
Otovo	JA Solar M54S31-MR	380	19.50%	1.96	12	23.5	4.56	10760	2360	0.83
	Hanwha Q.PEAK DUO	385	20.30%	1.90	12	22.8	4.62	12000	2597	0.78

Appendix 2. Full range of system sizes solutions (best in grey)

Quantity	Total Space (m2)	System Size (kWh)	Cost (€)
2	3.84	0.80	6280
3	5.76	1.20	6500
4	7.68	1.60	6720
5	9.60	2.00	6940
6	11.52	2.40	7160
7	13.44	2.80	7380
8	15.36	3.20	7600
9	17.28	3.60	7820
10	19.20	4.00	8040
11	21.12	4.40	8260
12	23.04	4.80	8480
13	24.96	5.20	8700
14	26.88	5.60	8920
15	28.80	6.00	9140

Appendix 3. Quotes from loan providers (best in grey)

Provider	Rate
Compass	12.47%
Bibanca	6.31%
Findomestic	6.03%
Prestitalia	8.57%
Figenpa	9.21%
Unicredit	6.16%

Appendix 4. Batteries quotes obtained by contacted providers (best in grey)

Provider	Brand	Cost (€)	Power (kWh)
Ingegneria Fotovoltaica	Huawei LUNA2000	3000	5
Be Next	Huawei LUNA2000	6500	5
Otovo	Huawei LUNA2000	7680	5

Appendix 5. Different scenario and main economic indicators without batteries

[Gov. subsidies and] 75% debt			
Number of panels	NPV (€)	IRR	Payback (years)
2	2819	8.46%	13
3	3518	9.73%	12
4	3664	9.78%	12
5	3604	9.43%	12
6	3429	8.87%	13
7	3197	8.24%	13
8	2931	7.57%	14
9	2644	6.90%	14.3
10	2342	6.23%	15
11	2030	5.57%	16
12	1711	4.92%	17
13	1388	4.28%	17
14	1059	3.65%	18
15	724	3.02%	19

[Gov. subsidies and] 100% equity			
Number of panels	NPV (€)	IRR	Payback (years)
2	3123	7.94%	11
3	3833	8.90%	11
4	3990	8.94%	11
5	3941	8.68%	11
6	3776	8.26%	11
7	3554	7.77%	12
8	3299	7.25%	12
9	3023	6.73%	13
10	2732	6.19%	13
11	2430	5.66%	14
12	2122	5.13%	15
13	1809	4.60%	15
14	1491	4.08%	16
15	1168	3.55%	17

[No gov. subsidies and] 100% equity			
Number of panels	NPV (€)	IRR	Payback (years)
2	106	1.84%	20
3	1069	2.93%	18
4	1550	3.39%	17
5	1853	3.63%	17
6	2056	3.77%	17
7	2209	3.85%	17
8	2332	3.90%	17
9	2438	3.93%	17
10	2530	3.95%	17
11	2613	3.96%	16
12	2691	3.97%	16
13	2764	3.97%	16
14	2833	3.97%	16
15	2897	3.96%	16

Appendix 6. Different scenario and main economic indicators with batteries

[Gov. subsidies and] 75% debt + Battery			
Number of panels	NPV (€)	IRR	Payback (years)
2	565	2.44%	20
3	3379	5.63%	15
4	5843	8.03%	12
5	7752	9.70%	11
6	8685	10.42%	10
7	9215	10.77%	10
8	9520	10.91%	10
9	9684	10.93%	10
10	9711	10.84%	10
11	9638	10.67%	10
12	9492	10.44%	11
13	9280	10.17%	11
14	9033	9.87%	11
15	8764	9.56%	11

[Gov. subsidies and] 100% equity + Battery			
Number of panels	NPV (€)	IRR	Payback (years)
2	870	2.76%	19
3	3694	5.67%	14
4	6168	7.80%	12
5	8088	9.26%	10
6	9032	9.88%	10
7	9573	10.17%	10
8	9888	10.28%	10
9	10063	10.29%	10
10	10101	10.20%	10
11	10038	10.05%	10
12	9904	9.85%	10
13	9702	9.62%	10
14	9465	9.36%	10
15	9207	9.09%	10

[No gov. subsidies and] 100% equity + Battery			
Number of panels	NPV (€)	IRR	Payback (years)
2	-2147	-0.23%	>25
3	930	2.45%	19
4	3729	4.40%	16
5	6001	5.75%	14
6	7312	6.42%	13
7	8227	6.83%	13
8	8921	7.11%	12
9	9477	7.30%	12
10	9898	7.41%	12
11	10221	7.47%	12
12	10472	7.49%	12
13	10657	7.49%	12
14	10807	7.46%	12
15	10936	7.43%	12

Genoa:

Figure 7: Financing Providers

Financing Provider	*TAEG*
Younitied credit	*5,60%*
BNL	*8,50%*
AGOS	*6,98%*
Ubi Banca	*7,06%*
Compass	*12,27%*
Unicredit	*6,13%*
Findomestic	***5,50%***
BPM	*8,84%*

REFERENCES

Milan:

Agrillo, V. Surace, P. Liberatore, *Rappor tistico solare fotovoltaico*. June 2021. (https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Solare%20Fotovoltaico%20-%20Rapporto%20Statistico%20GSE%202020.pdf)

Corporate Finance Institute, *Levelized Cost of Energy (LCOE)*. (https://corporatefinanceinstitute.com/resources/knowledge/finance/levelized-cost-of-energy-lcoe/)

Energia-Luce, *Quanto costa un kWh di energia in Italia nel 2022?*. April 20th, 2022. (https://energia-luce.it/guida/costo-kwh/)

European Central Bank. *Monetary policy*. 14th August 2021. (https://www.ecb.europa.eu/ecb/tasks/monpol/html/index.en.html)

European Commission, *Photovoltaic geographical information system*. *Interactive tools*. (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html)

Financial Chatham. *EURIBOR, SONIA, and Gilt Rates*. Chatham Financial. April 26 th 2022. (https://www.chathamfinancial.com/technology/european-market-rates)

F. Masci, *Prezzo fisso o Indicizzato Luce e Gas: quale conviene?*. April 14th, 2022 (https://luce-gas.it/guida/tariffe/prezzo-indicizzato)

Gazzetta Ufficiale della Repubblica Italiana, *Decreto Rilancio*. Law of May 19th, 2020, n.34. (https://www.gazzettaufficiale.it/eli/id/2020/05/19/20G00052/sg)

Global Data, *Rooftop solar installation price rise is temporary, to decline from 2023*. February 21st, 2022. (https://www.power-technology.com/comment/solar-price-rise-temporary/)

Global Data, *Rooftop Solar Photovoltaic (PV) Market Size, Share and Trends Analysis by Technology, Installed Capacity, Generation, Drivers, Constraints, Key Players and Forecast, 2021-2030*. December 16th, 2021. (https://store.globaldata.com/report/rooftop-solar-photovoltaic-market-analysis/)

Gruppo Findomestic, *Prestito Green Findomestic | Finanziamenti per Auto Elettriche e impianti fotovoltaici*. 2022. (https://www.findomestic.it/prestiti-personali/prestito-green.shtml)

M. Menichella, *Il Tuo consulente personale per il Risparmio Energetico*. 2019. (http://www.consulente-energia.com/ao-quanto-costa-la-manutenzione-dei-pannelli-fotovoltaici-costo-annuo-manutenzione-ordinaria-di-un-impianto-fotovoltaico-costi-interventi-manutenzione-periodica-fv.html)

M. Szczepaniak, P. Otreba, P. Otreba, T. Sikora, *Use of the Maximum Power Point Tracking Method in aPortable Lithium-Ion Solar Battery Charger*. December 21st, 2021. (https://www.mdpi.com/1996-1073/15/1/26)

N. Pflugradt, *LoadProfileGenerator*. 2022. (https://www.loadprofilegenerator.de)

Qui Finanza, *Cos'è il Bonus Ristrutturazione e quali interventi comprende*. December 28th, 2021. (https://quifinanza.it/soldi/bonus-ristrutturazione-cose-cosa-comprende/596288/)

R. Nicora, *Le marche di batterie per fotovoltaico*. December 2021. (https://www.otovo.it/blog/marche-batterie-fotovoltaico/#byd)

Statista, *Smart Home - Italy*. November 2021. (https://www.statista.com/outlook/dmo/smart-home/italy)

Wölmann. *Pannelli Solari E Pannelli Fotovoltaici*. Wölmann. 2022. (https://www.wolmann.com)

Y. Li, J. Wu, *Optimum Integration of Solar Energy WithBattery Energy Storage Systems*. March 2nd, 2020. (https://ieeexplore.ieee.org/abstract/document/9019606

Rome:

Roma climate table. (n.d.). Retrieved April 20, 2022, from https://en.climate-data.org/europe/italy/lazio/rome-1185/

PVGIS Photovoltaic Geographical Information System. EU Science Hub. (n.d.). Retrieved April 20, 2022, from https://ec.europa.eu/jrc/en/pvgis

Prefis de consumo. E.REDES. (n.d.). Retrieved April 20, 2022, from https://www.e-redes.pt/pt-pt/perfis-de-consumo

Solar Panel Maintenance Cost 2022. Go Soloar Quotes. (2022, March 5). Retrieved April 20, 2022, from https://gosolarquotes.com.au/cost/solar-panel-maintenance-cost

Solar Cell Efficiency. PVEducation. (n.d.). Retrieved April 20, 2022, from https://www.pveducation.org/pvcdrom/solar-cell-operation/solar-cell-efficiency

Storage in PV systems. PVEducation. (n.d.). Retrieved April 20, 2022, from https://www.pveducation.org/pvcdrom/batteries/storage-in-pv-systems

Fernando, J. (2022, March 21). Net present value (NPV). Investopedia. Retrieved April 20, 2022, from https://www.investopedia.com/terms/n/npv.asp#toc-what-is-net-present-value-npv

Fernando, J. (2022, March 17). Internal Rate of Return (IRR). Investopedia. Retrieved April 20, 2022, from https://www.investopedia.com/terms/i/irr.asp

Kagan, J. (2022, March 11). What is the payback period? Investopedia. Retrieved April 20, 2022, from https://www.investopedia.com/terms/p/paybackperiod.asp#toc-what-is-the-payback-period

Levelized cost of energy (LCOE). Corporate Finance Institute. (2022, February 9). Retrieved April 20, 2022, from https://corporatefinanceinstitute.com/resources/knowledge/finance/levelized-cost-of-energy-lcoe/

Porto Empedocle:

[1] "Redditi Irpef Comune Di Porto Empedocle" (n.d.), *Comuni*, accessed at http://www.comuni-italiani.it/084/028/statistiche/redditi.html on April 19, 2022.

[1] "Data.org" (n.d.), *Climate*, accessed at https://it.climate-data.org/europa/italia/sicily/porto-empedocle-13820/ on April 19, 2022.

[1] “Degree Day” (2022), *Wikipedia*, accessed at https://en.wikipedia.org/wiki/Degree_day on April 19, 2022.

[1] Nicora, R. (2022) “Scambio Sul Posto: Cos'è e Come Funziona,” *Otovo Italia | Blog Fotovoltaico in Italia*, accessed at https://www.otovo.it/blog/scambio-sul-posto-cose-come-funziona/ on April 19, 2022.

[1] “European Commission Database” (2016), *JRC Photovoltaic Geographical Information System (PVGIS) - european commission*, accessed at https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP on April 19, 2022.

1 “European Commission Database” (2016), JRC Photovoltaic Geographical Information System (PVGIS) - european commission, accessed at https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP on April 19, 2022.

[1] Lai, Chun Sing; McCulloch, Malcolm D. (March 2017). "Levelized cost of electricity for solar photovoltaic and electrical energy storage". *Applied Energy*. **190**: 191–203. doi:10.1016/j.apenergy.2016.12.153.

[1] Fernando, J. (2022) “Internal Rate of Return (IRR),” *Investopedia*, accessed at https://www.investopedia.com/terms/i/irr.asp on April 19, 2022.

[1] CFA Institute. "Chapter 8 Quantitative Concepts." Page 242. Accessed Oct. 15, 2021.

Genoa:

Climates to Travel. (2022). *Lisbon climate: weather by month, temperature, precipitation, when to go* . Retrieved April 28, 2022, from https://www.climatestotravel.com/climate/portugal/lisbon

Climates to Travel. (2022). *Genoa climate: weather by month, temperature, precipitation, when to go*. Retrieved April 13, 2022, from https://www.climatestotravel.com/climate/italy/genoa

E-REDES. (2021). *Perfis de Consumo | E-REDES*. Retrieved on 13 April 2022, from https://www.e-redes.pt/pt-pt/perfis-de-consumo-0

European Central Bank. (2021, 14 August). *Monetary policy*. Retrieved on 13 April 2022, from https://www.ecb.europa.eu/ecb/tasks/monpol/html/index.en.html

Facile. it. (2022). *Guida Consumo Medio*. Retrieved on 13 April 2022, from https://www.facile.it/energia-luce-gas/guida/consumo-medio-luce-di-una-famiglia-tipo.html

Financial Chatham (2022, 3 February). *EURIBOR, SONIA, and Gilt Rates*. Chatham Financial. Retrieved on 13 April 2022, from https://www.chathamfinancial.com/technology/european-market-rates

Gazzetta Ufficiale. (2020). *Decreto Rilancio*. Retrieved on 13 April 2022, from https://www.gazzettaufficiale.it/eli/id/2020/05/19/20G00052/sg

Gestore Servizi Energetici. (2020). *Obiettivo complessivo*. GSE. Retrieved on 12 April 2022, from https://www.gse.it/dati-e-scenari/monitoraggio-fer/monitoraggio-nazionale/obiettivo-complessivo

Go Solar Quotes. (2022, 5 March). *Solar Panel Maintenance Cost | New Price Guide 2022*. Retrieved on 13 April 2022, from https://gosolarquotes.com.au/cost/solar-panel-maintenance-cost/

Gouveia, J.P. and Palma, P. (2021) Infrastructure issues in Portugal. *EP-Pedia, ENGAGER COST Action.* Retrieved from https://www.eppedia.eu/article/infrastructure-issues-portugal

Gruppo Findomestic. (2022). *Prestito Green Findomestic | Finanziamenti per Auto Elettriche e impianti fotovoltaici*. Findomestic.it. Retrieved on 13 April 2022, from https://www.findomestic.it/prestiti-personali/prestito-green.shtml

Luce-Gas. (2022). *PUN Oggi 2022 e mese per mese: quanto vale il Prezzo dell’Energia Elettrica?* Luce-gas.it. Retrieved on 13 April 2022, from https://luce-gas.it/guida/mercato/andamento-prezzo/energia-elettrica

Markets and Markets. (2022). *Lithium-Ion Battery Market*. Retrieved on 13 April 2022, from https://www.marketsandmarkets.com/Market-Reports/lithium-ion-battery-market-49714593.html

Nicora, R. (2022). *Scambio sul posto: cos'è e come funziona*. Otovo Italia | Blog Fotovoltaico in Italia. Retrieved on 13 April 2022, from https://www.otovo.it/blog/scambio-sul-posto-cose-come-funziona/

Nicora, R. (2022). *Il Fotovoltaico in Liguria: peculiarità e costi*. Otovo Italia | Blog Fotovoltaico in Italia. Retrieved on 13 April 2022, from https://www.otovo.it/blog/fotovoltaico-liguria-peculiarita-costi/

PVGIS. (2022). *PVGIS Photovoltaic Geographical Information System*. EU Science Hub. Retrieved on 13 April 2022, from https://joint-research-centre.ec.europa.eu/pvgis-photovoltaic-geographical-information-system_en

ReCharge. (2022). *Recharge Batteries*. Retrieved from https://rechargebatteries.org/wp-content/uploads/2020/03/Guidance-for-the-30-SOC-implementation.pdf

Regalgrid®. (2020, 9 November). *La diffusione del fotovoltaico in Italia*. Regalgrid. Retrieved on 12 April 2022, from https://www.regalgrid.com/magazine/diffusione-fotovoltaico-italia/

S., Alessandro. (2022, 11 April). *Quanto costa un kWh di energia in Italia nel 2022?* Energia-Luce.it. Retrieved on 13 April 2022, from https://energia-luce.it/

Spotnitz, R. (2003). Simulation of capacity fade in lithium-ion batteries. *Journal of Power Sources*, *113*(1), 72–80. https://doi.org/10.1016/s0378-7753(02)00490-1

Statista. (2021, 13 December). *Solar photovoltaic industry in Italy - statistics and facts*. Retrieved on 12 April 2022, from https://www.statista.com/topics/4995/solar-photovoltaic-industry-in-italy/#dossierKeyfigures

Statista. (2022). *Smart Home - Italy*. Retrieved April 13, 2022, from https://www.statista.com/outlook/dmo/smart-home/italy

Statista. (2021). *Italy: household heating systems 2017, by type*. Retrieved on 13 April 2022, from https://www.statista.com/statistics/672294/type-of-heating-systems-by-macro-region-in-italy/

UrbiStat. (2020). *Demographic statistics Municipality of GENOVA, population density, population, average age, families, foreigners*. Retrieved on 12 April 2022, from https://ugeo.urbistat.com/AdminStat/en/it/demografia/dati-sintesi/genova/10025/4

Vidal, M., Martín, L., & Martín, M. (2014). Optimal Integration of a Concentrated Solar Plant Facility with a Biomass Based System. *Computer Aided Chemical Engineering*, 1603–1608. https://doi.org/10.1016/b978-0-444-63455-9.50102-1