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 PHOTOVOLTAIC SOLAR PANELS IN FLORENCE

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SUMMARY OF ROOFTOP SOLAR ANALYSIS

Location: Florence, Italy **Date of analysis**: Nov/2021

Recommendation*: install 12 solar panels (26.5 m^2), for a net present value of 5,781.05 euros, with a payback of 3.08 years.*

Main economic results:

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% debt	5,781.05	3.08	2.5	0.048
Gov. subsidies and 100% equity	6,988.07	7.8	12	0.019
No gov. subsidies and 100% equity	-3,311.66	Never	-3.84	0.038

Additional results:

A system with 12 panels requires an initial investment of ~4,380€ but provides a NPV of ~5,780€. If the household operates a smart use of the main appliances, by setting the load time during day hours, the NPV rises to ~7,225€.

Main inputs and assumptions:

Household and Economics					
Electricity Consumption	3020	kWh/year	Inflation	2%	per year
Electricity price – buy	0.24	EUR/kWh	Bank loan interest rate	4.5%	per year
Electricity price – sell	0.03	EUR/kWh	Bank loan maturity	15	years
			Equity cost of capital	0.091%	per year
PV panels chosen					
Peak power	445	W/panel	System losses	15%	of output
Panel area	2.21	m^2/panel	Degradation with age	1%	Per year
Useful life	30	Years	Maintenance costs	0	EUR/year per panel
			Total cost of optimal installation size	8756.5	EUR

Government subsidies:

The state offers a 50% discount on the invoice which brings the price down to 4,378.25€. It also offers an energy exchange service via the GSE agency at which the household can exchange the electricity it produces at a discount and can sell the energy it will not consume to the grid.

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INTRODUCTION

The scope of the Field Lab in question is to determine the economic value of Photovoltaic (PV) panels, in different geographic locations. This study performs some evaluations to determine the benefits of installing a PV system for domestic use. It will investigate the economic value in terms of savings on the electricity bills. It will omit all externalities of adopting the renewable energy source. This paper will be focused on the geographic area of Florence, Italy, and surroundings. It will consider the solar irradiance in the geographic area in examination as well as the typical electricity consumption of the representative household. Florence has a Mediterranean climate; it has hot summers with moderate rainfall but damp winters. The rare times it snows, it does not settle for more than a day or two. It also lacks a prevailing wind. Thus, solar energy is the best alternative to non-sustainable energy sources. Regardless, Florence's citizens are reluctant in the adoption of PV systems compared to other cities in Europe. Aside of the bureaucratic friction of landscape protection laws, the general public doesn't see enough of an added value to their savings. This paper will bring light over the actual economic value of a PV system for domestic use and highlight what is the optimal size of a PV rooftop in Florence.

ASSUMPTIONS

Consumption

For this study we will take in consideration a typical household of four people, two parents and two children. The household in consideration has an electricity consumption that fits the profile of others in the geographic area. The typical household in Florence uses a gas-fired heating system. It uses electricity for cooling and other appliances. We will assume both parents work, kids go to school. To allow for comparison with other studies we will consider a single-price system on the electricity bill. The study will use the average electricity consumption of three households of four around Florence. The data is organized in clusters of time brackets with similar consumption. Since one of the time brackets' consumptions is allocated almost entirely at daytime, we believe the clustering will not generate a consistent deviation to using the effective hourly resolution. By comparing the consumption with other years, it doesn't seem like the COVID restrictions in place from March 2020 to May 2020 in Italy had much impact on the electricity consumption.

Production

We will assume the household has the possibility to mount a photovoltaic system with no restrictions on the surface area that can be used for the panels, that panels can be mounted at an

optimal angle with no additional cost, and there are no areas of shade covering the solar panels. These assumptions serve the purpose of allowing us to use the Photovoltaic Geographic Information System (PVGS) solar radiance tool to estimate the energy production of a PV system. As we do not expect the climate nor the habits of electricity customers to change drastically, we will assume that the solar irradiance will, in average, be constant across multiple years, as well as the electricity consumption.

We gathered three real quotes from two Italian companies that mount solar systems in Florence. Assuming a linear relation between the price and the number of panels (APPENDIX) we interpolated the price of PV rooftops of other dimensions. As for estimating the surface area and productivity of panels change with technology, we averaged those values from the real quotes. Since most of the providers offer a warranty on the panels for 25 years, we find reasonable to consider a 30-year life span for the PV system. According to different PV panels manufacturers the efficiency of the panels will decrease at a rate of 1% per year. We will assume the panels are easy to keep clean. As maintenance is mandatory only for plants with peak power superior to 11.8kW, we assume there is no maintenance cost. The disposal of photovoltaic panels in Italy is free.

Savings

In Italy, PV customers can take advantage of a service provided by the Gestione dei servizi elettrici agency (GSE) to manage the electricity produced. The GSE service allows to use the grid as an accumulation facility at a cost. The electricity which is not consumed is sent in the grid to be used later. The household can re-purchase that electricity at a discount, typically 0.11€ per kWh. If the electricity produced by the PV system is not consumed directly or exchanged, the GSE will purchase it for 0.03€. The GSE will purchase excess energy only as long as it can deduct the price from the bill. When the customer's consumption exceeds the production in total values the customer will have to buy the electricity from the grid. According to Terna, the national statistics office of the electricity sector, the cost of one kW in Florence is around 0.24€. This study will assume that the cost of electricity and the contract with the GSE will remain constant throughout the life of the PV system.

Investment

As an incentive to expand the use of PV power, the Italian government provides substantial subsidies for both homeowners and businesses. At this time homeowners can benefit of a 50% of the total cost deduction The installation company can discount the invoice to the client by the detraction amount and benefit from the tax credit itself. This is the choice of most of the companies as it makes it easier for the clients to face the initial investment.

According to the Italian Bank statistics, the interest rate for consumer credit charged to families by banks is around 4.5%. For this study we want the homeowner to be able to adequately cover the loan's monthly payments with the savings on the electricity bill. Depending on the specs of the PV system a 10-year loan at a 4.5% rate generates a monthly payment that can be covered by the savings on the bills.

As the payments on the loan are set to be covered by the saving on the bill it's not necessary to discount the project at the weighted cost of capital. To compute net present value of the projects and compare them, an arbitrary discount rate was applied. Since Italian treasury bond are negative and it's assumed that the household can deposit without being charged an interest at a local bank, we used the rate on a 10-year Euro swap at 0.091%. The net present value is computed with an adjustment for inflation. The inflation rate for this study is set to be 2% which is slightly conservative compared to the estimates of the Italian national institute of statistics (Istat).

DATA

Household

The data gathered for this study consist in the electricity consumption and the solar irradiance in Florence, throughout a year period with an hourly resolution. The information about consumption was given by Estra Energie Srl a power distributer based in Florence. Estra Energie Srl provided

the consumption of three households of four during 2020 in kWh. The three hourly load profiles given by Estra Energie Srl were averaged to represent the typical load profile of a family of four in Florence.

The hourly irradiance was gathered from the PVGS website thanks to their solar radiance tool. The tool allows to download the solar irradiance in W per square meter in any given geographic location, on an hourly basis. We used an average over several years and converted to kWh to represent the solar radiance in Florence. Based on the dimensions and efficiency of our solar systems we can estimate the production of electricity each hour of the year.

Rooftop projects

For this study we collected the quotes from three different PV system providers. One, provided by the company Otovo, is a system of 8 panels of multi-busbar technology combined with half-cut mono PERC cells. It has a surface area of 14.7 square meters, and a maximum peak power of 3040 W and an efficiency of 20.7%. The full price of installation, including inverter and hooking to the grid is 6,823€. With the 50% discount on the invoice the price drops to 3,411.5€. The other two quotes were provided by the company TEST s.r.l. Both are also a multi-busbar technology with half cut cells. One system consists in 12 panels. It has a maximum peak power of 5,340 W. Discounted at 50% the system would cost 4,378.25€. The last quote that was proposed has a total surface area of 17.8 square meters. This system has a maximum peak power of 3,640 W and an

efficiency of 20.5%. the full price of installation is 6,922.7€ which is 3,461.38€ after the state incentive.

With the data collected from the different quotes we interpolated the specification for different system sizes. We assumed a linear relation between the number of panels and the price of the system. In regards of the dimensions, the peak power, and the efficiency, we used the average value. The interpolations for the different systems are listed in the table below.

N. of panels	Discounted Price (€)	Total area (m2)	Peak Power System (W)	Source
2	1682.70	4.04	825.00	interp.
4	2228.00	8.36	1706.67	interp.
6	**2711.38**	**13.38**	**2730.00**	**quote**
8	**3411.50**	**14.67**	**3040.00**	**quote**
10	3863.90	20.91	4266.67	interp.
12	**4378.25**	**26.51**	**5340.00**	**quote**
14	4954.50	29.27	5973.33	interp.
16	5499.80	33.46	6826.67	interp.
18	6045.10	37.64	7680.00	interp.
20	6590.4	41.82	8533.3	interp.

Table.1 Interpolated PV systems specification (Real quotes in bold).

ECONOMIC ANALYSIS

The representative household has a yearly consumption of approximately 3,000 kWh. Which, at the average price of electricity in Florence, at the moment we are conducting the study, corresponds to an expense of 720€ per year. Among the consumption, approximately 1,300 kWh per year are consumed during sunlight. Potentially the representative household in Florence could save around 312€ by installing a wide enough power plant. The initial investment of a plant that

can produce enough energy to fully supply the household demand without accumulation facility would not be covered by the saving. The household will have to find the convenient size of the plant. With the GSE exchange agreement the amount that can be saved annually and with it the size of the plant will improve drastically.

To find the best size on the PV rooftop we considered the different sizes as different investment projects. We computed classic corporate finance metrics to compare the different projects. The cash flows from the different PV projects are computed over the monthly savings on the bill. They are prospected over 30 years and adjusted with the efficiency loss of 1% per year. The financing payments are computed for a 15-year loan of 75% of the plant value at the current interest rate. As we assume the GSE agreement to have a great impact on the dimensions and value of the investment we both scenarios with and without the agreement.

PV plants without state incentives

As a benchmark we computed some metrics for the different projects without any state incentives; no price reduction and no GSE agreement. The NPV and IRR are computed with the inflation adjusted cashflows from the project.

N. panels	NPV
2	-372.12 €
4	-940.75 €
6	-1,817.82 €
8	-3,537.26 €

Table.2 Results for projects without state incentives financed at 75%.

The NPVs for all sizes of the installation are negative. We can see how, without the state incentives, it is not economically viable to mount a domestic solar plant in Florence unless financed 100% by equity. Even without bank loan it would be recommendable to mount a small, 2 panels system with a NPV of ~555€. Next, we will see how the state incentives and GSE agreement change the attractiveness of PV rooftops.

PV plants with discount on the price

The following table shows the same metrics for different size projects with the state incentive on the price but without the GSE service.

N. panels	NPV	IRR	Payback
2	1,774.48 €	1.92%	3.7
4	1,901.47 €	1.48%	4.7
6	1,641.05 €	0.98%	7.4
8	814.74 €	0.35%	19.6

Table.3 Net present value for plants without GSE exchange agreement.

With the price discount incentive, the solution that yields a better NPV is the 4 panels rooftop. The 4 panels offer a NPV of ~1,900€ and an internal rate of return of 1.48% with an ~2,230€ investment. The same system financed 100% by equity yields a NPV of ~2,515€ and an IRR of

8.82%. The 2 panels rooftop has a similar but lower NPV, it has a payback period of 3.6 years compared to 4.6 years for the 4 panels solution, and a better IRR which might make it a more attractive solution for a household that would rather invest less.

The Levelized Cost of Energy, LCOE, is a metric used to evaluate the performances of a power plant. It's the marginal cost of generating one unit of energy. The 4 panels power plant, in its 30-year estimated life, would produce ~60,600kWh and considering the financing, the total cost is ~6,800€. The LCOE of this power plant is around 0.092€ per kWh.

PV plants with all the state incentives

Thanks to the GSE agreement it is advantageous to produce more electricity than you can consume immediately. The table below shows the results for the different PV solutions taking advantage of the all the state incentives.

N. panels	NPV	IRR	Payback
10	5,500.44 €	2.73%	2.8
12	5,781.05 €	2.50%	3.1
14	5,617.97 €	2.09%	3.6
16	5,664.85 €	1.86%	3.8
18	5,707.65 €	1.68%	4.4
20	4,000.86 €	0.98%	7.4

Table.4 Net present value for plants with the GSE exchange agreement.

Thanks to the agreement the optimal plant size has tripled, from 4 panels to 12. The GSE agreement in conjunction with the price reduction and the possibility of financing at a relatively

low rate improve the attractiveness of installing bigger solar plants. The household profits from producing more energy than it can consume on the spot; it will consume directly ~1300 kWh of the yearly production and exchange ~1600 kWh. The 12 panels solution has a NPV of ~5,780€ and a payback period of 3.1 years. Without the bank loan the same project would have yield a NPV of ~6,990€. The 12 panels power plant, in its 30-year estimated life, would produce ~188,900kWh and the total cost is ~11,170€. The LCOE of this power plant is around 0.048€ per kWh.

Landscape protection laws delay

One of the holdbacks in the adoption of solar rooftops in Italy, is the bureaucratic friction necessary to obtain the permissions. This is especially true in the area of Florence. Despite the law provides facilitations for obtaining PV rooftops permits, this process is usually slow. Sometimes taking up to a year. To understand the impact this can have on the value of the project we pretend the household faces 50% of the investment to initiate the process and the other 50% in one year when the plant starts producing. Without changing the terms of the loan, the delay in the production can decrease the NPV by ~200€.

Smart use of appliances

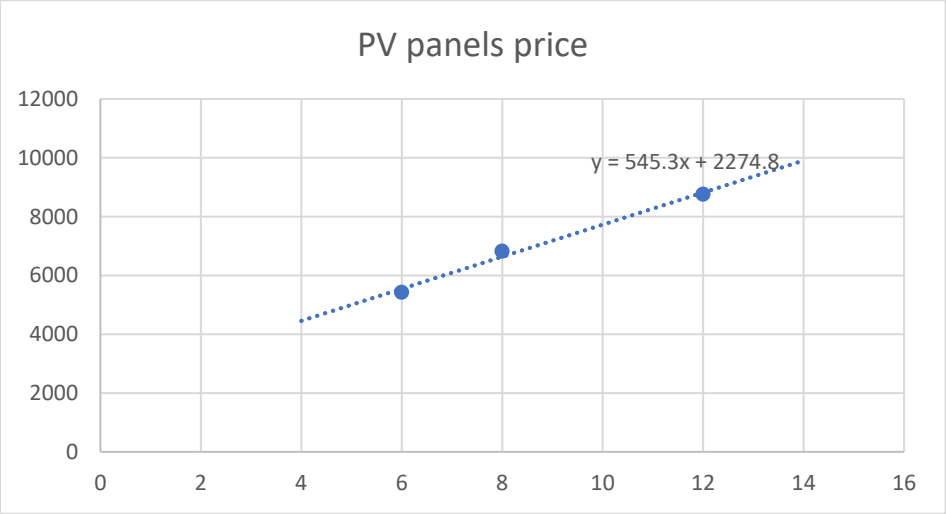
The results can improve further with a smart use of appliances. Some appliances like the dishwasher and the laundry machine can be programmed to run during the day, when the plant is

producing. Italian families use the dishwasher in average 220 cycles per year and the washing machine 260 cycles per year. For typical appliances this amounts to a total on 460kWh per year. Assuming the household takes advantage of the GSE agreement, the cost of washing clothes and dishes when the plant is not producing is ~60€. The smart use of laundry and dishwasher could improve the NPV by ~1,445€.

FINAL RECCOMENDATION

As the result of this study, we selected the best solution for a household in the area of Florence that wants to invest in a PV solar rooftop. From the analysis conducted it turns out the optimal solution varies greatly whether the state incentives are in place or not. Assuming the incentives hold, the best solution for a Florentine household of four, is a rooftop plant with 12 panels. This solution has yearly production of ~9,150kWh of which ~1,400kWh are consumed on the spot, ~1600kWh are exchanged, the rest is available to be sold to the grid. If the household operates a smart use of appliances the NPV rises to ~7,225€. This plant has a surface area of ~26.5 square meters which is adequate for a house in Florence. The levelized cost of electricity of this plant is ~0.048€ per kWh which is attractive for a photovoltaic plant. Even though Italy has among the lowest solar energy production cost in Europe an LCOE of ~0.048€ is well below the industry standards. The positive result is traceable to advantageous state incentives like the discount in the invoice instead of tax credits and the GSE exchange agreement that function as an accumulator.

APPENDIX



Graph.1. Linear regression to estimate prices of different size plants.

	DISCOUNTED						
	FINANCED			NON-FINANCED			
N. panels	NPV	IRR	Payback	NPV	IRR	Payback	
2	2,518.77 €	2.90%	2.583333	2,982.67 €	13.14%	6.583333	GSE
4	4,448.54 €	3.99%	2	5,062.77 €	16.40%	5.5	
6	5,409.09 €	3.99%	2	6,156.58 €	16.38%	5.5	
8	4,855.44 €	2.74%	2.75	5,795.94 €	12.66%	6.75	
10	5,500.44 €	2.73%	2.75	6,565.67 €	12.65%	6.75	
12	5,781.05 €	2.50%	3.083333	6,988.07 €	11.97%	7.083333	
14	5,617.97 €	2.09%	3.583333	6,983.85 €	10.73%	7.666667	
16	5,664.85 €	1.86%	3.833333	7,181.06 €	10.02%	8.083333	
18	5,707.65 €	1.68%	4.416667	7,374.20 €	9.44%	8.5	
20	4,000.86 €	0.98%	7.416667	5,817.74 €	7.09%	10.33333	
2	1,774.48 €	1.92%	3.666667	2,238.38 €	10.20%	8	NOGSE
4	1,901.47 €	1.48%	4.666667	2,515.70 €	8.82%	8.833333	
6	1,641.05 €	0.98%	7.416667	2,388.53 €	7.08%	10.33333	
8	814.74 €	0.35%	19.58333	1,755.24 €	4.37%	13.58333	
10	424.77 €	0.16%	23.25	1,489.99 €	3.36%	15.33333	
12	-140.43 €	NA	NA	1,066.59 €	2.21%	18	
14	-832.75 €	NA	NA	533.13 €	1.06%	22.08333	
16	-1,483.45 €	NA	NA	32.77 €	0.15%	28	
18	-2,141.66 €	NA	NA	-475.11 €	-0.65%	NA	
20	-2,805.57 €	NA	NA	-988.69 €	-1.35%	NA	

Table.5 All results for different size projects with the state incentive and discount on the invoice (Payback is NA when it surpasses the life expectancy of the plant).

	FULL PRICE						
	FINANCED			NON-FINANCED			
N. panels	NPV	IRR	Payback	NPV	IRR	Payback	
2	372.18 €	0.16%	23.25	1,299.97 €	3.37%	15.33333	GSE
4	1,606.32 €	0.54%	17.33333	2,834.77 €	5.29%	12.25	
6	1,950.22 €	0.54%	17.33333	3,445.20 €	5.29%	12.25	
8	503.44 €	0.11%	24.58333	2,384.44 €	3.08%	12.25	
10	571.32 €	0.11%	24.58333	2,701.77 €	3.08%	15.91667	
12	195.78 €	0.04%	27.5	2,609.82 €	2.66%	16.83333	
14	-702.42 €	NA	NA	2,029.35 €	1.89%	18.91667	
16	-1,351.17 €	NA	NA	1,681.26 €	1.45%	20.5	
18	-2,004.00 €	NA	NA	1,329.10 €	1.08%	21.91667	
20	-4,406.42 €	NA	NA	-772.66 €	-0.46%	NA	
2	-372.12 €	NA	NA	555.68 €	1.55%	20.08333	NOGSE
4	-940.75 €	NA	NA	287.70 €	0.68%	23.91667	
6	-1,817.82 €	NA	NA	-322.85 €	-0.46%	NA	
8	-3,537.26 €	NA	NA	-1,656.26 €	-2.30%	NA	
10	-4,504.35 €	NA	NA	-2,373.91 €	-3.01%	NA	
12	-5,725.71 €	NA	NA	-3,311.66 €	-3.84%	NA	
14	-7,153.14 €	NA	NA	-4,421.37 €	-4.69%	NA	
16	-8,499.46 €	NA	NA	-5,467.03 €	-5.37%	NA	
18	-9,853.31 €	NA	NA	-6,520.21 €	-5.97%	NA	
20	-11,212.85 €	NA	NA	-7,579.09 €	-6.51%	NA	

Table.6 All results for different size projects without the state incentive discount on the invoice (Payback is NA when it surpasses the life expectancy of the plant).

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