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Economic analysis of a residential photovoltaic system in Ravello, Italy

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Abstract

This study aims to assess the economic viability of installing rooftop photovoltaic panels (PVs) in Ravello, a town located in the district of Salerno (Campania, Italy). From the perspective of a standard household, this paper focuses on determining the optimal installing decision in economic terms.

It is noteworthy that the economic analysis reveals promising results across all scenarios considered. Each installation, involving different PV providers and debt/equity combinations, shows a positive Net Present Value (NPV): the net financial benefit ranges from a minimum of €7,574 to a maximum of €12,058, confirming the financial feasibility of potential PV installations in Ravello.

Keywords: rooftop solar; PV system; LCOE; renewable energy

Summary of rooftop solar analysis

Location: Ravello, Italy **Date of analysis**: January/2024

Recommendation*: install 15 solar photovoltaic (PV) panels (31.21 m^2), for a net present value (NPV) of €10,297.05, with a payback of 10.72 years.*

Main economic results

Financing	NPV (EUR)	Payback (years)	IRR (%/year)	LCOE (EUR/kWh)
Gov. subsidies and 75% bank debt	10,297.05	10.72	11.31	0.05
Gov. subsidies and 100% supplier's credit	9,563.34	11.10	11.56	0.05
Gov. subsidies and 100% equity	11,674.57	9.09	11.33	0.04
No gov. subsidies and 100% equity	9,960.34	10.77	9.62	0.05

(All rows are for the same number of panels)

Additional results

The final recommendation is robust to alternative electricity prices evolutions – only in the most extreme scenarios evaluated (with energy prices plummeting below reasonable levels), the NPV turns negative. Adding to the system a battery is not monetarily advantageous.

Main inputs and assumptions

Household and Economics

Electricity Consumption	2700	kWh/year	Inflation	2%	per year
Electricity price – buy	0.27	EUR/kWh	Bank loan interest rate	7%	per year
Electricity price – sell	0.04	EUR/kWh	Bank loan maturity	5	years
			Equity cost of capital	2.54%	per year

PV panels

Peak power	435	W/panel	System losses	13.5%	of output
Panel area	2.08	m^2/panel	Degradation with age	0.6%	Per year
Useful life	25	Years	Maintenance costs	150	EUR/year per panel
			Total cost of optimal installation size (without subsidies)	11,217.75	EUR
			Total cost of optimal installation size (after subsidies)	9,254.64	EUR

Government subsidies

Tax deduction calculated at 50% of the installation costs and subject to a maximum of €96,000 per housing unit (receivable in equal installments over 10 years). This incentive does not represent a direct cash rebate but rather a reduction in taxable income.

i. Introduction

The region of Campania boasts one of the most significant renewable energy potentials, making it an ideal candidate for the adoption of PVs (Battaglia et al. 2022). Solar energy, as a renewable resource, holds strong promise in combating climate change and fostering environmentally friendly policies supported by both private and public actors. The economic and environmental performance of such investments is influenced by a multitude of factors, including average annual irradiation, consumer consumption patterns, incentive systems, rated power of modules, available surface area for installation and more.

By employing indicators such as NPV, Internal Rate of Return (IRR), Payback Period and Levelized Cost of Electricity (LCOE), this paper aims to provide a comprehensive evaluation of the feasibility and potential benefits of PV installations for households in Ravello. Through rigorous analysis and comparison of various scenarios, this study seeks to inform citizens, policymakers and other stakeholders about the opportunities and challenges associated with solar energy adoption in the region.

ii. Data and assumptions

a. Solar irradiance

The hourly power output of a 1 kilowatt-peak PV system, optimally angled and including losses, was determined using the Photovoltaic Geographical Information System website, accessing the PVGIS-SARAH2 database. The data used for the hourly global irradiance on the inclined plane corresponds to the years 2018, 2019 and 2020, which are the most recent available. Indeed, to ensure accuracy and account for any irregularities caused by seasonal atmospheric events, the estimated hourly power output is based on the average irradiance calculated from these three years, aiming to smooth out any outliers. Finally, power output was then scaled in accordance with the nominal peak power of each PV under study, assuming a linear relationship.

b. Electricity consumption

To estimate the typical annual electricity consumption of a standard household in Ravello, information from a range of nine families living in the municipality was collected. The sample is outlined in *Table 1*.

Obs	People	Size	Year	Stove	A/C	kWh
1	2	59	1967	-	-	1043
2	2	62	2008	-	-	1080
3	2	54	1920		-	1160
4	2	81	1965	x	x	1498
5	3	100	1970	-	x	2475
6	3	127	1966	-	-	1811
7	3	109	1808	-	-	1438
8	4	110	1971	-	-	2294
9	4	95	1930	x	-	2881

Table 1: Electricity consumption sample (n = 9)

This dataset includes the number of family members, size of the property in square meters, year of construction, and specifics regarding energy consumption including whether households use gas or electric stoves and/or cooling systems. The results indicate that, on average, the annual electricity consumption for a household of four is approximately 2,588 kilowatt-hour (kWh), with families using electric stoves being above this number. This figure was compared against the National Energy Situation Report by the Italian Ministry of Environment and Energy Security (2023), which reveals that a typical family of four residing in our area of interest, classified as "Climatic Zone E", is expected to consume around 2,700 kWh annually. In light of this information, for the purposes of this work, the total annual electricity usage is projected to align with the estimation reported by the Ministry, given their analysis is likely to be more reliable and representative of the typical consumption patterns in the region[1].

Finally, the assessment of electricity load patterns employs a top-down approach. In detail, total annual consumption is allocated according to the typical hourly domestic profile provided by Arera, the Italian Regulatory Authority for Energy, Networks and Environment, for the district of Salerno[2].

[1] Higher statistical validity as it is based on random sampling, greater sample size, etc.
[2] Within which Ravello is located. Data available at this link.

c. Economic data

1) Electricity cost

Analyzing the bills collected, the sample reveals that the average cost per kWh[3] is approximately €0.27. This price includes only the components that are variable and that so would be directly offset by the installation, i.e. price of the electricity consumed, accounting for network losses, dispatching, other related charges and value added tax (VAT).

2) Revenue

Regarding revenue, in Italy, excess electricity[4] produced by domestic PVs is sold at a wholesale market-driven price directly to Gestore Servizi Energetici (GSE), a state-owned company that supports the development of renewable energy sources. The revenue from the sale of energy under this scheme is fiscally significant and needs to be accounted for in the personal annual income declaration, but it is not subject to VAT. Thus, to compute the net financial benefit, an adjustment by the marginal tax rate is made. Considering an average Italian income per capita of €40,000 (OECD, 2024), the typical citizen falls into the 35% marginal tax bracket and so this one is considered the relevant rate throughout this work. Moreover, selling prices are segmented into three time-bands (F1, F2, and F3), depending on the time and day of the week, and into regional markets, given the location[5]. Summarizing, the overall selling price is calculated as in *Equation 1*.

$$Selling\ Price_t = [w_1 \times Price_{F1} + w_2 \times Price_{F2} + w_3 \times Price_{F3}] \times (1 - t) \times (1 + \pi_t) \quad (1)$$

w_1, w_2, and w_3 represent the proportion of hours in the year for each time band relative to the total hours in the year, where "delta" is positive (i.e. where PV energy supply is greater than demand, given the load profile)

t is the marginal tax rate

π_t is the projected energy price inflation as forecasted by the European Central Bank (ECB, 2024)

[3] Prices may vary slightly depending on the specific contracts and promotions applied (-/+ €0.03).

[4] Excess electricity refers to hours when the PV produces more energy than needed to cover household demand, resulting in surplus energy that is sold to the grid.

[5] In this work, data referred to the "Central-Southern grid" was used.

This analysis reveals that the average net selling price stands at €0.06 per kWh[6]. However as shown in *Figure 1*, given the downward trend observed in 2023 and since it continued in the first months of 2024, the benchmark scenario assumes that electricity is sold at €0.04 per kWh, considering this is the minimum offered price capped by GSE. Further examination of alternative price scenarios is detailed in Section iii.

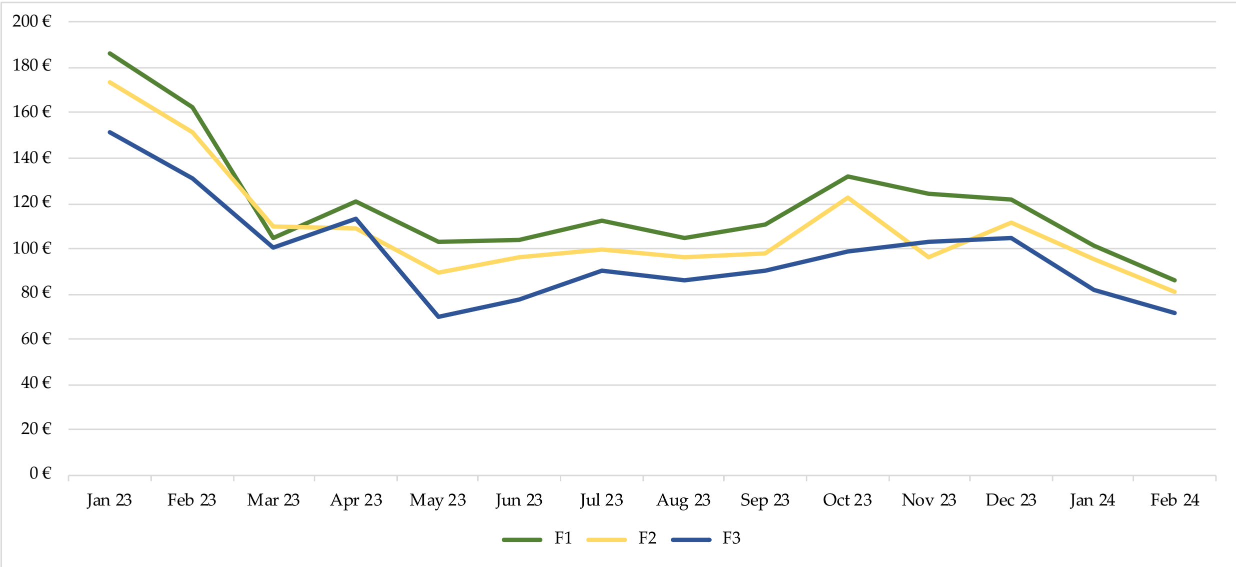

Figure 1: In euro per MWh, gross selling prices granted by the GSE on residential excess electricity (y = selling price; x = time)

3) Installation costs

To assess installation costs, quotes from three main PV providers were obtained. Each presents a distinct choice in panel technology and in the associated warranty. In this regard, the work assumes the length of each project equals the guarantee offered. All suppliers include comprehensive installation costs, covering design, authorizations, etc. as well as ordinary maintenance[7] for the first five years. Beyond this initial period, recurring maintenance is assumed to amount to €150 per year (Forbes, 2024). In detail, it was assessed the financial convenience of installing: i) Offer A, that features REC405TP5 with a yearly degradation rate of 0.5%, a 25-year warranty and offering 405 watts peak power per panel, with an efficiency of 20.6%. This option, provided by EnelX, comes at

[6] We may note using this average, constant selling price is a reliable approximation. Indeed, switching to a specific price for each time-band only changes the NPV by a few euros.
[7] Which usually include cleaning the surface from dust and other debris to ensure optimal performance and energy production.

an average price of €858 per panel; ii) Offer B, that envisages JKM470N-60HL-V with a longer 30-year warranty, providing higher panel peak power of 470 watts and efficiency at 21.8%. Sorgenia is the provider for this alternative, priced at €1,110 per panel, with a yearly degradation rate of 0.4%; iii) Offer C, that considers HiE-S435HG with a 25-year warranty and a yearly degradation rate of 0.6%, delivering 435 watts peak power per panel and an efficiency of 20.9%. This offering, from Iren, is priced at €748 per panel. The three are summarized in *Table 2*.

2. PV Panels	A	B	C
Model	REC405TP5	JKM470N-60HL-V	HiE-S435HG
Warranty (in years)	25	30	25
Watt peak	405	470	435
Efficiency	20,6%	21,8%	20,9%
Dimension (in squared meters)	1,97	2,16	2,08
Price	858 €	1.110 €	748 €
Interest rate	7,77%	8,25%	8,34%
Yearly degradation rate	0,5%	0,4%	0,6%
Provider	EnelX	Sorgenia	Iren

Table 2: Summary of the main characteristics of scouted providers

4) Interest rate for consumer loan

After conducting research into the interest rates for consumer loans and considering an average borrowing of around €10,000 for the installation, it was found that the most competitive options are offered by Banca Sella (7.24%), Agos (7.76%) and Findomestic (7.85%). These banks provide specialized consumer finance products tailored to PV purchases. Banca Sella emerged offering the most advantageous terms, with the lowest annual effective interest rate: this is considered to be cost of debt throughout this work.

5) Government subsidies

The Italian government introduced tax incentives for the installation of PVs. First, a legislation that reduces the VAT to 10% is enforced. Further, homeowners are also offered a tax deduction. To qualify for it, the installation must adhere to specific regulatory requirements (e.g. certified equipment, traceable payment method). Regarding the technical aspects, the subsidy is calculated at 50% of the initial costs, subject to a maximum of €96,000 per housing unit and receivable over 10 years. It is essential to note that this incentive does not represent a direct cash rebate but rather a reduction in taxable income. As analyzed in Section ii. Paragraph c2), the net benefit will depend on the specific citizen's marginal tax rate. All in all, given the clarity of regulation, the procedure for obtaining the subsidy appears relatively straightforward and so the cash flows (CFs) associated with tax savings are discounted at the risk-free rate[8]. Formally, these are calculated as in *Equation 2*.

$$Tax\ Savings_{1-10} = \frac{Installation\ Costs_0 \times 0.5 \times t}{10} \quad (2)$$

iii. Economic Analysis

a. Ravello

The economic analysis of the proposed PVs reveals promising results across all options presented. *Table 3* summarizes the main findings of the explored installation scenarios.

	Debt	Equity	NPV	Payback	IRR	LCOE	Panels	
Benchmark	75%	25%	8.259 €	12,05	9,24%	0,062 €	14	EnelX
Suppliers Credit	100%	0%	7.574 €	12,89	8,82%	0,065 €	14	
All Equity	0%	100%	9.734 €	10,06	9,63%	0,054 €	14	
Excluding Subs and Debt	0%	100%	7.899 €	12,10	7,97%	0,064 €	14	
Benchmark	75%	25%	10.150 €	14,45	7,60%	0,058 €	14	Sorgenia
Suppliers Credit	100%	0%	9.034 €	15,62	7,02%	0,062 €	14	
All Equity	0%	100%	12.058 €	12,15	8,15%	0,050 €	14	
Excluding Subs and Debt	0%	100%	9.683 €	14,51	6,76%	0,060 €	14	
Benchmark	75%	25%	10.297 €	10,72	11,31%	0,050 €	15	Iren
Suppliers Credit	100%	0%	9.461 €	11,68	10,69%	0,054 €	15	
All Equity	0%	100%	11.675 €	9,09	11,33%	0,044 €	15	
Excluding Subs and Debt	0%	100%	9.960 €	10,77	9,62%	0,052 €	15	

Table 3: Main economic indicators across all explored optimal scenarios

It is noteworthy that each installation, assuming different providers and debt/equity mixes, yields a positive NPV when maximizing it for the number of panels. In detail, among the alternatives considered, the least value accretive involves choosing EnelX and funding the project entirely through a bank loan, in partnership with the provider (NPV amounts to €7,574). Conversely, the most financially advantageous entails financing the project only with equity and selecting Sorgenia (NPV

[8] For discounting, this work adopts a 10-year risk-free rate (i.e.10-year Interest Rate Euro Swap rate). Since all the future cash flows are avoided costs, the risk is assumed to be zero.

equals €12,058). Considering this as an unrealistic option[9], the benchmark case involves assuming the installation is mostly financed through debt (75%) and partly with equity (25%). In such case, the optimal decision in economic terms involves commissioning Iren as provider and yields a NPV of €10,297, installing 15 panels.

Deepening the analysis, *Figure 2* represents the NPV as a function of the number of panels, displaying a concave relation.

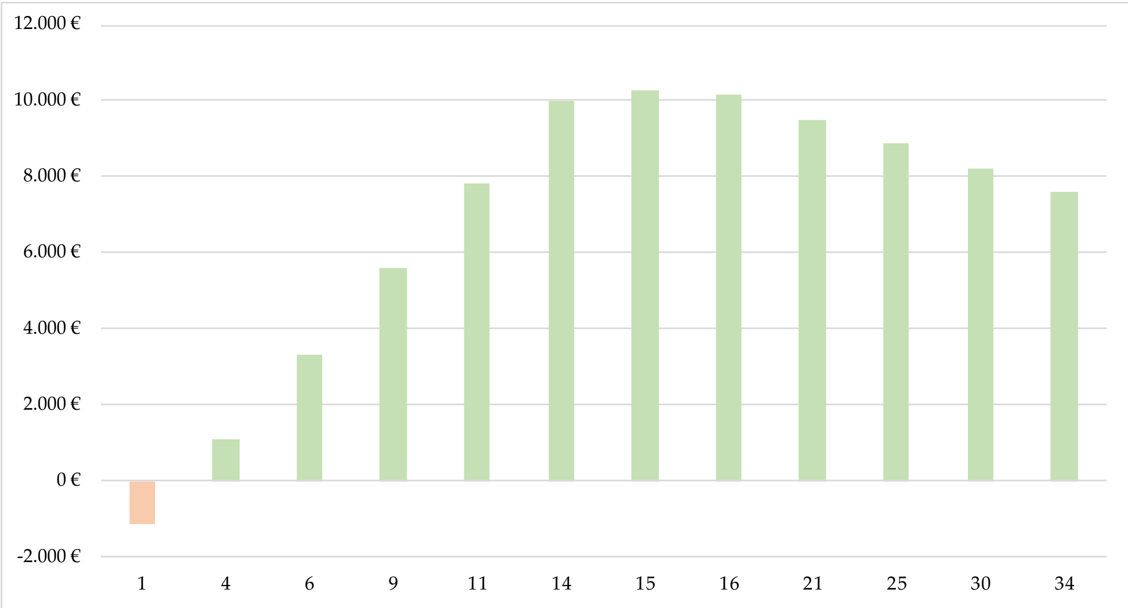

Figure 2: y = NPV; x = number of panels installed

To explain such result, we may break down the annual incremental CFs, observing three components: energy savings, tax savings and revenue from selling excess energy. Energy savings represent electricity produced by the PV and directly consumed by the household and are obtained multiplying the annual volume of power consumed by the *retail* price, representing costs that would otherwise be incurred purchasing from the grid. Differently, as described in Section ii. Paragraph c2), revenue from selling excess energy to the grid is priced at a lower rate, typically reflective of *wholesale* market prices. Mathematically, CFs are calculated as in *Equation 3*.

$$\Delta CF_t = Energy\ Consumed_t \times Electricity\ Cost_t + Sold_t \times Selling\ Price_t + Tax\ Savings_t \quad (3)$$

[9] As outlined in Section ii. Paragraph c2), the average Italian income per capita is €40,000: 100% equity funding would mean disposing of roughly 1/4 of annual wealth.

Despite the volume of excess energy sold is higher compared to the amount consumed[10], the lower price significantly impacts overall revenue. Consequently, since additional panels installed beyond what is necessary to cover household consumption primarily contribute to selling electricity, this results in costs that outweigh the marginal financial benefit of installing. As a result, the NPV decreases as additional panels are added surpassing a certain threshold[11]. To give a visual representation of how the price effect greatly prevails on the volume effect, *Figure 3* shows the composition of CFs and its evolution year by year.

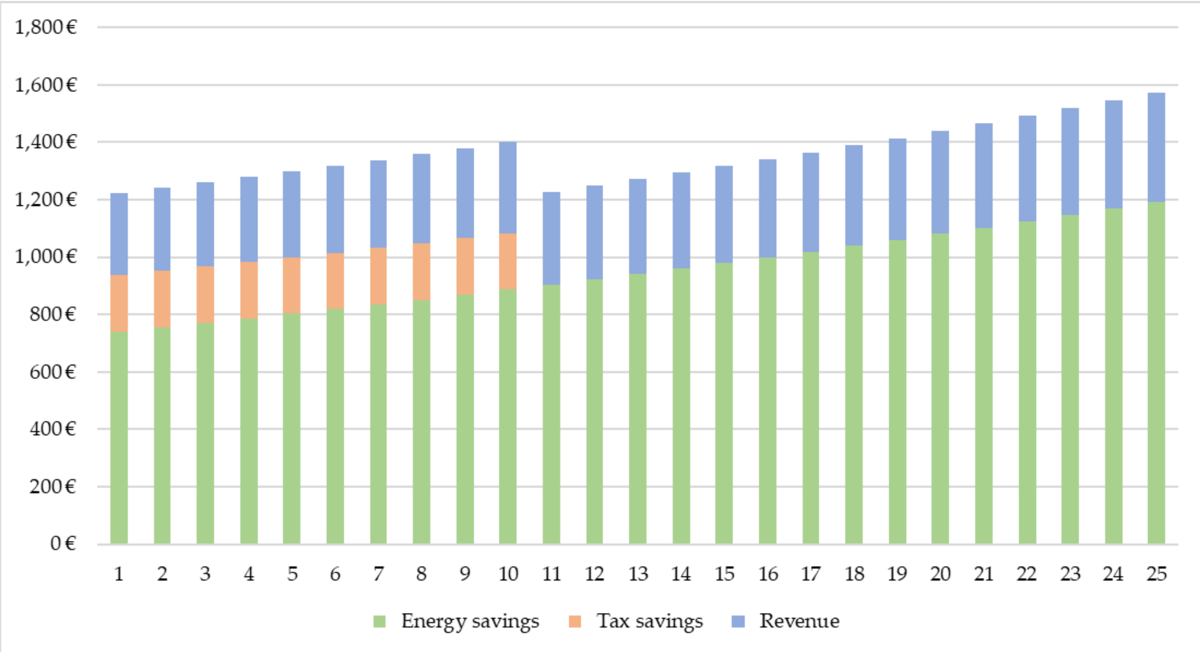

Figure 3: y = annual CFs; x = time

An additional supporting argument in favor of the installation is provided through scenario analysis, which here involves evaluating changes in NPV as electricity prices fluctuate.

As illustrated in *Table 4*, NPV remains positive across all reasonable price levels. Only in extreme scenarios, e.g. when electricity retail prices drop below €0.15 – €0.18 per kWh and jointly selling prices fall below the capped minimum of €0.04 per kWh, NPV turns negative.

[10] On average, 70% of the electricity produced by the PV is sold.
[11] The maximum point in the benchmark case, choosing Iren, equals 15 panels.

	0.003 €	0.010 €	0.018 €	0.025 €	0.033 €	0.040 €	0.048 €	0.055 €	0.063 €	0.070 €	0.078 €	0.085 €
0.09 €	-6693	-5572	-4451	-3330	-2209	-1088	33	1155	2276	3397	4518	5639
0.12 €	-4830	-3709	-2588	-1466	-345	776	1897	3018	4139	5260	6381	7502
0.15 €	-2966	-1845	-724	397	1518	2639	3760	4881	6002	7123	8244	9365
0.18 €	-1103	18	1139	2260	3381	4502	5623	6744	7865	8987	10108	11229
0.21 €	760	1881	3002	4123	5244	6366	7487	8608	9729	10850	11971	13092
0.24 €	2623	3744	4866	5987	7108	8229	9350	10471	11592	12713	13834	14955
0.27 €	4487	5608	6729	7850	8971	10092	11213	12334	13455	14576	15697	16819
0.30 €	6350	7471	8592	9713	10834	11955	13076	14198	15319	16440	17561	18682
0.33 €	8213	9334	10455	11577	12698	13819	14940	16061	17182	18303	19424	20545
0.36 €	10077	11198	12319	13440	14561	15682	16803	17924	19045	20166	21287	22408
0.39 €	11940	13061	14182	15303	16424	17545	18666	19787	20908	22030	23151	24272
0.42 €	13803	14924	16045	17166	18287	19409	20530	21651	22772	23893	25014	26135

Table 4: Scenario analysis for NPV varying electricity prices (y = buy price; x = sell price)

Conversely, if prices were to rise, NPV would offer significant upside potential, rendering the installation particularly attractive with an "upward-biased" asymmetric payout. For example, with electricity prices matching those observed during the first half of 2023 in Italy (Eurostat, 2023), NPV would reach approximately €20,000. In this context, we may note PVs could be regarded as safe-haven assets as they naturally hedge against unfavorable[12] fluctuations in electricity prices.

The work also evaluates four different schemes[13]:

1) The benchmark case, where initial investment is financed by 75% bank debt and 25% equity, resulting in an NPV of €10,297

2) 100% financing through supplier's credit, in which NPV is €9,461. This lower convenience is attributed to higher debt service costs, due to interest payments on a larger notional amount and a higher interest rate (7.85%), against 7.24% assumed in 1)

3) The all-equity funding (NPV €11,675), emerging as the most value accretive option because of no interest payments. However, this scenario is deemed unrealistic as the average installation cost is €10,000, making it unlikely that a standard household would be willing to pay such a large amount upfront

4) Lastly, an alternative excluding both government subsidies and debt (NPV €9,960) is considered. Here, the absence of interest payments is outweighed by the lack of government subsidies,

[12] From the perspective of a household.

[13] Only scenarios related to Iren as provider were described here for brevity. In reality, the same analyses were conducted for other two distinct suppliers, resulting in a total of twelve scenarios as shown in *Table 3*.

resulting in a lower NPV compared to 3)

On top of NPV, other financial metrics were computed. The LCOE represents the average price per unit of electricity generated that would be needed to recover the costs of building and operating the PV during its expected useful life. In other words, it is the selling price of energy that makes the NPV null, assuming all production is sold to the grid. LCOE also point in favor of an installation. According to the results obtained from computing such metric, the installation becomes financially unfeasible, i.e. NPV negative, if the family consumes a minimal portion, or none, of the generated electricity, and sells production at a price lower than €0.05 per kWh. In this regard, we may remind that GSE sets the minimum price for excess electricity sold to the grid at €0.04/kWh and that retail prices typically average €0.27/kWh, with standard households expected to consume approximately 30% of the generated energy. Additionally, a simple payback analysis[14] was conducted for each of the four different investment alternatives. For the very same dynamics described in the NPV, the option which takes the longest in recovering the initial costs is 100% funding with suppliers credit (11.1 years). Conversely, the quickest in paying back involves funding the project entirely through equity, with 9.1 years.

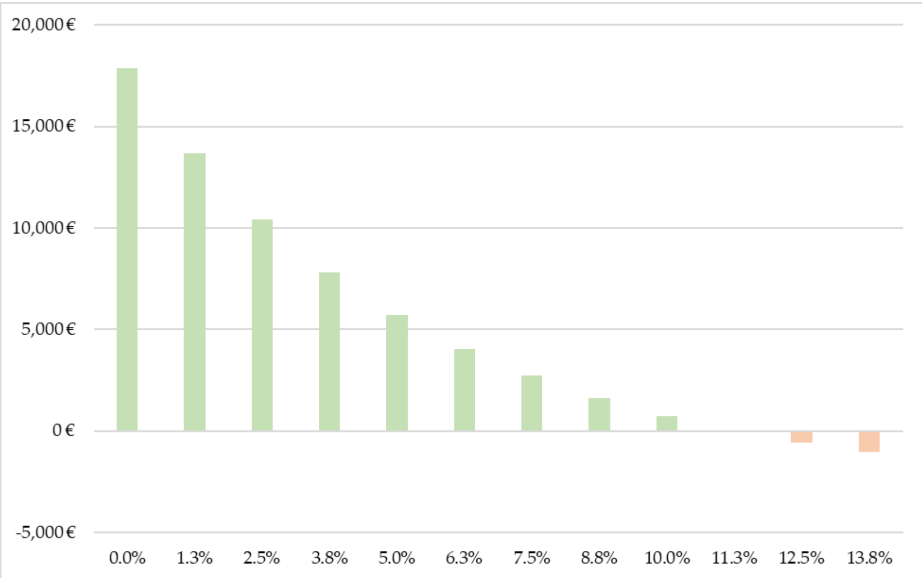

Figure 4: y = NPV; x = discount rate

[14] In this case, the payback period represents the time it takes for the initial installation costs to be recouped through CFs generated by the PV.

The findings related to the IRR are also quite favorable. Firstly, we note that NPV plotted against the discount rate follows a typical monotonic pattern, decreasing as the discount rate increases, as shown in *Figure 4*. This relation is characteristic of a "standard-CFs" project, where negative CFs precede positive ones. Consequently, the NPV function intersects the x-axis at a single point, where NPV is null, representing an IRR of 11.31%. As described in Section ii. Paragraph c5) this analysis employs a 10-year risk-free rate standing at 2.54%. In this context, the IRR for each alternative, hovering around 11%, offers a particularly promising scenario since even in the most unrealistic discount rate dynamics, meaning risk-free rates spiking, the NPV would not turn negative.

Finally, the addition of a battery to the setup was also considered (2.88 kWh Fox-ESS CS2900 V2.0 Energy Cube): when adjusting capacity to maximize financial benefit, we still note incorporating a battery would not be monetarily advantageous (NPV when minimizing losses amounts to -€1,571).

b. Ravello vs. Padua

The paper also encompasses a comparative analysis exploring the divergent economic landscapes of installations in Padua versus Ravello. This offers valuable insights into the interplay of geographical, economic and environmental factors influencing the financial viability of solar energy projects in distinct regional contexts.

We now delve into the financial benchmarks of the two distinct scenarios, each structured with a 75% debt and 25% equity funding arrangement.

In Ravello, the installation reaches an optimal NPV of €10,297 with 15 panels, corresponding to a nominal power of 6.525 kW. On the other hand, Padua's NPV peaks at €7,070, with 12 panels delivering a nominal power of 5.160 kW. Further, Ravello boasts a shorter payback period of 10.72 years and a higher IRR at 11.31%, versus Padua's longer payback of 13.39 years and lower IRR of 9.94%.

This variance can be attributed to a mix of geographical and economic factors intrinsic to the areas where these installations have been developed. Starting from electricity annual consumption, in the former it is assumed to be 2,700 kWh, while a standard household in Padua is expected to consume 3,970 kWh annually. Firstly, we tend to explain this because Ravello is located in Southern Italy, enjoying a milder climate compared to Padua, which is situated in the Northern part of the country. The warmer summers and colder winters in the region of Veneto likely contribute to higher energy consumption (e.g. for heating and cooling purposes) compared to the Amalfi Coast-based town. Additionally, cultural factors may also play a role. Padua can indeed be considered a more progressive city with a greater openness to innovation. As a result, households are more inclined to use electric stoves and electric water heating systems, rather than gas-powered solutions that are more common in Southern Italy.

Another difference we encountered stands at LCOE level: Ravello's figure is €0.05, whereas in Padua it stands at €0.07. Since the LCOE captures both capital and operational expenses over the system's lifetime against total energy produced, examining such factors can explain the disparity. Indeed, we note a not negligible difference in installation expenses: the comprehensive cost, for five panels of similar characteristics, in Padua amounts to €4,354, while in Ravello is €3,739. We tend to attribute this to substantial variations in regional GDP per capita. In Campania, GDP per capita is around €20,000 (Regione Campania, 2022), whereas in Veneto, it stands at €34,000 (Regione Veneto, 2022). Higher GDP per capita often correlates with higher average income levels, which can translate into more elevated labor costs, demand for goods and services, thus higher prices.

Moving to energy production, a significant discrepancy between the two towns is that Ravello experiences more sunny days throughout the year compared to Padua. This is directly reflected in the global irradiance on the inclined plane, a measure of the amount of solar energy available for conversion into electricity by the PV system, mounted at an optimal angle. According to data from the Photovoltaic Geographical Information System website, accessed from the PVGIS-SARAH2 database and based on a three-year average (2018, 2019, 2020), the global irradiance in Padua is recorded at 1739 kW/m², while in Ravello it stands at 1988 kW/m² per year. This difference implies that, ceteris paribus, PVs installed in Ravello have a higher potential for power production, meaning higher energy density efficiency (i.e. energy output generated per m²). In numbers, this translates to a higher NPV per m² for Ravello (€332.48) compared to Padua (€297.14). This, coupled with the lower installation and maintenance costs, makes the financial benefit of installing greater for households living in Ravello.

iv. Final recommendation

The analysis recommends the installation of 15 solar photovoltaic panels, covering a total area of 31.21 m². In this setup, the chosen panels are the Hyundai HiE-S435HG and Iren is selected as the provider, offering the most advantageous terms. The system would allow an estimated annual revenue of €300, selling excess electricity to the grid. Significant savings on the energy bill are also forecasted, amounting to €742 in 2025, with an expected increase to €1,193 by 2049, factoring in the impact of inflation. Regulatory risk is deemed low, as subsidies only account for a minor part of NPV: the installation would remain monetarily advantageous even without incentives (NPV excluding contribution from the government is €9,960).

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