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Economic Analysis of a Photovoltaic System: A Resource for Residential Households

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Abstract: New installed annual solar photovoltaic (PV) capacity was equal to 76.1 GW in 2016 (+49%), reaching the total of 305 GW around the world. PV sources are able to achieve a greater energy independence, to tackle the climate change and to promote economic opportunities. This work proposes an economic analysis based on well-known indicators: Net Present Value (NPV), Discounted Payback Time (DPBT) and Levelized Cost of Electricity (LCOE). Several case studies are evaluated for residential households. They are based on three critical variables: plant size (1, 2, 3, 4, 5 and 6 kW), levels of insolation (1350, 1450 and 1550 kWh/($m^2 \times y$)) and share of self-consumption (30%, 40% and 50%). The profitability is verified in all case studies examined in this work. The role of self-consumption, that is the harmonization between demanded and produced energy, is strategic in a mature market to improve financial performance. A sensitivity analysis, based on both electricity purchase and sales prices (critical variables), confirms these positive results. The Reduction in the Emissions of Carbon Dioxide (ER_{cd}) signifies an environmental improvement when a PV system is used as an alternative to a mix of fossil fuels. Finally, a policy proposal is examined based on a fiscal deduction of 50% fixing the period of deduction equal to 5 years.

Keywords: economic analysis; energy; photovoltaic; residential sector; sustainability

1. Introduction

The Energy Union Framework Strategy set out the ambition to move away from an economy dependent on fossil fuels [1]. The share of renewables reached 16.7% of the gross final energy consumption of the European Union in 2015 (this indicator is equal to 20% in the Europe 2020 strategy). Furthermore, European countries agreed on a new 2030 Framework on climate and energy, in which is defined to reach at least 27% by 2030 [2].

The widespread development of renewable energy sources (RESs) is mainly driven by the aim to contrast the climate change and the reduction of greenhouse gas (GHG) emissions, in addition to the reduction of energy dependency that characterizes most European countries [3–5]. RESs play a key-role in the transition towards a low-carbon economy and are guided by sustainable principles [6]. The sustainability of PV source is a popular topic in literature [7,8] and the growth of this resource is impressive in the last years. Global solar power market grew by about 49% to around 76.1 GW in 2016, from about 51.2 GW in 2015 in according to data provided by Solar Power Europe. China (45%), US (19%) and Japan (11%) represent three quarters of this installed power capacity. European countries present, on the other hand, a value equal to 6.9 GW, with a 20% decrease compared to the 8.6 GW installed in 2015 (Table 1). Germany and Italy occupy the third and the fifth position in the ranking of cumulative installed capacity in 2016, respectively. Italy is one of the leading countries in the world in which solar energy contributes largely to the national energetic demand [9]. However, the power installed capacity in 2016 is very low (1%) compared with that installed in China.

Table 1. Top five countries—installed PV.

Countries	Power Installed in 2016 [1]	% Total of 2016	Countries	Cumulative Power Installed	% Total
China	34.2 GW	45	**China**	77.7 GW [1,2]	25
US	14 GW	19	**Japan**	43.0 GW [1,2]	14
Japan	8.6 GW	11	**Germany**	40.9. GW [3]	13
Europe	6.9 GW	9	**USA**	39.6 GW [1,2]	13
India	4.5 GW	6	**Italy**	19.3 GW [4]	6
Other	7.9 GW	10	**Other**	84.5 GW	29
Total	76.1 GW	100	**Total**	305 GW [1,2,3,4]	100

[1] Solar Power Europe; [2] IEA-PVPS; [3] Fraunhofer ISE (1.2 GW); [4] Anie Rinnovabili (370 MW).

The development of the PV sector is linked to subsidies. They are strategic in developing markets [10,11] and the share of self-consumption becomes relevant in mature markets [12,13]. The next years will be characterized by an integration of PV installations in urban areas with the development of models of distributed generation increasing numbers of prosumers (consumers are also producers) [14,15]. The impacts of climate change, the increasing demand for energy and the diminishing fossil fuel resources have favoured the development of PV technologies in building applications [16]. Economic assessment and policy implications need to be evaluated [17] and the role of residential sector investigated in PV market without subsidies [18]. These assessments required also the definition of environmental improvements [19].

The literature on investment decisions shows whether to make an investment or not [20]. NPV, DPBT, Internal Rate of Return (IRR), Benefit to Cost Ratio (B/C) and LCOE are the indicators typically used in the PV context [21]. NPV and DPBT are basically used to evaluate residential PV systems [18], IRR can cause conflicting answers (multiple IRR can occur) when compared to NPV in mutually exclusive investments [22], B/C permits to translate environmental impacts in economic terms [23] and LCOE is typically used to compare the cost of the energy obtained from different sources [24]. The grid parity is obtained when the solar PV LCOE is comparable with conventional technologies grid electricity prices [13]. The International Energy Agency Report 2015 (projected costs of generating electricity) defines that the costs of generating electricity vary in according to both market conditions and operative conditions of the use of individual technologies. Consequently, it is not possible to define that a technology is the cheapest in different case studies (Table 2).

Table 2. Projected costs of generating electricity.

LCOE (€/kWh)	Min [1]	Max [1]
	Italy	
Solar PV Residential	0.15	0.24
Solar PV Commercial	0.13	0.20
Solar PV Large	0.11	0.16
On Shore Wind	0.07	0.10
Smally Hydro	0.12	0.19
Biogas	0.20	0.26
Solid Biomass	0.27	0.32
Solid Waste Incineration	0.15	0.19
Geothermal	0.06	0.09
Natural Gas CCGT	0.09	0.09
	OECD Countries	
Solar PV Residential	0.09	0.34
Solar PV Commercial	0.05	0.21
Solar PV Large	0.05	0.27
On Shore Wind	0.03	0.20
Off Shore Wind	0.09	0.30
Natural Gas CCGT	0.06	0.13
Coal	0.06	0.11

[1] International Energy Agency–2015 Edition. Conversion factor: 1$ = 0.93€.

The sustainability of a PV system is defined also by estimation of the energy and environmental performances. A previous analysis has quantified these values for Italian context: Energy Payback Time (EPBT) is equal to 2.4–3.0 years, Greenhouse Gas Payback Time (GPBT) is equal to 2.5–3.2 years, Energy Return on Investment (EROI) is equal to 6.2–7.9 and Greenhouse Gas Return on Investment is equal to 5.8–7.5 [25]. ER_{cd} permits a comparison between PV source and a mix of fossil fuels [18].

This paper evaluates the profitability of a photovoltaic system for residential households. Discounted Cash Flow (DCF), a well-known methodology, is proposed and three indicators are used: NPV, DPBT and LCOE. The analysis is applied to several case studies that depend on three critical variables: (i) plant size; (ii) levels of solar irradiation and (iii) share of self-consumption. Furthermore, alternative values of both electricity purchase and sales price are considered in according to modifications that will characterize the Italian energy bill. The work is completed by an environmental evaluation through the calculation of ER_{cd} and is defined a policy proposal with relative economic advantageous for consumers.

The paper is organised as follows: Section 2 presents the methodology used in this paper and an economic model is defined to evaluate the profitability of PV system in households. Results in terms of NPV and DPBT are proposed in Section 3 and a sensitivity analysis is conducted in Section 4. Finally, Section 5 proposes a discussion of the results and Section 6 presents some concluding remarks.

2. Materials and Methods

DCF is a valuation method used to estimate the profitability of an investment opportunity. The determination of an investment's cash flows is based on the incremental approach and an appropriate discount rate is used to aggregate cash flows. This method considers only cash inflows and outflows [12,26]. NPV, DPBT and LCOE are three financial typically used indicators. The first is defined as the sum of present values of individual cash flows, the second represents the number of years needed to balance cumulative discounted cash flows and the initial investment and the third ascribes all future costs to the present value, resulting in a present price per unit energy value [27–29]. NPV does not consider the size of the plant and consequently the ratio between NPV and size of PV system is also used.

Italy is a PV mature market, in which subsidies, such as Feed-in-Premium or Feed-in-Tariff, are no longer provided. The Italian Council of Ministers has approved a 50% tax deduction (compared to the usual 36%) for PV systems used to produce electricity for self-consumption and not for commercial purposes. The deduction is divided into ten equal yearly amounts. Furthermore, the Net Metering Service is provided by Gestore Servizi Energetici (GSE), which is the institutional actor responsible for the control of renewable energies plants. It regulates the electricity generated by a consumer/producer in an eligible on-site plant and injected into the grid and the share extracted from the grid [10,18].

Three items typically characterize cash inflows: (i) fiscal deduction; (ii) saving energy through internal consumption and (iii) selling energy not used for internal consumption. The first item produces a reduction in the taxable costs in the income statement, while the second in the energy bill. Consequently, they are costs with negative value and so can be interpreted as revenues in according to approach used by [18,30]. In this paper the purchase price of electricity (that will be evaluated as savings using the PV system) is calculated using market data and the sale of energy is evaluated by increasing the energy price produced and sold to the grid of a certain delta in accordance with a previous paper [31]. Investment costs are the main item of cash outflows, but are characterized by a great reduction in the last years (was equal to 4500 €/kW in residential sector in 2010) [12]. The amount of energy produced is calculated with the approach used by Cucchiella et al. [23]. The mathematical reference model, for the calculation of NPV, DPBT and LCOE, is reported below:

$$\mathrm{NPV} = \mathrm{DCI} - \mathrm{DCO} \tag{1}$$

$$\sum_{t=0}^{\mathrm{DPBT}} (\mathrm{CI_t} - \mathrm{CO_t})/(1+\mathrm{r})^{\mathrm{t}} = 0 \tag{2}$$

$$\mathrm{LCOE} = \mathrm{DCO}/\sum_{t=1}^{N} \mathrm{E}_{\mathrm{Out,t}} \tag{3}$$

$$\mathrm{DCI} = \sum_{t=1}^{N} \frac{\omega_{\mathrm{self,c}} \times \mathrm{E}_{\mathrm{Out,t}} \times \mathrm{p}_t^c + \omega_{\mathrm{sold}} \times \mathrm{E}_{\mathrm{Out,t}} \times \mathrm{p}_t^s}{(1+r)^t} + \sum_{t=1}^{N_{\mathrm{TaxD}}} \left((\mathrm{C}_{\mathrm{inv}}/\mathrm{N}_{\mathrm{TaxD}}) \times \mathrm{TaxD}_{\mathrm{u-sr}}\right)/(1+r)^t \tag{4}$$

$$\mathrm{p}_{t+1}^c = \mathrm{p}_t^c \times (1 + \mathrm{inf}_{\mathrm{el}});\ \mathrm{p}_{t+1}^s = \mathrm{p}_t^s \times (1 + \mathrm{inf}_{\mathrm{el}}) \tag{5}$$

$$\begin{aligned}\mathrm{DCO} = &\sum_{t=0}^{N_{\mathrm{debt}}-1} \left(\mathrm{C}_{\mathrm{inv}}/\mathrm{N}_{\mathrm{debt}} + (\mathrm{C}_{\mathrm{inv}} - \mathrm{C}_{\mathrm{lcs,t}}) \times \mathrm{r_d}\right)/(1+r)^t \\ &+ \sum_{t=1}^{N} \frac{\mathrm{P_{Cm}} \times \mathrm{C_{inv}} \times (1+\mathrm{inf}) + \mathrm{P_{Cass}} \times \mathrm{C_{inv}} \times (1+\mathrm{inf}) + \mathrm{SP_{el,t}} \times \mathrm{P_{Ctax}}}{(1+r)^t} \\ &+ \frac{\mathrm{P_{Ci}} \times \mathrm{C_{inv}}}{(1+r)^{10}} + \mathrm{C_{ae}}\end{aligned} \tag{6}$$

$$\mathrm{C_{inv}} = \mathrm{C_{inv,unit}} \times (1 + \mathrm{Vat}) \times \mathrm{P_f} \times \eta_f \tag{7}$$

$$\mathrm{E_{Out,t}} = \mathrm{t_r} \times \mathrm{K_f} \times \eta_m \times \eta_{bos} \times \mathrm{A_{cell}} \times \mathrm{P_f} \times \eta_f \tag{8}$$

$$\mathrm{E_{Out,t+1}} = \mathrm{E_{Out,t}} \times (1 - \mathrm{dE_f}) \tag{9}$$

$$\mathrm{E_{Out}} = \sum_{t=1}^{N} \mathrm{E_{out,t}} \tag{10}$$

where DCI = discounted cash inflows; DCO = discounted cash outflows; t = single period; CI = cash inflows; CO = cash outflows; E_{Out} = energy output of the system; C_{inv} = total investment cost; C_{lcs} = loan capital share cost; SP_{el} = sale of energy; η_f = number of PV modules to be installed and P_f = nominal power of a PV module. Other economic inputs, used in this analysis, are defined in Table 3.

In particular, it is paid a price of 10.9 cent €/kWh compared to 9.8 cent€/kWh for plants that annually feed in the grid a net amount of electricity below the reference value of 3750 kWh. The feasibility of solar systems varies significantly due to the changes in all parameters involved in the economic evaluation [32]. Several case studies are proposed in this paper in according to the combinations of the following variables:

- plant size, in which values that typically characterize the residential sector are selected [33]. Starting with an initial size equal to 3 kW and 6 kW, six plant sizes (1, 2, 3, 4, 5 and 6 kW) are considered.
- levels of solar irradiation, in which Italy presents several insolation levels due to its geographical conformation. Three values are considered for each area of the country [23]. In fact, a northern region (1350 kWh/m^2×y in Lombardia), a central region (1450 kWh/m^2×y in Abruzzo) and a southern region (1550 kWh/m^2×y in Puglia) are evaluated.
- share of self-consumption, that varies in function of consumers' use [12]. Three different values (30%, 40% and 50%) are hypothesized.

Furthermore, the choice concerning these variables is coherent with the survey conducted among several business operators [18].

From an environmental perspective, the life cycle analysis of GHG emissions from electricity technologies presents a wide range: natural gas 290–930 gCO_2eq/kWh, oil 510–1170 gCO_2eq/kWh, coal 675–1689 gCO_2eq/kWh and photovoltaic 5–92 gCO_2eq/kWh [34]. ER_{cd} is calculated as the difference between emissions released by a mix of fossil fuels (E_{cd}^{FF}) and ones produced by PV source (E_{cd}^{PV}), when is used a PV system in alternative to fossil fuels. This reduction is linked to the amount of energy produced (E_{Out}):

$$\mathrm{ER_{cd,unit}} = \mathrm{E_{cd}^{FF}} - \mathrm{E_{cd}^{PV}} \tag{11}$$

$$ER_{cd} = \sum_{t=1}^{N} \left(E_{cd}^{FF} - E_{cd}^{PV}\right) \times E_{Out,t} \quad (12)$$

A previous analysis has estimated the following emissions for an Italian case study: E_{cd}^{FF} = 776 gCO_2eq/kWh (considering a mix of 45% oil, 44% natural gas and 11% coal) and E_{cd}^{PV} = 49 gCO_2eq/kWh. Consequently, the reduction in the emissions can be estimated equal to 727 gCO_2eq/kWh using a PV system alternatively to fossil sources [18].

Table 3. Economic inputs [10,18].

Acronym	Variable	Value
A_{cell}	Active surface	7 m^2/kWp
C_{ae}	Administrative and electrical connection cost	250 €
$C_{inv,unit}$	Specific investment cost	1900 €/kW
dE_f	Decreased efficiency of a system	0.7%
inf	Rate of inflation	2%
inf_{el}	Rate of energy inflation	1.5%
k_f	Optimum angle of tilt	1.13
N	Lifetime of a PV system	20 y
N_{debt}	Period of loan	15 y
N_{TaxD}	Period of tax deduction	10 y
η_{bos}	Balance of system efficiency	85%
η_m	Module efficiency	16%
p^c	Electricity purchase price	19 cent €/kWh
p^s	Electricity sales price	9.8–10.9 cent €/kWh
P_{Cass}	Percentage of assurance cost	0.4%
P_{Ci}	Percentage of inverter cost	15%
P_{Cm}	Percentage of maintenance cost	1%
P_{Ctax}	Percentage of taxes cost	43.5%
r	Opportunity cost of capital	5%
r_d	Interest rate on a loan	3%
t_r	Average annual insolation	1350–1550 $kWh/(m^2 \times y)$
S	Size	1–6 kW
$TaxD_{u\text{-}br}$	Specific tax deduction (baseline rate)	36%
$TaxD_{u\text{-}sr}$	Specific tax deduction (subsidized rate)	50%
$\omega_{self,c}$	Percentage of energy self-consumption	30–50%
ω_{sold}	Percentage of the produced energy sold	50–70%
Vat	Value added tax	10%

3. Results

Citizens' awareness of environmental issues has increased sharply in the last years. They want to apply solutions to the changes of ecosystems. However, a citizen is also an investor and consequently, the economic feasibility must be evaluated. In this paper fifty-four case studies are proposed. They depend by the combinations of the following variables: six plants size, three levels of solar irradiation and three different share of self-consumption. NPV, NPV/Size, DPBT and LCOE are calculated for each case study in Tables 4–7, respectively.

Table 4. Net Present Value (€) of small-scale photovoltaic systems.

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	*30%*	265	781	1296	1623	1809	2843
	40%	492	1234	1977	2719	3171	4203
	50%	719	1688	2657	3626	4595	5318

Table 4. *Cont.*

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Abruzzo	*30%*	428	1106	1783	2128	2583	3817
	40%	671	1593	2514	3435	3949	5278
	50%	915	2080	3245	4409	5490	6373
Puglia	*30%*	590	1430	2270	2650	3356	4791
	40%	850	1951	3051	4013	4751	6353
	50%	1111	2471	3832	5193	6362	7471

Table 5. Net Present Value/Size (€/kW) of small-scale photovoltaic systems.

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	*30%*	265	391	432	406	362	474
	40%	492	617	659	680	634	701
	50%	719	844	886	907	919	886
Abruzzo	*30%*	428	553	594	532	517	636
	40%	671	797	838	859	790	880
	50%	915	1040	1082	1102	1098	1062
Puglia	*30%*	590	715	757	663	671	799
	40%	850	976	1017	1003	950	1059
	50%	1111	1236	1277	1298	1272	1245

Table 6. Discounted Payback Time (years) of small-scale photovoltaic systems.

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	*30%*	16	7	6	7	7	6
	40%	8	6	5	5	5	5
	50%	6	5	4	4	4	4
Abruzzo	*30%*	14	6	5	6	5	5
	40%	7	5	4	4	4	4
	50%	6	4	4	3	4	3
Puglia	*30%*	7	5	5	5	5	5
	40%	6	4	4	4	4	4
	50%	5	4	3	3	3	3

Table 7. Levelized cost of electricity (€/kWh) of small-scale photovoltaic systems.

Region	Plant Size					
	1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	0.12	0.11	0.11	0.11	0.11	0.11
Abruzzo	0.11	0.10	0.10	0.10	0.10	0.10
Puglia	0.10	0.10	0.10	0.10	0.10	0.10

The profitability is always verified. This work proposes a quantitative analysis and the financial feasibility varies in function of several variables. The maximum value is equal to 1298 €/kW in 4 kW plant located in Puglia with a self-consumption of 50% and the minimum value is equal to 265 €/kW in 1 kW plant situated in Lombardia with a self-consumption of 30%.

The southern regions have more benefits than northern ones, as they enjoy greater levels of insolation and consequently, the financial indicator presents a better performance [23]. The average value of NPV/Size is equal to 626 €/kW in Lombardia considering eighteen scenarios of this region. The increase is equal to 174 €/kW when is evaluated a territory with a level of insolation greater than 100 kWh/($m^2 \times$y). In fact, the average value of NPV/Size is equal to 800 €/kW and 972 €/kW in Abruzzo and Puglia, respectively.

The literature has defined also as the self-consumption is the critical variable that influences the profitability or less of a PV system in a mature market without subsidies [12,13]. Consumers can try to match own consumption with peaks of production solar, but not always this is possible. For example, work commitments or health visits can be valid obstacles to this aim. Consequently, the use of intelligent machinery and/or battery storage is a valid solution [35,36]. The average value of NPV/Size is equal to 543 €/kW, 804 €/kW and 1050 €/kW, when are considered eighteen scenarios with a self-consumption of 30%, 40% and 50%, respectively.

The optimal configuration of plant size is well described in literature and it depends by the final purpose (technical, environmental, economic or a mix of them) [23,37]. The average value of NPV/size ranges:

- from 671 € per kW installed for the 1 kW plant
- to 860 € per kW installed for the 6 kW plant

Considering for each the respective nine case studies. The unitary cost of investment is the same for all sizes analysed and consequently NPV increases with the size of the plant. However, this is not always verified due to the reduction of the sale price of energy. For example, a 4 kW plant is more profitable than a 5 kW one in seven of nine case studies.

The DPBT results are coherent with the NPV ones. In fact, the profitability is always verified. In the worse scenario, the investor defines the cut-off period equal to the lifetime of the plant and consequently, a DPBT > 20 defines that the investment cannot be recovered within this period. DPBT is equal to 3 years in six case studies, but generally presents interesting values. In fact, it is equal to 4 years and 5 years in seventeen and fifteen case studies, respectively. The choice of third-party funds permits to distribute the investment cost over the years instead to place it in the year zero.

NPV and DPBT define the profitability of a PV system considering both discounted cash inflows and outflows, while LCOE is able not to provide the same result. However, LCOE results obtained in this work are very interesting. They are equal to 0.10–0.11 €/kWh (only 1 kW plant with 1350 kWh/($m^2 \times$y) is 0.12 €/kWh). This range is lower than minimal value proposed in Table 2 concerning Italy (0.15 €/kWh) and is similar to one calculated for OECD countries (0.09 €/kWh). In according to existing literature, the reduction of PV investment costs has pushed this technology towards greater competitiveness [21,24]. A comparison with values of other technologies proposed in Table 2 confirms this evaluation.

A useful tool is represented by the analysis of the distribution of discounted cash inflows (Table 8) and discounted cash outflows (Table 9). In these tables are reported the average values among six sizes analysed. The main item of revenues is represented by the selling of energy only when is evaluated the scenario with the share of energy self-consumption equal to 30%. Previous analysis have defined as the avoided cost in energy bill is the main item in correspondence of 35% and 32% of self-consumption for a 3 kW and 6 kW plants, respectively [18]. Also, in this work the saving energy through internal consumption is equal to 44–45% in scenario with self-consumption of 40% that is greater than 33–34%. This last value is the percentage of revenues produced by selling of electricity. The difference increases when is evaluated a self-consumption equal to 50% (52–54% as avoided cost in energy bill and 26% as selling of energy). Furthermore, these two items are cash flows for all lifetime of the plant, while the fiscal deduction is verified only during the first ten years. Its contribution is relevant and equal to 20–24%. As highlighted in Section 2, the investment cost is the main expenditure item (62–66%). Maintenance cost is the greater among operative ones (16–17%) and the replacement of inverter during the tenth year has a relevant impact on this item. The variation of self-consumption has not a direct impact on operative costs, but an increase of electricity self-consumption determines also a reduction in sold electricity and also the taxes cost are reduced. For this motive, the item "other operative costs" is characterized by lower percentages when is increased the share of self-consumption.

Table 8. Distribution of discounted cash inflows.

Region	Self-Consumption	Fiscal Deductions	Saving Energy through Internal Consumption	Sale of Energy not for Internal Consumption
Lombardia	*30%*	24%	35%	41%
	40%	23%	44%	33%
	50%	22%	52%	26%
Abruzzo	*30%*	23%	35%	42%
	40%	21%	45%	34%
	50%	21%	53%	26%
Puglia	*30%*	22%	36%	42%
	40%	21%	45%	34%
	50%	20%	54%	26%

Table 9. Distribution of discounted cash outflows.

Region	Self-Consumption	Investment Costs	Maintenance Costs	Other Operative Costs
Lombardia	*30%*	64%	16%	20%
	40%	65%	17%	18%
	50%	66%	17%	17%
Abruzzo	*30%*	63%	16%	21%
	40%	64%	16%	20%
	50%	66%	17%	17%
Puglia	*30%*	62%	16%	22%
	40%	64%	16%	20%
	50%	65%	17%	18%

4. Sensitivity Analysis

NPV results are based on the assumptions of a set of input variables. Hence, variance of the expected NPV could occur. This limitation can be overcome by implementing a sensitivity analysis on the critical variables [31,38]. The new electricity tariff will produce changes on two critical variables examined in previous works [12,18]. The first is the annual electricity purchase price that assesses the reduction of energy costs reported in electricity bill. An increase of this value is a positive scenario for investors. Variations are proposed in the range of about 1–2 cent €/kWh, both in positive and negative terms. Consequently for each plant size are evaluated the following four alternative scenarios: $\mathbf{p}^{\mathbf{c}}_{++}$ ($\mathbf{p}^{\mathbf{c}}$ = 21 cent €/kWh); $\mathbf{p}^{\mathbf{c}}_{+}$ ($\mathbf{p}^{\mathbf{c}}$ = 20 cent €/kWh); $\mathbf{p}^{\mathbf{c}}_{-}$ ($\mathbf{p}^{\mathbf{c}}$ = 18 cent €/kWh) and $\mathbf{p}^{\mathbf{c}}_{--}$ ($\mathbf{p}^{\mathbf{c}}$ = 17 cent €/kWh) with an initial value of p^c equal to 19 cent €/kWh—Table 10.

Table 10. Sensitivity analysis electricity purchase price-Net Present Value/Size (€/kW).

Self-Consumption	**1 kW**				**2 kW**				**3 kW**			
	p^c_{++}	p^c_{+}	p^c_{-}	p^c_{--}	p^c_{++}	p^c_{+}	p^c_{-}	p^c_{--}	p^c_{++}	p^c_{+}	p^c_{-}	p^c_{--}
Lombardia												
30%	388	327	204	143	513	452	329	268	555	493	371	310
40%	656	574	410	329	781	699	536	454	822	741	577	495
50%	923	821	617	515	1049	946	742	640	1090	988	783	681
Abruzzo												
30%	559	494	362	296	685	619	487	421	726	660	529	463
40%	847	759	584	496	972	884	709	621	1014	926	750	662
50%	1134	1025	805	695	1260	1150	930	821	1301	1191	972	862
Puglia												
30%	731	660	520	449	856	786	645	575	898	827	686	616
40%	1038	944	757	663	1163	1070	882	788	1205	1111	923	829
50%	1345	1228	993	876	1471	1353	1119	1001	1512	1395	1160	1043

Table 10. *Cont.*

Self-Consumption	4 kW				5 kW				6 kW			
	$\mathbf{p}^{\mathbf{c}}_{++}$	$\mathbf{p}^{\mathbf{c}}_{+}$	$\mathbf{p}^{\mathbf{c}}_{-}$	$\mathbf{p}^{\mathbf{c}}_{--}$	$\mathbf{p}^{\mathbf{c}}_{++}$	$\mathbf{p}^{\mathbf{c}}_{+}$	$\mathbf{p}^{\mathbf{c}}_{-}$	$\mathbf{p}^{\mathbf{c}}_{--}$	$\mathbf{p}^{\mathbf{c}}_{++}$	$\mathbf{p}^{\mathbf{c}}_{+}$	$\mathbf{p}^{\mathbf{c}}_{-}$	$\mathbf{p}^{\mathbf{c}}_{--}$
Lombardia												
30%	528	467	344	283	484	423	301	239	596	535	413	351
40%	843	762	598	516	798	716	552	471	768	702	570	505
50%	1111	1009	804	702	1123	1021	817	715	1091	989	784	682
Abruzzo												
30%	664	598	466	401	648	582	451	385	768	702	570	505
40%	1035	947	771	683	965	878	702	614	1055	968	792	704
50%	1322	1212	993	883	1317	1208	988	878	1282	1172	953	843
Puglia												
30%	803	733	592	522	812	742	601	530	939	869	728	658
40%	1191	1097	910	816	1138	1044	856	763	1247	1153	965	871
50%	1533	1416	1181	1064	1507	1390	1155	1038	1480	1362	1128	1011

The second is the annual electricity sales price that assesses incomes coming from the selling of energy not consumed. It is applied the same variation of the previous variable. Consequently for each plant size are evaluated the following four alternative scenarios: $\mathbf{p}^{\mathbf{s}}_{++}$ ($\mathbf{p}^{\mathbf{s}}$ = 13 cent €/kWh); $\mathbf{p}^{\mathbf{s}}_{+}$ ($\mathbf{p}^{\mathbf{s}}$ = 12 cent €/kWh); $\mathbf{p}^{\mathbf{s}}_{-}$ ($\mathbf{p}^{\mathbf{s}}$ = 10 cent €/kWh) and $\mathbf{p}^{\mathbf{s}}_{--}$ ($\mathbf{p}^{\mathbf{s}}$ = 9 cent €/kWh) when is sold a net amount of electricity lower than 3750 kWh (initial value of $\mathbf{p}^{\mathbf{s}}$ equal to 10.9 cent €/kWh). If, instead, the reference value is greater than 3750 kWh, all prices are decreased of 1 cent€/kWh (initial value of $\mathbf{p}^{\mathbf{s}}$ equal to 9.8 cent €/kWh) with $\mathbf{p}^{\mathbf{s}}_{++}$, $\mathbf{p}^{\mathbf{s}}_{+}$, $\mathbf{p}^{\mathbf{s}}_{-}$ and $\mathbf{p}^{\mathbf{s}}_{--}$ equal to 12, 11, 10 and 9 cent €/kWh—Table 11.

Table 11. Sensitivity analysis electricity sales price-Net Present Value/Size (€/kW).

Self-Consumption	1 kW				2 kW				3 kW			
	$\mathbf{p}^{\mathbf{s}}_{++}$	$\mathbf{p}^{\mathbf{s}}_{+}$	$\mathbf{p}^{\mathbf{s}}_{-}$	$\mathbf{p}^{\mathbf{s}}_{--}$	$\mathbf{p}^{\mathbf{s}}_{++}$	$\mathbf{p}^{\mathbf{s}}_{+}$	$\mathbf{p}^{\mathbf{s}}_{-}$	$\mathbf{p}^{\mathbf{s}}_{--}$	$\mathbf{p}^{\mathbf{s}}_{++}$	$\mathbf{p}^{\mathbf{s}}_{+}$	$\mathbf{p}^{\mathbf{s}}_{-}$	$\mathbf{p}^{\mathbf{s}}_{--}$
Lombardia												
30%	387	329	214	156	512	454	339	281	553	496	380	323
40%	595	546	448	399	720	671	573	524	762	713	615	566
50%	804	763	683	642	929	889	808	767	970	930	849	809
Abruzzo												
30%	558	496	372	310	683	621	497	435	725	663	539	477
40%	782	729	624	571	907	855	749	697	949	896	791	738
50%	1006	963	876	832	1131	1088	1001	958	1173	1129	1042	999
Puglia												
30%	729	663	530	464	854	788	656	590	896	830	697	631
40%	969	912	800	743	1094	1038	925	869	1135	1079	966	910
50%	1208	1162	1069	1023	1333	1287	1194	1148	1375	1328	1236	1189

Self-Consumption	4 kW				5 kW				6 kW			
	$\mathbf{p}^{\mathbf{s}}_{++}$	$\mathbf{p}^{\mathbf{s}}_{+}$	$\mathbf{p}^{\mathbf{s}}_{-}$	$\mathbf{p}^{\mathbf{s}}_{--}$	$\mathbf{p}^{\mathbf{s}}_{++}$	$\mathbf{p}^{\mathbf{s}}_{+}$	$\mathbf{p}^{\mathbf{s}}_{-}$	$\mathbf{p}^{\mathbf{s}}_{--}$	$\mathbf{p}^{\mathbf{s}}_{++}$	$\mathbf{p}^{\mathbf{s}}_{+}$	$\mathbf{p}^{\mathbf{s}}_{-}$	$\mathbf{p}^{\mathbf{s}}_{--}$
Lombardia												
30%	608	514	325	231	569	475	287	192	595	537	422	364
40%	847	767	608	529	806	727	568	489	804	755	656	607
50%	1042	978	848	784	1055	990	861	796	1026	961	832	767
Abruzzo												
30%	752	651	449	348	739	638	436	334	766	704	580	518
40%	1038	953	782	697	976	891	721	635	990	938	832	780
50%	1248	1179	1040	971	1245	1176	1037	968	1213	1144	1005	936
Puglia												
30%	900	792	576	467	909	801	585	476	938	871	739	673
40%	1198	1107	925	833	1151	1060	877	786	1177	1121	1003	952
50%	1454	1380	1232	1158	1432	1357	1209	1135	1408	1333	1239	1111

This work proposes four hundred and thirty-two alternative scenarios. They are obtained by the combinations of six plants size, three levels of insolation and three share of self-consumption with four values of electricity purchase price and also with four values of electricity sales price.

The profitability is verified in all scenarios taken into consideration. The maximum and minimum values are verified in the same scenario proposed in Section 3, when the electricity purchase price is increased/decreased of 2 cent €/kWh. They are equal to 1533 €/kW and 143 €/kW, respectively. The aim of this section is give solidity to results obtained in previous section, while is not assigned a probability to single alternative scenarios. This quantitative analysis offers a photography, in which is illustrated the change of NPV in function of electricity sales and purchase prices.

An increase of about 1 cent €/kWh of electricity purchase price determines the increase of NPV especially in case studies characterized by a greater amount of energy self-consumption. In fact, from the perspective of levels of insolation this increase is equal to 70 €/kW in Puglia, 66 €/kW in Abruzzo and 62 €/kW in Lombardia, when is considered a self-consumption of 30%. From the perspective of harmonization between consumption and production of energy the increase of NPV/Size, with a level of insolation of 1550 kWh/($m^2 \times y$), is equal to 117 €/kW, 94 €/kW and 70 €/kW for a rate of self-consumption of 50%, 40% and 30%, respectively. These values are verified for all sizes examined considering the model proposed in Section 2, in which the variable assumes the same value and presents a linear relationship with relative revenues.

An increase of about 1 cent €/kWh of electricity sales price produces the increase of NPV especially in case studies characterized by a lower amount of energy self-consumption. This increase is not the same for all sizes analysed and it depends by two different prices of selling that change during the lifetime of PV investment. For example, when is evaluated a 1 kW or 2 kW or 3 kW plant with a self-consumption of 30% (reference value equal to 12 cent €/kWh) and a 6 kW plant always with the same self-consumption (reference value equal to 11 cent €/kWh), NPV/Size increases of 64 € per kW installed. In a 4 kW o 5 kW plant, instead, the change is equal to 108–113 €/kW.

5. Discussion

A comparison with existing literature, that analyses case studies of the same country, highlights that the investment in PV plants is characterised by a moderate profit and a low risk. A summary of economic values reported in literature is as follows: 716–913 €/kW [12], 1804–2386 €/kW [39], 1101–3312 €/kW [23] and (−1300)–3300 €/kW [33] for a 3 kW plant. Considering instead a 6 kW plant, NPV/Size is equal to 565–2000 €/kW [23] and 250–2000 €/kW [33]. A review on the various PV incentive systems has defined an average NPV equal to 9570 €/inhabitant under a feed-in premium tariff in 2012, 5906 €/inhabitant under an all-inclusive feed-in tariff in 2013, 2065 €/inhabitant under a 50% tax deduction in 2013 and 2380 €/inhabitant under both 50% tax deduction in 2014 with a reduction of investment costs [40]. Also, DPBT proposes interesting values with existing literature: 3–12 years [12], 4–8 years [41] and 7–15 years [21]. The case studies proposed in this work show that the profitability can reach very interesting values and consumers also play a key-role. In fact, NPV is significant when an alignment between consumption and production of energy is obtained considering furthermore the reduction of PV investment costs.

An increase of energy bill is seen with behaviour by the citizens, which is justified by the sector operators to balance the higher costs. The components of the energy bill are several and their cost varies in function of time bands. On the one hand, consumers' responsibility can be enhanced making their own economic benefits coincident with the national energy strategy. On the other hand, a country can opt to achieve not only its energy and environmental targets, but also to play a leading role towards establishing a model based on a circular economy. Italy has already reached the 2020-target fixed by the European Union in terms of energy from renewables in gross final energy consumption in 2014, but offers a great potential to reach further sustainable objectives [4].

From an environmental perspective, ER_{cd} varies from 19.6 to 22.5 tCO_2eq per kW installed during the whole lifetime of a PV investment (20 years)—Table 12. In fact, for example the electricity produced by a 1 kW plant in Abruzzo is equal to 1560 kWh/y. Considering a decrease of productivity during the lifetime (see Table 3), it is possible to calculate the total energy produced by this system in 20 years. It is equal to 28,936 kWh. Multiplying this value for the unitary reduction of emissions equal to 727 gCO_2eq/kWh–see Section 2 (electricity produced by fossil fuels replaced by one obtained by PV systems), it is calculated the environmental indicator equal to 21 tCO_2eq.

Table 12. Reduction in the Emissions of Carbon Dioxide (tCO_2eq).

Region	Plant Size					
	1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	19.6	39.2	58.8	78.3	97.9	117.5
Abruzzo	21.0	42.1	63.1	84.1	105.2	126.2
Puglia	22.5	45.0	67.5	89.9	112.4	134.9

The environmental analysis, like the economic one, depends on the assumptions of the input variables. Alternative scenarios show the reduction in the emissions can vary from 687 to 777 gCO_2eq/kWh using a PV system as an alternative to fossil sources [18] and consequently, the final value of ER_{cd} is also modified. It ranges from 18.5–20.9 tCO_2eq per kW installed in Lombardia, 19.9–22.5 tCO_2eq per kW installed in Abruzzo and 21.3–24.0 tCO_2eq per kW installed in Puglia.

This paper verifies that the aims of environmental protection and economic profit can co-exist investing in PV systems under the perspective of a residential consumer and the development of RES contribute in a significant way to reach a greater energy independence, especially for a country characterized by a low production of fossil fuels. Future research directions are aimed at improving the diffusion of PV systems. From an environmental perspective, technological evolution can improve the performance of these systems and reduce the emissions of manufacturing processes relative to the production of PV system components. Also, their recycling is crucial for a perspective that analyses the lifecycle of a product. From the economic side, the integration of PV plants with battery storage or heat pumps permits one to increase the percentage of self-consumed energy. PV is a policy-driven market [42]. Subsidies cannot be seen as a perpetual assistance and consequently they are typically removed once a sector achieves maturity. Fiscal deductions are a useful policy adopted by a government that does not cause higher costs for citizens [43]. In this direction, a previous study has evaluated two tools to favour PV investments in the residential sector: (i) a rate of fiscal deduction equal to 50% (instead of 36%) and (ii) a period of deduction equal to 5 years (instead of 10 years) [18].

The first point is evaluated in baseline scenario (see Table 3), while the analysis of the second point completes this work. If the tax return of a consumer permits a reduction of this period, the revenues are concentrated in the early years determining an increase of NPV and an improvement of DPBT. Both are proposed in Tables 13 and 14, respectively.

Table 13. Net Present Value/Size (€/kW)—A new proposal.

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	*30%*	363	489	530	504	460	572
	40%	590	715	757	778	732	799
	50%	817	942	984	1005	1017	984
Abruzzo	*30%*	526	651	692	630	614	734
	40%	769	895	936	957	888	978
	50%	1013	1138	1179	1200	1196	1160
Puglia	*30%*	688	813	855	760	769	896
	40%	948	1074	1115	1101	1048	1157
	50%	1209	1334	1375	1396	1370	1343

Table 14. Discounted Payback Time (years)—A new proposal.

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	*30%*	4	3	2	2	2	2
	40%	3	3	2	2	2	2
	50%	3	2	2	2	2	2
Abruzzo	*30%*	3	3	2	2	2	2
	40%	3	2	2	2	2	2
	50%	3	2	2	2	2	2
Puglia	*30%*	3	2	2	2	2	2
	40%	3	2	2	2	2	2
	50%	3	2	2	2	2	2

The results obtained confirm the advantages of this proposal. DPBT is equal to 2 years in forty-two case studies and the increase of NPV is equal to 98 € per kW installed in all scenarios. This aspect is linked to linear relationship between cash inflows and returns obtained by fiscal deduction that is proposed in Section 2.

Finally, eco-efficiency is defined as the ratio between the (added) economic value of what has been produced and the (added) environment impacts of the product [44]. An eco-efficiency comparison among several energy technologies represents a future address research, but according to values obtained in this work it is possible to estimate two possible indicators:

- Profits per unit of emissions (PREM), calculated as the ratio between NPV per unit of energy produced and E_{cd}^{PV}—Table 15. For example, NPV is equal to 265 € (see Table 4) in a 1 kW plant in Lombardia with self-consumption equal to 30% and E_{out} is equal to 26,941 kWh (see Equation (10)). Dividing their ratio for E_{cd}^{PV} (49 gCO_2eq/kWh—see Equation (11)) a value of PREM equal to 201 €/tCO_2eq is obtained.
- Costs per unit of emissions (COEM), calculated as the ratio between LCOE and E_{cd}^{PV}—Table 16. For example LCOE is equal to 0.12 €/kWh (see Table 7) in a 1 kW plant in Lombardia and E_{cd}^{PV} is 49 gCO_2eq/kWh (see equation (11)), so COEM is equal to 2365 €/tCO_2eq.

Table 15. Profits per unit of avoided emissions (€/tCO_2eq) of small-scale photovoltaic systems.

Region	Self-Consumption	Plant Size					
		1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	*30%*	201	296	327	307	274	359
	40%	373	467	499	515	480	531
	50%	545	639	671	687	696	671
Abruzzo	*30%*	302	390	419	375	364	449
	40%	473	562	591	606	557	620
	50%	645	733	763	777	774	749
Puglia	*30%*	389	472	499	437	443	527
	40%	561	644	671	662	627	699
	50%	733	815	843	857	840	822

Table 16. Costs per unit of avoided emissions (€/tCO_2eq) of small-scale photovoltaic systems.

Region	Plant Size					
	1 kW	2 kW	3 kW	4 kW	5 kW	6 kW
Lombardia	2365	2270	2239	2223	2214	2207
Abruzzo	2222	2134	2105	2090	2081	2075
Puglia	2098	2015	1988	1974	1966	1960

6. Conclusions

Solar PV generates renewable electricity by converting energy from the Sun. Its energy is intermittent and depends on the weather conditions. PV sources present lower levels of production than other RESs. However, PV is a relevant player in the global electricity market as highlighted by its notable growth in the last years all over the world. This topic is timely and multidisciplinary. This work shows economic profits in residential sector, but also environmental advantages. Furthermore, a policy proposal is suggested.

Several countries aim to delete or reduce subsidies given to PV systems. Business operators can apply for a reduction of investment costs by proposing specific business plans for consumers, but the sector is not always able to restart. Italy is an example, in fact it is fifth country globally for installed PV capacity in 2016, but the power installed in the last years after the end of subsidies is low.

The residential sector permits all citizens to improve their quality of life in terms of reduction of GHG emissions. Plant sizes from 1 kW to 6 kW are analysed in this work and the financial indicators are very interesting. Certainly, they are lower than ones obtained during the subsidy period (in particular when the incentive was given for energy produced, but also to incentives linked to the energy fed into the grid). Actually, the profits increase significantly with an alignment between the amount of demanded and supplied electricity.

LCOE is equal to 0.10–0.11 €/kWh and a comparison with other technologies underlines the fact that the PV source can be competitive. Furthermore, the profitability is verified in all case studies. In our baseline scenario, NPV ranges from 265 to 1298 €/kW and DPBT is typically equal to 3–5 years. Sensitivity analysis, in which both electricity purchase and sales price are changed, confirms these results. Furthermore, a policy proposal can be an attractive measure for the sector. The period of deduction can be fixed also equal to 5 years and the unitary tax deduction is maintained equal to 50% (NPV ranges from 363 to 1396 €/kW and DPBT is equal to 2 years). Finally, ER_{cd} varies from 19.6 to 22.5 for each kW installed during the 20 years of useful life of the investment. The eco-efficiency indicator (PREM) ranges from 201 to 822 €/tCO_2eq. Finally, PV investments increase the energy independence of a country and the installations of these systems produce a positive environmental improvement and offer economic opportunities.

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