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Photovoltaic systems and sustainable communities: New social models for ecological transition. The impact of incentive policies in profitability analyses

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ABSTRACT

The issue of energy independence and sustainability are two major challenges in energy decision-making models. Prosumer development and sustainable community models are identified as drivers to achieve the ecological transition. This work proposes an economic analysis based on Net Present Value (NPV) also supported by the assessment of alternative scenarios (sensitivity, scenario and risk analysis). This study concerns a photovoltaic (PV) plant located in a mature market (Italy) under a collective self-consumption (CSC) scheme.

The first aim is to assess the profitability of a PV plant by considering different political (tax deduction, subsidies) and market (purchase price, selling price) contexts. The results show significant economic returns with very modest levels of risk. The NPV varies in the range 2136–8084 €/kW in the baseline policy scenario and 1919–7868 €/kW in the alternative policy scenario, and thus the variations in NPV are more significant in the market scenarios than in the policy scenarios.

The second aim seeks to propose how benefits among renewable self-consumers can be divided, and three scenarios are proposed for a CSC scheme: i) revenues split equally; ii) revenues shared entirely according to energy consumption profile and iii) revenues shared according to a partial energy consumption profile. The share of self-consumption plays a key role, but soaring energy costs also push prosumers to make a choice for the future and make their contribution to the development of a sustainable community.

1. Introduction

The European Environment Agency has well identified the difference/contact points between the concepts of green economy (GE) and circular economy (CE) [1]. CE is seen as a part of the green economy focused on waste management, waste prevention, and resource efficiency. GE extends these aspects to human well-being and ecosystem resilience. The core element of CE is to bring back into production any end-of-life (EoL) products that up until now were destined for landfills [2]. Another important aspect of the CE concept is that it has two parts: "circular", which emphasizes the technical cycle of materials and "economy", which offers new opportunities and trends for the economy and society [3]. Some authors believe that through reducing material flows and utilizing renewable energy sources, CE helps an economy transition from linear to circular thinking [4,5]. Within this framework, the development of renewables is helpful in decarbonizing the energy system [6], but the EoL of these products must also be designed [7].

The REPowerEU plan aims to reduce dependence on Russian fossil fuels and accelerate the green transition (economy). It concerns energy efficiency, diversification of energy supply and faster deployment of renewable energy to replace fossil fuels in homes and industry. It proposes to increase the 2030 headline target for renewables from 40% to 45% as part of the "Fit for 55 package". The goal is to reduce net greenhouse gas emissions by at least 55% by 2030 from 1990 levels, and

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energy production and use are responsible for 75% of EU emissions. This push for renewables does not conflict with the classification of gas and nuclear as transitional activities contributing to climate change mitigation since renewables are clearly not currently able to meet energy demand. The development of renewables promotes ecological transition [8–10] and diagnosis of PV systems is verified with machine learning and deep leaning methods [11]. Regulation and energy community are thought to be the most significant categories in this ecological transformation [12].

To support the energy transition, new concepts are included in the 2019 European Clean Energy Package, such as individual self-consumption, collective self-consumption (CSC), renewable energy communities (RECs) and citizen energy communities (CECs) [13]. Collective self-consumption schemes have the key property of constituting a distinct activity without expressly focusing on the organizational format. Energy communities, on the other hand, place a lot more emphasis on organizational and market issues [14]. The term CSC refers to "jointly acting renewables self-consumers (RSC)" which are defined as having at least two RSCs "who are located in the same building or multi-apartment block". On the other side, energy communities group a variety of actors who are capable of self-producing energy through PV systems nearby, though not always put on the same building [14].

The topic of energy communities is gaining an increasing role in the literature. There has been a shift in particular away from a concept of community understood as a process that emphasizes participatory aspects and toward a concept of community that primarily refers to a place. Furthermore, there is a growing emphasis on economic objectives rather than social or political goals in communities [15]. However, while financial incentives are the main elements in encouraging participation, they are also not the decisive objectives. Indeed, a mix of social, economic, technical and environmental motivations are triggered [16]. However, savings are shown on the overall community bill compared to the scenario in which members are not organized as a community [17]. Community planning and capacity, environmental protection, grid access and payment-based are the four main categories of governmental measures created to assist community energy [18].

The main energy change is the transformation from central to decentralized systems. The role of energy storage systems is critical to the development of decentralized models [19,20]. The energy transition and decentralized energy system has focused attention on two concepts: i) "energy democracy" and ii) "energy citizenship." The latter tends to focus on individuals as agents of change, while the former on institutionalizing new forms of participatory governance in which collectives are the agents of change [21]. In this scenario, the role of the prosumer becomes strategic [22,23]. When prosumers can sell energy, as opposed to when they can only try to maximize their own consumption, communal autarky is slightly higher [24]. Three types of prosumers, defined as active market participants, are identified: i) single prosumer; ii) aggregated multiple prosumers; and iii) energy community with possibility of peer-to-peer trading [25]. The development of prosumers can be severely constrained by regulation [26]. Different policy programs and funding policies highlight how the development of sustainable communities is closely related to the choices of policy makers. In some scenarios, households do not invest in solar because they consider political risks more critical than market risks [27]. Some works point out that no additional tools are needed for residential prosumers [28], while others point out that they are important for the implementation of photovoltaic (PV) systems [29]. The benefits of these systems increase at high electricity prices [30]. This perspective is complemented by social analyses according to which the main enabling factor for being a prosumer is monetary [31], while in others it is pointed out that awareness and personal and social norms have equal weight [32]. In addition, PV systems stimulate green electrical and thermal energy [33]. Subsidies for energy produced and self-consumed could be useful in this perspective [31], and in mature markets the use of the subsidized tax deduction is considered [34,35]. Economic analyses are critical in providing judgment to stakeholders, and Net Present Value (NPV) is critical in assessing global ecosystem services [36]. Similarly, break-even point (BEP) analyses allow monitoring the key role to the share of self-consumed energy [37], which affects the profitability of a PV plant.

A record-breaking 175 GW of newly installed PV capacity was added in 2021, bringing the total historical value to 942 GW. With 54.9 GW, China dominated the world in newly installed PV capacity in 2021, followed by the United States (26.9 GW) and the European Union (26.8 GW) [38]. In Europe, Germany is the leading country (5th globally), followed by Italy placed 7th globally analysing the cumulative value. Italy is a mature market favored by attractive solar conditions in which installed capacity in recent stalls. The literature pays attention to this country as a case study [39,40].

The comparison of residents' motivations to participate in RECs is not the same in different innovation segments. In fact, attitudes toward behavior and altruism characterize the willingness of "early adopters," the perceived behavior control the willingness of "mid-term adopters," and the subjective norms and community identity the willingness of "later adopters" [41]. CSC is an approach for better energy management in which human activity is the focus of electricity consumption [42].

The literature has shown that economic models for evaluating CSCs tend to be deficient, and this aspect is critical [37]. Indeed, if the profitability of PV systems is tested, the goal is to assess how the profits will be distributed. In this context, an approach based on the concept of sustainable communities that sees citizens involved in the green transition is also essential [37,43,44]. This study continues in this research direction and proposes an economic analysis related to a sustainable community, and specifically an analysis related to the SCC scenario in Italy. This work is conducted with NPV and BEP, and the baseline analysis will be complemented by a sensitivity, scenario and risk analysis in which the main critical variables of a PV system will be varied (investment costs, energy selling price, avoided cost in the bill, insolation levels, value of the tax deduction, CSC incentive). The analysis will evaluate different policy scenarios and then considerations will be proposed that can be extended to other geographic contexts. In addition, it will be highlighted that sustainable communities can support the development of both GE and CE concepts.

2. Materials and methods

2.1. Italian framework

In accordance with Article 42-bis, Paragraph 9 of Decree-Law No. 162/2019 (referred to as Milleproroghe), transformed by Law No. 8/2020, the Ministerial Decree of September 16, 2020, specifies the subsidy for the compensation of renewable plants included in the experimental configurations of CSC and RECs. This Decree puts the RED II into practice. Self-consumed energy is priced at 100 € per MWh for CSCs and 110 € per MWh for RECs. The 20-year-long incentive can be paired with the Revival Decree's 110% tax reduction. The restriction applies to plants with an output of little more than 200 kW.

The Revival Decree also stipulates that the deduction is divided over 5 years, instead of 10 years, and the energy produced and not self-consumed is sold to the state at a zero price. Subsequent modifications also led to analyzing values other than the null value. This measure covers a maximum size of 20 kW. Prior to this decree, a 50% tax deduction was used compared to the basic one set at 36%. Decree FER1, also known as D.M. July 04, 2019, is another instrument in use in Italy that offers subsidies for electricity generated and fed into the grid. The value of the subsidies varies depending on the size of the plant, with 105 €/MWh paid for installations between 20 and 100 kW for a 20-year term. It provides also a bonus of 10 €/MWh for energy produced and self-consumed, if it exceeds 40%.

2.2. The identification of scenarios

This work provides a mix of scenarios in order to provide economic assessments and policy implications. The literature on energy gives attention to this aspect [45,46]. With regard to the PV system, three distinct scenarios are considered:

- Scenario "Tax D 50% + S(CSC) 100 €/MWh", in which there is 50% subsidized tax deduction with subsidy associated to CSC equal to 100 €/MWh.
- Scenario "Tax D 50% + S(CSC) 100 €/MWh for 5y", in which there is 50% subsidized tax deduction with subsidy associated to CSC equal to 100 €/MWh with a repeated reduction of 20 €/MWh after 5 years.
- Scenario "Tax D 36% + S(CSC) 100 €/MWh", in which there is 36% tax deduction with subsidy associated to CSC equal to 100 €/MWh.

The first scenario is the baseline scenario in effect at present, if the Revival Decree that will expire at the end of 2022 is not used. Two alternative scenarios are then proposed, in which either the value of the tax deduction or the value of the subsidy is affected. Both are not provided for in the current rules, but they may be feasible scenarios and thus to be evaluated for future choices. Then present and future scenarios are considered based on policy directions that could be implemented by intervening on specific components of policy instruments in order to measure how prosumer profitability changes.

Once the gain obtained from a PV system has been defined, it is necessary to define how it is divided among the RSCs and any third parties. Two business models can be configured in a CSC scheme. The first concerns that the energy produced by a PV system can be owned by a third party (independent of prosumers), who sells the energy produced on-site to self-consumers and the remainder to the grid. Self-consumption economic gains are divided up between partners in accordance with contracts. The second regards that the prosumer owns all the energy produced by the plant, and several ways can be adopted for sharing the economic benefits among the participants. Important in this model is the presence of a third party called upon to manage both the operation of the plant and its cash flows. Where it is not necessary to use this figure, because carried out by one of the RSCs or in turn, obviously part of the profit should not be allocated to a possible external party or the condominium administrator.

This work considers that all RSCs contribute equally to the initial investment and we do not consider the assumption that the energy is sold to the grid, since the goal of a CSC should be to foster the development of decentralized systems and sustainable communities. We then consider a scenario in which a portion of the energy produced is self-consumed collectively, while the remainder is sold to the grid. Three possible scenarios are identified according to literature [37]:

- Scenario "revenues split equally", in which benefits are divided equally among RSCs independently of their energy consumption profile.
- Scenario "revenues shared entirely according to energy consumption profile", in which benefits are divided among RSCs according to their energy consumption. This scenario thus tends to reward users who make greater use of energy self-consumption.
- Scenario "revenues shared according to a partial energy consumption profile", in which benefits consider only a part of the self-consumed energy. In fact, an intermediate mechanism between the two highlighted above is triggered by means of an exchange price. This price stipulates that those who self-consume more than the average will pay that price to another RSC and it should be lower than what they pay to the grid. On the other hand, as for those who self-consume less, they will have to buy energy from another RSC and pay them an exchange price, which obviously should be lower than what they pay to the grid. A "win-win" situation can be created in such an equilibrium context.

Regarding the last scenario, trading algorithms could also be proposed to define the wholesale market of energy communities [47]. The presence of a battery requires considering multi-level models that can consider the different agents present but also the related systems [42].

2.3. Economic model

The discounted cash flow (DCF) methodology evaluates a project's viability purely on its cash inflows and outflows, which are calculated incrementally and combined using a discount rate [48]. The BEP determines the value of the important variable at which profitability occurs, and NPV is a frequently used indication of the profitability of PV systems [35,49].

The economic model used in this work consists of two parts. The profitability of a PV plant is as proposed in a mathematical model proposed in the literature [37], while a new model is developed to also calculate the distribution of benefits among RSCs. Relative to the profitability of a PV plant, the following revenue items must be considered:

- tax deductions, taken into account in their subsidized forms;
- subsidies associated with collective self-consumption;
- avoided energy costs, shown by the electricity purchase price (i.e., a negative cost, read as income);
- sale of energy that was not used for self-consumption.

Operating costs were typically low among the things that accounted for cash outflows, while investment costs were the main item. It was thought that the inverter would need to be replaced after ten years. The model used in this work is presented below and can be replicable in other contexts. Equations (1)–(7) are used to evaluate the profitability of a PV plant.

$$\mathrm{NPV} = \sum_{t=0}^{N} (\mathrm{CI} - \mathrm{CO}) / (1 + r)^{t} = \mathrm{DCI} - \mathrm{DCO} \tag{1}$$

$$\mathrm{DCI} = \sum_{t=1}^{N} \left(\omega_{self,c} \times E_{Out,t} \times p_t^c + \left(1 - \omega_{self,c}\right) \times E_{Out,t} \times p_t^s + \omega_{self,c} \times E_{Out,t} \times S_{scc}^u\right) / (1 + r)^t + \sum_{t=1}^{N_{TaxD}} \left(\left(C_{inv} / N_{TaxD}\right) \times TaxD_u\right) / (1 + r)^t \tag{2}$$

$$E_{Out,t} = t_r \times K_f \times \eta_m \times \eta_{bos} \times A_{cell} \times S \tag{3}$$

$$E_{out,t+1} = E_{out,t} * (1 - dE_f) \tag{4}$$

$$p^c_{t+1} = p^c_t \times (1 + inf_{el}) \tag{5}$$

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

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

in which CI = cash inflow, CO = cash outflow, DCI = discounted cash inflow, DCO = discounted cash outlow, t = period time, C_{lcs} = loan capital share cost, C_{inv} = investment cost, and E_{Out} = energy produced by the PV system.

The equations 8-27 are used to evaluate the distribution of profits among RSCs. The model is distinct according to the RSC scenario. We consider for scenario "revenues split equally":

$$NPV_{RSCj} = \frac{NPV}{N_{RSC}} \text{ with } j = 1 \ldots N_{RSC} \tag{8}$$

in which NPV_{RSCj} = NPV associated with j RSC; N_{RSC} = number of RSC. We consider for scenario "revenues shared entirely according to energy consumption profile":

$$E_{pj} = \frac{E_{out}}{N_{RSC}} \tag{9}$$

$$E_{SCj} = E_{pj} \times \omega_{selfj} \tag{10}$$

$$E_{NSCj} = E_{pj} - E_{SCj} \tag{11)a}$$

$$S_{billj} = E_{SCj} \times p^c \tag{11)b}$$

$$S_{earj} = E_{NSCj} \times p^s \tag{12}$$

$$OB_j = S_{billj} + S_{earj} \tag{13}$$

$$OB_{TOT} = \sum_{j=1}^{N_{RSC}} OB_j \tag{14}$$

$$PD_{OVj} = \frac{OB_j}{OB_{tot}} \tag{15}$$

$$NPV_{RSCj} = NPV \times PD_{OVj} \text{ with } j = 1 \ldots N_{RSC} \tag{16}$$

in which E_p = energy produced by each RSC; E_{SC} = energy self-consumed by each RSC; E_{NSC} = energy not self-consumed by each RSC; S_{bill} = savings bill of each RSC; S_{ear} = earnings from sale of each RSC; OB_j = overall benefits of each RSC; OB_{tot} = overall benefits; PD_{OV} = percentage benefits of each RSC NPV_{RSCj} = NPV associated with j RSC; N_{RSC} = number of RSC. We consider for scenario "revenues shared according to a partial energy consumption profile":

$$\overline{\omega}_{selfj} = \frac{\sum_{j=1}^{N_{RSC}} \omega_{selfj}}{N_{RSC}} \tag{17}$$

$$E_{pj} = \frac{E_{out}}{N_{RSC}} \tag{18}$$

$$E_{PSCj} = E_{pj} \times \min\left[\overline{\omega}_{selfj};\ \omega_{selfj}\right] \tag{19}$$

$$E_{PNSCj} = E_{pj} \times \min\left[\overline{\omega}_{selfj};\ 1 - \omega_{selfj}\right] \tag{20}$$

$$S_{SCj} = E_{PSCj} \times p^c \tag{21}$$

$$S_{Netj} = E_{PNSCj} \times p^s \tag{22}$$

$$S_{EXj} = \left(E_{pj} - E_{PSCj} - E_{PNSCj}\right) \times p^{ex} \tag{23}$$

$$OB_j = S_{SCj} + S_{Netj} + S_{EXj} \tag{24}$$

$$OB_{tot} = \sum_{j=1}^{N_{RSC}} OB_j \tag{25}$$

$$PD_{OVj} = \frac{OB_j}{OB_{tot}} \tag{26}$$

$$NPV_{RSCj} = NPV \times PD_{OVj} \text{ with } j = 1 \ldots N_{RSC} \tag{27}$$

in which $\overline{\omega}_{selfj}$ = average self-consumption value; E_p = energy produced by each RSC; Ep_{SC} = partial energy self-consumed by each RSC; E_{PNSC} = partial energy not self-consumed by each RSC; S_{SC} = savings from self-consumed energy by each RSC; S_{Net} = sale of energy produced and not self-consumed to the grid of each RSC; S_{EX} = economic savings associated with the exchange between RSCs; p^{ex} = price exchange; OB_j = overall benefits of each RSC; OB_{tot} = overall benefits; PD_{OV} = percentage benefits of each RSC; NPV_{RSCj} = NPV associated with j RSC; N_{RSC} = number of RSC.

2.4. Input data

From the political-economic scenarios proposed in section 2.2, the next goal is to populate the equations given in section 2.3. The plant size considered in this work is 20 kW that might be suitable to meet the needs of a multi-apartment block consisting of four households. The space it would occupy is that of the roof of such a dwelling and if necessary other spaces used for car parking. Thus, no additional land occupation is made. Each household will represent one RSC and thus the total number of RSCs considered in this work is four. The plant is located in central Italy with an intermediate level of insolation. The energy production level is 38,996 kWh in the first year and decreases to 33,477 kWh in the 20th year. Third parties cover the investment. Within the DCF model, there is a plant time horizon set at 20 years [50] and an opportunity cost of capital of 5% [35].

Section 1 showed that the percentage of self-consumption plays a key role in assessing the profitability of a PV system, and therefore scenarios ranging from 0% to 100% are considered. Scenarios with low percentages, particularly 0%, tend to be unrealistic in a residential context. However, it is calculated since it is mathematically useful. In addition, it is worth pointing out that energy changes are leading to large variations

Table 1
Economic inputs [35,37,50–54].

Acronym	Variable	Value
A_{cell}	Active surface	7 m^2/kWp
C_{ae}	Administrative/electrical connection cost	1000 €
$C_{inv,\ unit}$	Unitary investment cost	2000 €/kW
dE_f	Decreased system efficiency	0.8%
inf	Rate of inflation	3%
inf_{el}	Rate of energy inflation	3%
k_f	Optimum tilt angle	1.13
N	PV system lifetime	20 years
N_{debt}	Loan period	10 years
N_{TaxD}	Deduction period	10 years
η_{bos}	Balance of system efficiency	85%
η_m	Module efficiency	20%
p^c	Electricity purchase price	250-400 €/MWh
P_{Cass}	Percentage of assurance cost	1%
P_{Ci}	Percentage of inverter cost	15%
P_{Cm}	Percentage of maintenance cost	2%
P_{Ctax}	Percentage of taxes cost	27.5%
p^{ex}	Exchange price	180-320 €/MWh
p^s	Electricity selling price	120-240 €/MWh
r	Opportunity cost of capital	5%
r_d	Loan interest rate	3%
S	Plant size	20 kW
S^u_{scc}	Unitary subsidy CSS	100 €/MWh
t_r	Average annual insolation	1450 kWh/m^2 × y
$TaxD_u$	Unitary tax deduction	36–50%
Vat	Value added tax	10%
$\omega_{self,c}$	Percentage of self-consumed energy	0-10-20-30-40-50-60-70-80-90-100%

in electricity prices. It was thus decided to consider two distinct market scenarios:

- Scenario "pc 250 €/MWh and ps 120 €/MWh", in which avoided energy costs are equal to 250 €/MWh and electricity selling price are equal to 120 €/MWh.
- Scenario "pc 400 €/MWh and ps 240 €/MWh", in which avoided energy costs are equal to 400 €/MWh and electricity selling price are equal to 240 €/MWh.

It should be noted that averages of data collected from consumers and the energy service provider's website were considered for the choices of the values of these two variables. It was assumed that they are related to each other, in a scenario where sustainable communities are favored by energy purchase prices that are more advantageous than sales prices. As for the exchange price, an average value between electricity purchase price and electricity selling price was considered. Thus, the two values chosen are 180 €/MWh e 320 €/MWh for the scenario "pc 250 €/MWh and ps 120 €/MWh" and "pc 400 €/MWh and ps 240 €/MWh", respectively. The choice of prices attempts to capture a wide price variability that has come with the energy shock that has affected Europe following the conflict in Ukraine. There have been even higher values than those examined in this paper, but the values considered seem to be the most appropriate to describe reliable future scenarios. All input data are reported in Table 1 and the assumed materials were monocrystalline for PV plants.

3. Results

This section presents the profitability of a PV plant in the baseline case (section 3.1) and alternative (section 3.2) scenarios. From these values, some application examples on the distribution of benefits among RSCs are then proposed (section 3.3). Finally, section 3.4 proposes the role of energy communities towards green and circular principles.

3.1. Profitability analysis of PV plants – baseline scenarios

Starting from the economic model given in Equations (1)–(7) and the input data provided in Table 1, it is possible to calculate how NPV varies under multiple scenarios considering the percentage of self-consumption as a critical variable. The number of case studies analyzed is sixty-six related to the eleven possible values of self-consumption, the two market scenarios, and the three policy scenarios. Fig. 1a-c shows the NPV values in the base model (specific values are shown in Tables A1-A3).

The results show great variation confirming how the percentage of self-consumption significantly influences the indicator. Profitability is verified in all scenarios except for scenarios where all energy is sold to the grid and purchase and selling prices are low.

The BEP analyses confirm this result. Thus they turn out to be 0% for all "pc 400 €/MWh and ps 240 €/MWh" scenarios, while for "pc 250 €/MWh and ps 120 €/MWh" scenarios they have a value of 4–6% (Table A4). There are reductions compared to the same 20 kW plant analyzed in a previous work [37], since a higher selling price is considered and this inevitably brings more convenience to sell the energy to the grid. However, this concept should not be read in such a way that it does not favor self-consumption since in both market scenarios analyzed the purchase price always turns out to be significantly larger than the sale price. Thus, we are in a market condition in which the kWh produced if self-consumed produces greater economic wealth. This condition is essential to foster decentralized models and push plants to be self-sufficient. We can also calculate the Levelized Cost of Electricity (LCOE) of 94 €/MWh which is in line with the values of utility-scale

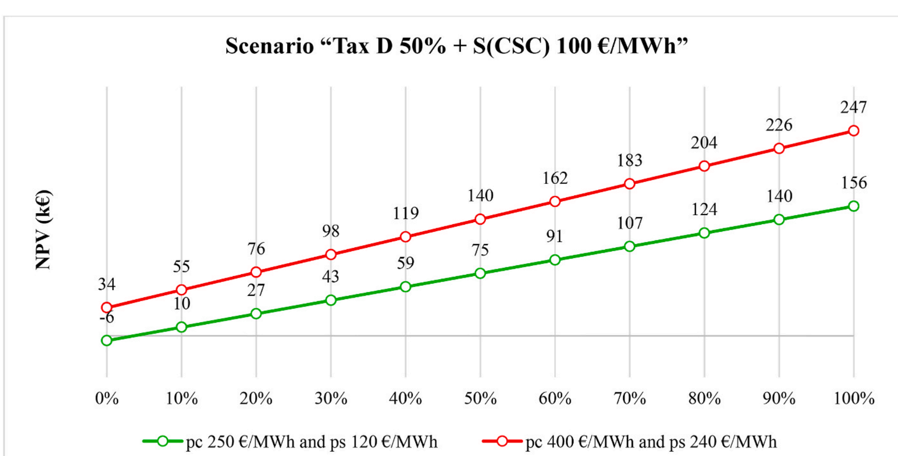


Fig. 1a. NPV (thousand €). Baseline scenario – scenario tax D 50% + S(CSC) 100 €/MWh.

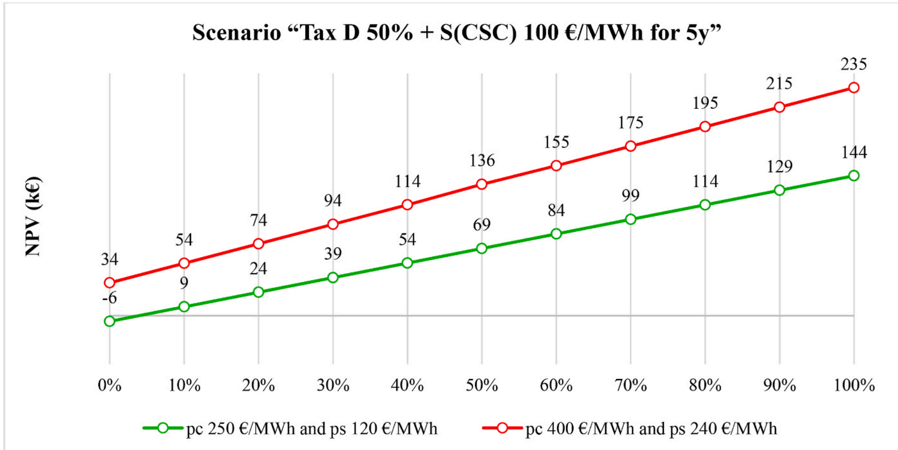


Fig. 1b. NPV (thousand €). Baseline scenario – scenario tax D 50% + S(CSC) 100 €/MWh for 5y.

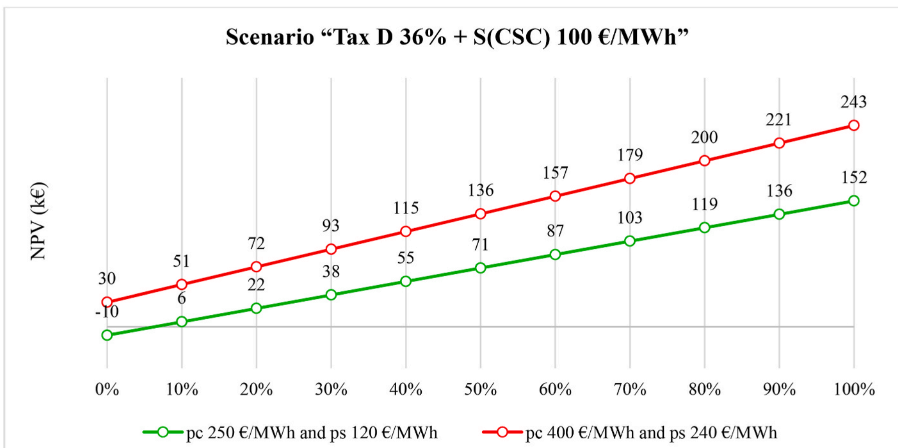


Fig. 1c. NPV (thousand €). Baseline scenario - scenario tax D 36% + S(CSC) 100 €/MWh.

plants [55]. Thus, it is confirmed that the competitiveness of PV systems has significantly increased over time. LCOE is strongly influenced on investment costs and therefore on this the Revival Decree policies have evidently influenced a non-reduction of these costs.

The literature has highlighted the most likely self-consumption values in residential settings: 30%, 40%, 50% [35,53,56,57] or 60% [31]. The NPV value ranges from 2136 to 8084 €/kW in the "TaxD 50% + S(CSS) 100 €/MWh" scenario, which is much more significant than 892–2439 €/kW [37]. This result is also explained by soaring energy costs. Owners of PV systems stand to gain more profit as they save a much higher cost in their bills and if they sell the non-self-consumed energy to the grid they could get a higher price. At this point it is necessary to start comparing the different scenarios.

The first consideration concerns the comparison where the value of the tax deduction is changed and a value of 36% is used resulting in a reduction of the NPV of 216 €/kW. Because the deduction is linked to the investment cost, the reduction in NPV does not vary under different market scenarios or as the percentage of self-consumption changes. The second consideration concerns the scenario in which the 50% tax deduction is kept fixed, but a reduction in the subsidy is applied every 5 years. Since the subsidy is linked to the percentage of self-consumption, there is a variation of 175 €/kW and 350 €/kW for 30% and 60% self-consumption, respectively. Instead, they do not vary according to market conditions since only the incentive variable is changed. Both of these results were expected given the assumed policy structure, but they allow the legislature to have future scenarios. In fact, the approach through which the value of public support for renewables tends to decline over time is considered. However, there is a thought-provoking fact: as long as the percentage of self-consumption is 30%, the "Tax D 36% + S(CSC) 100 €/MWh" scenario has a higher NPV than the "Tax D 50% + S(CSC) 100 €/MWh for 5y" scenario, while at 40% we have the opposite situation. Thus the subsidy that reduces by 20 €/MWh every 5 years on self-consumed energy results in a greater reduction in profitability than the tax deduction at 36% compared to 50% as the percentage of energy-self-consumed increases.

Shifting the focus from policy scenarios to market scenarios, we can point out that an energy scenario in which prices rise favors those who have built a renewable plant or who will build one if such an increase continues. However, this should be monitored in terms of social economics, as it should not penalize the less affluent who cannot afford to install a renewable system. This comparison clearly motivates why the results of this work based on very recent data are different from those found in the literature: the "pc 250 €/MWh and ps 120 €/MWh" scenario presents a reduction in NPV of 2753–3519 €/kW compared to the "pc 400 €/MWh and ps 240 €/MWh" scenario. Evidently as the percentage of self-consumption increases, the change becomes more significant.

The final consideration concerning the evaluation of the baseline scenario is that of the key variable. Indeed, we can measure how NPV varies as the percentage of self-consumption changes. A 10% increase results in a NPV that increases by 810 and 1065 €/kW in the two market scenarios. The tax deduction has no influence on the changes associated with the percentage of self-consumption, so there are different NPVs only in the policy scenario in which the subsidy associated with the CSC is expected to be reduced over time. These increases are 751 and 1007 €/kW in the two market scenarios. Clearly, the incremental delta increases at the cost saved in the bill.

The results that emerged from this work can be compared with the 20 kW size analyzed in literature in the basic scenarios: 2802 €/kW [58], 2123 €/kW [59] and 424 €/kW [60]. The need to also consider alternative scenarios is highlighted: 3022 €/kW [59] and 2284 €/kW [60]. Values that are more significant are also recorded up to 3000–5500 €/kW [61]. These scenarios show low values in the absence of subsidies and with low self-consumption rates. In the presence of the Feed in Tariff scheme, values as high as 3300 €/kW were also recorded [62] and recent analyses propose values 98–1967 €/kW with a 110% tax deduction [35]. However, the subsidies provided for residential PV because of funds provided with the pandemic recovery did not only affect Italy [63]. The issue of self-consumption and policy intervention with the effects on consumers are considered key [31,64]. Economic analyses on energy communities are not yet much in the literature as highlighted in section 1. Other works point to profits that can be as high as 700–1400 k€ [65] and 50–1174 k€ [66]. Italian residential users using a CSC can achieve financial savings of up to 32% [44].

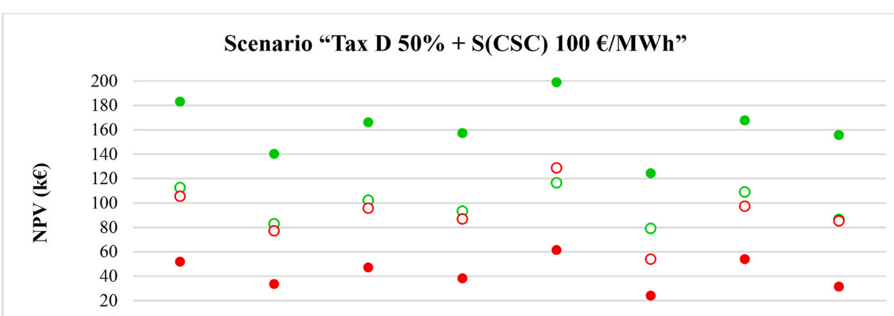
3.2. *Profitability analysis of PV plants – alternative scenarios*

The economic study of the baseline scenario in the previous subsection focused mainly on variations in the percentage of self-consumption. Here, we go over the analysis based on changes to the key variables. The objective of the alternative scenarios is to evaluate how profitability changes as a function of their variation. It is intended to emphasize that in sensitivity analysis there is change in only one variable, in scenario analysis there is change in several variables, and in risk analysis, there is change in several variables with the assignment of a probability of occurrence. The value of the tax deduction and the value of the CSC subsidy is already made to vary in the policy scenarios, the same could be said for the market scenarios. However, these two variables tend to vary very easily over time, while typically policy directions have stability over time. For this reason, both are considered. In both cases an increase in them results in an optimistic scenario. Both a pessimistic and an optimistic scenario are considered for all variables (Table A5). Relative to the change in the purchase price a value of 100 €/MWh is considered, and for the selling price a value of 50 €/MWh. The third variable involved in the analysis is investment costs, which are the main cost component. A variation of 200 €/kW is considered whereas this component increases, there is a pessimistic scenario. Finally, the fourth variable is technical in nature and is represented by the different level of insolation that characterizes Italy. Values are therefore chosen that also represent the northern and southern zones and the variation is 150 kWh/m^2 × y. Clearly, the higher insolation conditions result in an optimistic scenario. The choice of variables and their variations is also taken in accordance with the literature [37,67,68]. Additionally, the analysis was limited to a share of self-consumption between 30 and 60%. Fig. 2a-c shows the NPV values in the sensitivity analysis (specific values are shown in Tables A6-A8).

The results confirm the profitability of the PV plant, which is found to have a positive value in all scenarios considered in the sensitivity analysis. The variations are very significant: 1202–9952 €/kW for "Tax D 50% + S(CSC) 100 €/MWh" scenario, 1027–8884 €/kW for "Tax D 50% + S(CSC) 100 €/MWh for 5y" scenario and 954–9736 €/kW for "Tax D 36% + S(CSC) 100 €/MWh" scenario. It is worth noting that these extremes are always associated with the change in purchase price considering the scenario of self-consumption at 60% with purchase price at 500 €/MWh in the optimistic version, while in the pessimistic version self-consumption at 30% and purchase price at 150 €/MWh. The comparison with the variables cannot be done in a complete way since different ranges of variation are considered, as we chose to consider the real-life applicability that these values might have. The purchase price is greater than the selling price so its variation has a greater effect that is amplified as the percentage of self-consumption increases. The same is manifested by the level of solar insolation, which results in a greater amount of energy produced and thus greater opportunities for economic gain. Investment costs have experienced a peculiar market phenomenon during this period, but probably explainable by the Revival Decree. In fact, in scenarios where the focus is on a higher tax deduction, provided there is fiscal capacity, investment costs may not follow a reduction.

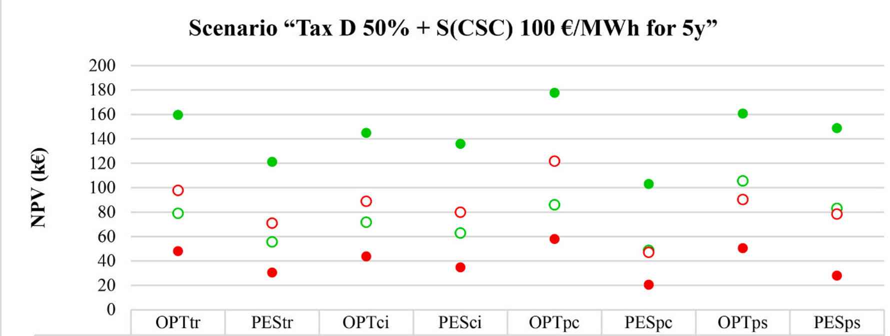
The results proposed so far are affected by the variation of only one of these variables. In order to get a more complete view, a scenario analysis was conducted in which all four variables are made to vary simultaneously. Fig. 3 show the NPV values in the sensitivity analysis (specific values are shown in Tables A9).

The scenario analysis highlights the possibility that the profitability condition may not be verified. However, it is restricted to only two scenarios, in which the percentage of self-consumption is at 30%, the simultaneous change in the four critical variables is negative, the market scenario is the reduced-value scenario (MS2 with pc 250 €/MWh and ps 120 €/MWh), but it occurs in only two of the three policy scenarios analyzed. In fact, in the "Tax D 50% + S(CSC) 100 €/MWh" scenario, the NPV is 114 €/kW. In contrast, the maximum NPV is 11,770 €/kW, and yet in all six optimistic scenarios related to the higher-value market



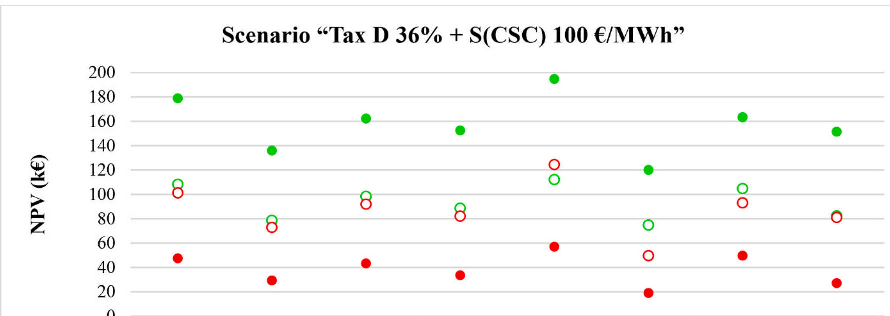
	OPTtr	PEStr	OPTci	PESci	OPTpc	PESpc	OPTps	PESps
30% MS1	113	83	102	93	116	79	109	86
60% MS1	183	140	166	157	199	124	168	156
30% MS2	52	34	47	38	61	24	54	31
60% MS2	105	77	96	87	129	54	97	85

Fig. 2a. NPV (thousand €). Sensitivity Analysis - Scenario Tax D 50% + S(CSC) 100 €/MWh. The following acronyms are used: OPT = optimistic; PES = pessimistic; tr = level of insolation; ci = investment cost; pc = purchase price; ps = selling price; MS1 = market scenario 1 (pc 400 €/MWh and ps 240 €/MWh); MS2 = market scenario 2 (pc 250 €/MWh and ps 120 €/MWh).



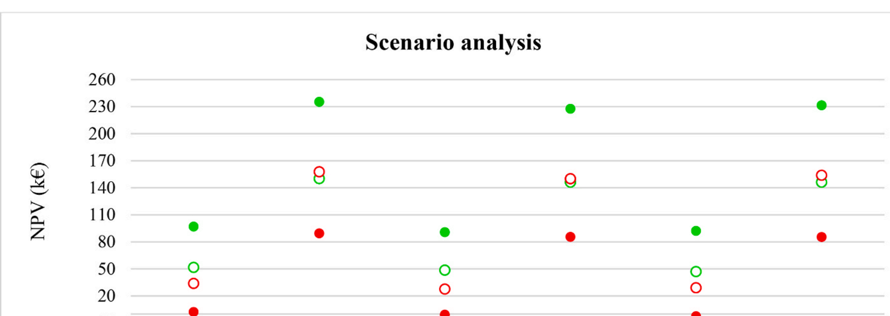
	OPTtr	PEStr	OPTci	PESci	OPTpc	PESpc	OPTps	PESps
30% MS1	79	56	72	63	86	49	106	83
60% MS1	160	121	145	136	178	103	161	149
30% MS2	48	30	44	35	58	21	50	28
60% MS2	98	71	89	80	122	47	90	78

Fig. 2b. NPV (thousand €). Sensitivity Analysis - Scenario Tax D 50% + S(CSC) 100 €/MWh for 5y. The following acronyms are used: OPT = optimistic; PES = pessimistic; tr = level of insolation; ci = investment cost; pc = purchase price; ps = selling price; MS1 = market scenario 1 (pc 400 €/MWh and ps 240 €/MWh); MS2 = market scenario 2 (pc 250 €/MWh and ps 120 €/MWh).



	OPTtr	PEStr	OPTci	PESci	OPTpc	PESpc	OPTps	PESps
30% MS1	108	79	98	89	112	75	105	82
60% MS1	179	136	162	152	195	120	163	151
30% MS2	48	29	43	33	57	19	50	27
60% MS2	101	73	92	82	124	50	93	81

Fig. 2c. NPV (thousand €). Sensitivity Analysis - Scenario Tax D 36% + S(CSC) 100 €/MWh. The following acronyms are used: OPT = optimistic; PES = pessimistic; tr = level of insolation; ci = investment cost; pc = purchase price; ps = selling price; MS1 = market scenario 1 (pc 400 €/MWh and ps 240 €/MWh); MS2 = market scenario 2 (pc 250 €/MWh and ps 120 €/MWh).



	PES - P1	OPT - P1	PES - P2	OPT - P2	PES - P3	OPT - P3
30% MS1	52	150	48	146	47	146
60% MS1	97	235	91	228	92	232
30% MS2	2	89	-1	85	-2	85
60% MS2	34	158	28	150	29	154

Fig. 3. NPV (thousand €). Scenario Analysis. The following acronyms are used: OPT = optimistic; PES = pessimistic; MS1 = market scenario 1 (pc 400 €/MWh and ps 240 €/MWh); MS2 = market scenario 2 (pc 250 €/MWh and ps 120 €/MWh); P1=Scenario "Tax D 50% + S(CSC) 100 €/MWh"; P2=Scenario "Tax D 50% + S(CSC) 100 €/MWh for 5y"; P3=Scenario "Tax D 36% + S(CSC) 100 €/MWh".

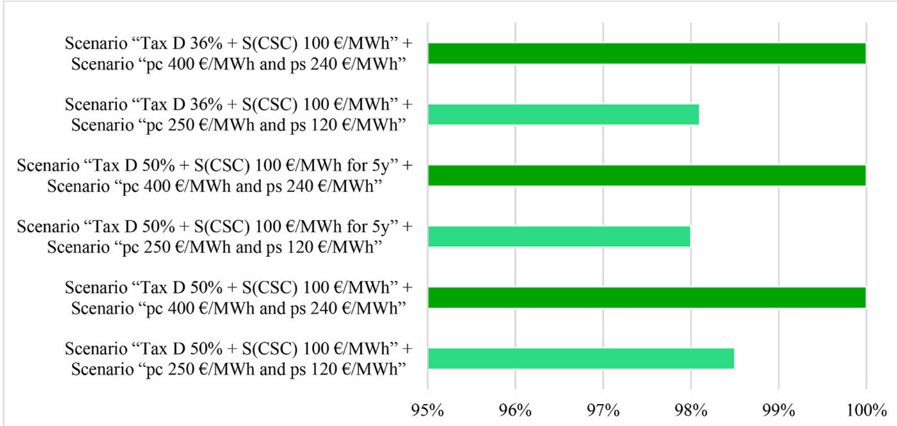


Fig. 4. Probability of having positive NPV. Risk Analysis.

scenario (MS1 with pc 400 €/MWh and ps 240 €/MWh) there is a value above 10,000 €/kW. Thus, this analysis also confirmed how investment in PV can have a large fluctuation in value. The decision maker could be supported in her/his choice by the opportunity to have probabilistic values.

A risk analysis is conducted for this purpose. The cumulative distribution function connected to stochastic variables is utilized in the Monte Carlo approach to assess the risk analysis of a project. The technique is used on 1000 runs of NPV values under different economic circumstances. We have used the following Excel function: =NORM.INV(RAND (mean, standard_dev) and for this analysis we have considered the same critical variables proposed in the previous analysis. The mean is established using the input data, whereas the standard deviation is computed using the range (Table A10). Fig. 4 shows the probability of having a positive NPV under the mix of political and market scenarios. A value at 50% was assumed as the percentage of self-consumption. Figures A1-A6 show the map for each scenario.

The results of this analysis confirm the judgment that had emerged in previous analyses. Profitability is significantly high, and market scenarios leading to higher prices inevitably lead to higher profitability. However, it is significant to show that at the 50% self-consumption rate there is an investment that certainly shows a positive NPV. All three scenarios have a probability equal to 100%. Instead, in the scenario where prices are more moderate, however, values ranges between 98.0 and 98.5%.

Table 2
Distribution of benefits - scenario "revenues shared entirely according to energy consumption profile".

	RSC1	RSC2	RSC3	RSC4	Total
Energy produced	9749	9749	9749	9749	38,996
Energy self-consumed	6824.3	5849.4	3899.6	2924.7	19,498
Energy not self-consumed	2924.7	3899.6	5849.4	6824.3	19,498
	Scenario "pc 250 €/MWh and ps 120 €/MWh"				
Savings bill	1706	1462	975	731	4874
Earnings from sale	351	468	702	819	2340
Overall benefits	2057	1930	1677	1555	7214
Percentage distribution of benefits	28.5%	26.8%	23.2%	21.6%	100%
	Scenario "pc 400 €/MWh and ps 240 €/MWh"				
Savings bill	2730	2340	1560	1170	7799
Earnings from sale	702	936	1404	1633	4680
Overall benefits	3432	3276	2964	2808	12,479
Percentage distribution of benefits	27.5%	26.2%	23.7%	22.5%	100%

3.3. *Profitability of renewables self-consumers in a collective self-consumption scheme*

The second part of the work is aimed at showing how the benefits obtained from a PV system can be distributed. Clearly, not all the scenarios proposed earlier can be replicated, so some assumptions must be made. The assumption is that the prosumer consists of four RSCs and they are entitled to distribute among themselves all the benefits they are going to get because of the installation of the PV system. It is assumed that the value of the self-consumption percentage is always set at 50% and that the four RSCs have different consumption profiles (Table A11): rates of 70%, 60%, 40% and 30% are recorded for RSC1, RSC2, RSC3 and RSC4, respectively.

Starting from the results obtained in section 3.1 and considering equations 8-27, we can calculate the benefit split among the different RSCs. The "revenues split equally" scenario is simple since it involves all RSCs having 25%. As for the other two scenarios, which are more realistic than the previous one, some calculations need to be made. In order to allow replicability we proceed to propose step by step the procedure that leads us to obtain the distribution of benefits. Relative to the "revenues shared entirely according to energy consumption profile" scenario, we start from the total energy produced equal to 38,996 kWh and are divided according to its wire. For example, RSC1 which has a

Table 3
Distribution of benefits - scenario "revenues shared entirely according to energy consumption profile".

	RSC1	RSC2	RSC3	RSC4	Total
Energy produced	9749	9749	9749	9749	38,996
Energy self-consumed	6824.3	5849.4	3899.6	2924.7	19,498
Energy not self-consumed	2924.7	3899.6	5849.4	6824.3	19,498
Partial energy self-consumed	4874.5	4874.5	3899.6	2924.7	16,573.3
Partial energy not self-consumed	2924.7	3899.6	4874.5	4874.5	16,573.3
Exchange energy	1949.8	974.9	974.9	1949.8	5849.4
	Scenario "pc 250 €/MWh and ps 120 €/MWh"				
Savings bill	1219	1219	975	731	4143
Earnings from sale	351	468	585	585	1989
Economics exchange	351	175	175	351	1053
Overall benefits	1921	1862	1735	1667	7185
Percentage distribution of benefits	26.7%	25.9%	24.1%	23.2%	100%
	Scenario "pc 400 €/MWh and ps 240 €/MWh"				
Savings bill	1950	1950	1560	1170	6629
Earnings from sale	702	936	1170	1170	3978
Economics exchange	624	312	312	624	1872
Overall benefits	3276	3198	3042	2964	12,479
Percentage distribution of benefits	26.3%	25.6%	24.4%	23.8%	100%

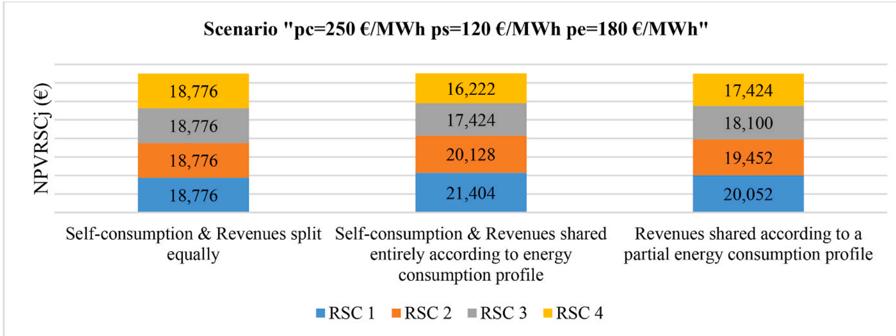


Fig. 5a. NPV distribution among RSCs with 50% self-consumption. Scenario "Tax D 50% + S(CSC) 100 €/MWh" – Scenario "pc = 250 €/MWh ps = 120 €/MWh pe = 180 €/MWh".

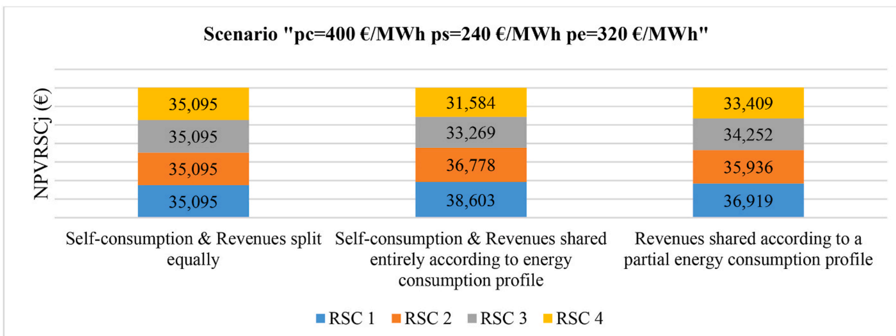


Fig. 5b. NPV distribution among RSCs with 50% self-consumption. Scenario "Tax D 50% + S(CSC) 100 €/MWh" – Scenario "pc = 400 €/MWh ps = 240 €/MWh pe = 320 €/MWh".

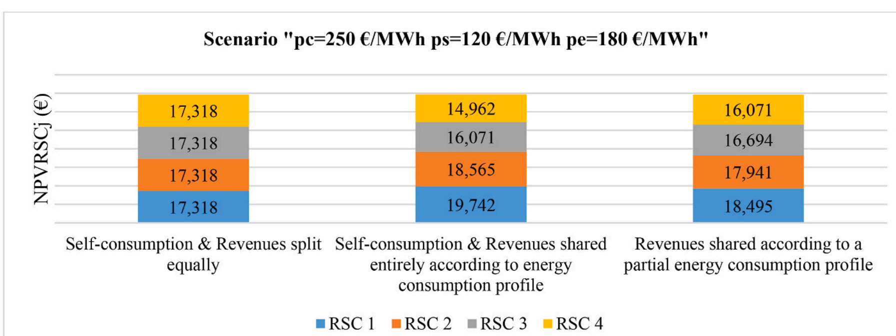


Fig. 6a. NPV distribution among RSCs with 50% self-consumption. Scenario "Tax D 50% + S(CSC) 100 €/MWh for 5y" – Scenario "pc = 250 €/MWh ps = 120 €/MWh pe = 180 €/MWh".

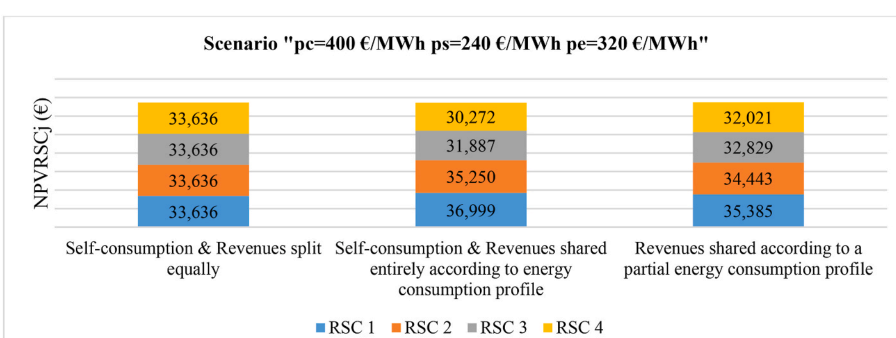


Fig. 6b. NPV distribution among RSCs with 50% self-consumption. Scenario "Tax D 50% + S(CSC) 100 €/MWh for 5y" – Scenario "pc = 400 €/MWh ps = 240 €/MWh pe = 320 €/MWh".

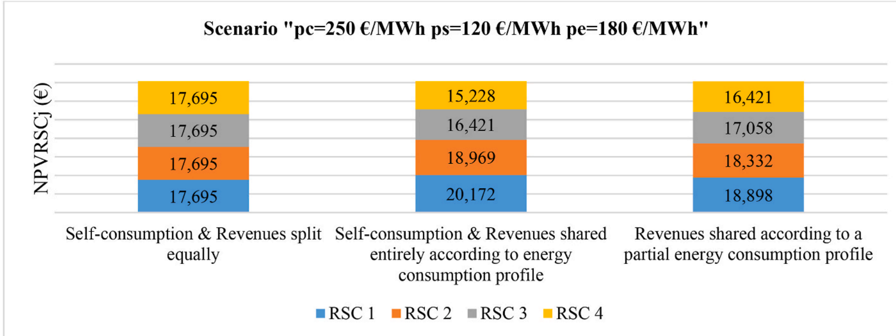


Fig. 7a. NPV distribution among RSCs with 36% self-consumption. Scenario "Tax D 50% + S(CSC) 100 €/MWh" – Scenario "pc = 250 €/MWh ps = 120 €/MWh pe = 180 €/MWh".

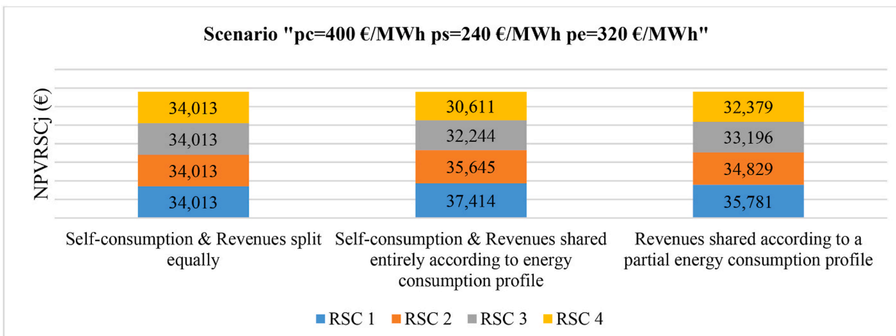


Fig. 7b. NPV distribution among RSCs with 36% self-consumption. Scenario "Tax D 50% + S(CSC) 100 €/MWh" – Scenario "pc = 400 €/MWh ps = 240 €/MWh pe = 320 €/MWh".

self-consumption of 70%, proceeds to self-consume 6824.3 kWh, which leads to a savings of 1706 € or 2730 € depending on whether the purchase price is 250 €/MWh or 400 €/MWh respectively. Similarly, the energy that is not self-consumed is sold to the grid and revenues of 351 € or 702 € are recorded depending on whether the selling price is 120 €/MWh or 240 €/MWh respectively. By summing these two contributions, the specific benefit associated with the individual RSC can be obtained, which can be related to the overall benefit. In the lower price market scenario it is 28.5% while in the higher price market scenario it is 27.5%. Mirroring this, RSC4 which is characterized by 30% self-consumption has a benefit distribution of 21.6% and 22.5% depending on whether the market scenarios involve lower or higher prices, respectively – Table 2.

We now proceed to consider the scenario "revenues shared according to a partial energy consumption profile," in which we expect to have a distribution of benefits that is intermediate between the two values found compared to the other two scenarios. Again, we describe the method with a practical calculation. The difference from the previous scenario is that RSC1 while self-consuming 70% is only entitled to access the purchase price up to 50%. Thus, the avoided bill savings amount to 1219 € and 1950 € in the two market scenarios, respectively. The remaining 30%, on the other hand, is regularly sold to the grid from which revenues of 351 € and 702 € arise. It happens that the remaining 20% of energy RSC1 pays a value quantified by the exchange price. In the setup of our model, an approximately intermediate value between the buy and sell value was identified in a win-win perspective with the other RSCs. For example, RSC4 is entitled for the 30% that it self-consumes to savings of 731 € and 1170 €, respectively; while the energy it sells is divided into two blocks. The maximum value that can equal 50% allows for benefits from sale of 585 € and 1170 €, respectively. The remaining 20% is sold to another RSC by exchange price. Thus, the total value is composed not only of the avoided cost in partial bill and partial energy sale, but also considers the economic contributions related to the exchange. Thus, it can be found that the distribution of benefits sees RSC1 and RSC4 with 26.7% and 23.2% in the low market price scenario respectively; while they are 26.3% and 23.8% in the higher market price scenario – Table 3.

At this point in the work, now that it is known how the percentage of benefits are assigned among the RSCs and the NPV to be divided among them, we can proceed to quantify NPV that is gained by each RSC. Clearly, the assumption is made that the percentage of the self-consumption assigned to each RSC is the average over the lifetime of the plant. Figures 5a-5b-6a-6b-7a-7b show NPV distribution among RSCs.

These results from an economic point of view do not deviate from what was presented in section 3.1, but they do allow us to show how differences between individual RSCs clearly tend to be implicated in market conditions where prices are high. However, it is also worth noting that the variations are not so significant among individual RSCs. This result from a mathematical point of view is motivated by the difference that exists among purchase price, selling price and exchange price. Such values might prompt the observation that the economic component is not so significant for a 20 kW plant, a reason that might reduce potential discussions among RSCs about economic allocation. However, this is an impression; to assert such an analysis, a social analysis should be conducted on the topic. In conclusion, this work compared to the previous research project differs for several reasons. From a methodological point of view, a detailed model for the distribution of benefits is proposed, and from a managerial point of view, new scenarios considering changes in market prices are analyzed. In addition, different policies are evaluated through a profitability analysis for RSCs.

3.4. The contribution of energy communities towards green and circular principles

Energy recovery from waste in CE models is critical to close material and energy cycles [5,69]. The transition to a low carbon economy is mostly driven by increased PV panel capacity. EoL management for PV panels can increase resource usage and recovery effectiveness [70], providing a support to the development of CE models [71]. In addition, incorrect EoL of PV modules can reduce the net environmental benefit associated with solar energy [72].

The combination of CE models and renewables supports the mitigation of carbon emissions [73]. However, the salient aspect that emerges and is overlooked in the literature is the role that sustainable communities can play within CE approaches [74]. Combining energy and waste management analysis allows a deeper understanding of household systems and can more effectively address national resource efficiency, fuel poverty, and environmental challenges [75]. In fact, the application of the CE concept needs the involvement of the local community [76] with a close cooperation of various actors [77] through stakeholders' engagement [78] based on a circular management [79]. This aspect aims to include the human dimension that tends to be lacking in CE research [80], and other authors confirm the social gap in circular models [81]. Thus, communities foster a sharing of both materials and energy sources [82]. This change, supported by the development of renewable energy, can have a major impact on household behavior and foster sharing economy models [83]. In this way, decision-making processes turn out to be as accountable as they are transparent [84].

The existence or non-existence of a green-circular premium links directly to the concepts of GE and CE, with values that might even coincide [31]. Energy communities can be realized when the links between means-objectives and end-objectives are clear [74]. Within the PV sector, the goal is maximization of harvested energy and minimization of costs [19]. With this in mind, the use of storage can be decisive in achieving a decentralized model, but attention should be paid to environmental concerns [85]. This work from a waste management perspective has the limitation of not considering the EoL impact of PV modules and from an economic as well as environmental perspective, the impact of storage in sustainable communities.

However, this work can provide insights from an operational as well as a conceptual perspective. In fact, the operational aspect that characterizes a sustainable energy community is to foster a decentralized model where energy is produced at a site to meet consumer needs. Thus, the mean-objective of an environmental benefit translates into the end-objective of economic opportunity. In addition, the maximization of energy produced and self-consumed prompts the development of the concept of resource efficiency, proper to the principles of CE. In fact, this reduces the steps in which unconsumed energy is sold to the grid. However, an opposite energy flow from the grid to the residential user occurs when there is a demand for energy that cannot be met by the absence of solar generation. This shift is made possible by more responsible approaches in energy uses by citizens.

This transition related to residential users is connected to a new business model, where prosumers are the key players in the change. However within a sustainable community, there is the cooperation of multiple prosumers who can foster the sharing economy. This aspect is evidently combined with a human sphere, which is determined in three stages: i) an initial one in which an energy community is chosen; ii) an intermediate one in which we outline how the revenues will be shared; and iii) a final one in which we frame the practical actions that can maximize these benefits.

Thus from a conceptual point of view, PV-based energy communities are new social forms of aggregation that can achieve GE principles. As far as those of CE are concerned, they are only partially met unless business models that include the EoL of these materials are also included. Those countries that are lacking in raw materials to realize green technologies could gain a competitive advantage. In fact, the presence of recycling processes would make it possible to close the conceptual cycle of a sustainable community and make raw materials available for integrations of more sustainable communities. In this way, sustainable communities use green and circular resources, reducing geopolitical risks because the challenge of global competitiveness must be met by valuing local resources.

4. Conclusions and policy implications

The energy shock that is enveloping Europe stems from an incorrect choice of the past in which excessive energy dependence on foreign sources was used, and geopolitical risks, too often overlooked in decision-making processes, are causing high bills for multiple businesses and citizens. Europe has an ambitious program for the development of renewable energy, which in time replacing fossil sources in fact will cause an economic shock in the interests of some investors. There have already been multiple instances of grid parity circumstances. The subsidies given in recent years were intended to increase competitiveness and in particular, the growth of PV systems globally has been very significant. Thus, the goal has been partially achieved, but more is needed. In fact, the production of energy sources must be able to meet energy demand. Along with energy efficiency actions, transitional forms of less polluting fossil sources should be used to maintain a balance.

In a market scenario in which the holders of fossil fuels are aware that they have a product whose demand will decrease in the future and may instead have a position of commercial dominance today, they feel free to raise prices in order to derive revenue that will no longer be available in the future. Considering, moreover the effect of discounting money, profits are even more maximized if they materialize in a present time. In this context, the issue of energy communities, which represent a social energy revolution, is emerging. A country's energy strength is to increase domestic production by exploiting its own resources. This approach allows one to be sheltered from geopolitical risks and speculative phenomena. Italy has very favorable levels of insolation and has an incentive tool that can encourage both collective self-consumption and energy communities.

The results of our work focusing on collective self-consumption show significant economic benefits, which clearly increase as virtuous behaviors geared toward maximizing the percentage of self-consumption increase. However, sustainable communities are a more complex challenge than a single residential PV system because shared resources need to be managed. They can pursue the principles of both GE and CE. Participatory models if applied make it easy for energy communities to develop, while greater difficulties can be seen in communities that are not well amalgamated. On this aspect, it was observed how the role of local governments and the low sense of trust they give to their citizens can also weigh. Thus, the first result of this work is that collective self-consumption models with the current incentive decree that provides a 50% tax deduction and a subsidy of 100 €/MWh are profitable, characterized by a low level of economic risk, and the profits that are made are significant. In particular, this will be increasingly true in a market scenario where energy prices will rise.

This thinking opens up a problematic issue: governments need to provide plans for the development of PV systems for less affluent households, who will otherwise risk having to pay a very significant cost of energy. The issue of social equity by which sustainability cannot be only for the benefit of those with higher incomes. On this issue and on social analyses in general regarding consumer behavior toward sustainable communities new analyses are needed. The second important outcome of this work is to provide a snapshot for the future. Two different policy scenarios are proposed that may require less public outlay and may still make the installations of these plants cost-effective. The two proposed scenarios are different from each other because one involves a reduction in the tax deduction, while the other involves a reduction in the subsidy over time. Even for such policy approaches, PV installation remains characterized by a low level of risk. An important goal for the market is to design incentive policies for the long term, characterized also by their gradual reduction.

Future directions of work can be aimed at measuring the economic viability associated with energy communities, assessing the relative desirability of larger installations, and as mentioned earlier, conducting social analysis on this issue. Where the intermittent nature of solar may be a problem, integration with energy storage system should also be studied, also from a circular perspective. The model used in this work can be replicated in other territorial contexts, as the deployment of PV systems on rooftops or otherwise on structures that do not take away land turn out to be decisive for sustainable development. A subsidy for self-consumption could make consumers more aware of their behaviors, since it is not enough to install a PV system but also approaches in different consumption are needed. Sustainable energy management therefore is a goal that can be achieved, and sustainable communities can be an enabling factor toward that goal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2022.11.127.

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