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Prosumers as drivers of SDG7 in Palestine: Net-benefit analysis of grid-connected photovoltaic systems

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ABSTRACT

The present study assessed the prosumer benefits of a residential photovoltaic system based on a net-benefit analysis. Net present value ranged from 187 to 2811 $/kW in the low-market scenario and 1226–5642 $/kW in the high-market scenario. Net benefits were verified in net metering contexts, while contexts without net metering had break-even points of 31% and 48% self-consumption for the two scenarios, respectively. Policy recommendations are proposed to encourage investment in renewable energy plants in the Palestinian territory to increase energy security while contributing to the attainment of Sustainable Development Goal 7.

1. Introduction

Sustainable communities organized around photovoltaic (PV) systems have been proposed as a new social model for the ecological transition. PV systems are also critical for achieving Sustainable Development Goal (SDG) 7 (clean and affordable energy) and addressing energy poverty (Biancardi et al., 2023; Fotio et al., 2023), particularly in their capacity to increase energy security (Nasir et al., 2022). The prosumer role promotes household self-sufficiency and the creation of new energy communities (D'Adamo et al., 2023). Prosumers have been widely studied in previous research (D'Adamo et al., 2022b), which has predominantly focused on consumer energy habits and behavior (Niamir et al., 2020). Studies have also shown that the financial risks associated with prosumerism can be reduced by incentive policies (de Oliveira Pinto Coelho et al., 2021). Such findings apply to high-, middle- and low-income countries, where sustainability challenges prevail (Liu et al., 2024; Rahaman et al., 2024).

Although Europe initially dominated the PV market, significant growth has been observed in China, the United States, Japan, and India (International Energy Agency, 2023). These countries are now called upon to maximize the production of renewable sources, replace plants at the end of their useful life, and apply appropriate circular solar models (D'Adamo et al., 2023). However, all countries require sustainable initiatives (Acheampong et al., 2022; Esily et al., 2023).

Renewable energy has the potential to alleviate energy poverty in the Palestinian territory (Hamed and Peric, 2020). In that context, investment in sustainable sources may preserve energy resources and increase energy independence (Salah et al., 2021). Some authors have argued that the most significant barrier to investment in renewable energy in Palestine is the complex political situation (Abboushi and Alsamamra, 2021). Area C, comprising approximately 60% of the Palestinian territory and demonstrating rich potential for solar and wind energy, is under full Israeli control, hindering development and investment. Another legal barrier is requiring energy to be sold exclusively to the Palestinian Electricity Transmission Line Company (PETL). However, this restriction is only a formality, as distributors and industrial or commercial consumers may also participate in the market. Weak infrastructure (Damayra and Khatib, 2022), limited technical labor, insufficient governmental assistance, and low investment innovation have also been recognized as impediments to the adoption and diffusion of renewable energy in Palestine. Additionally, low consumer awareness and a lack of funding plans due to low local banking sector knowledge represent further challenges (Juaidi et al., 2016).

Among renewable energy sources, PV plants hold significant potential in Palestine, particularly with respect to rural development. Previous research has shown that implementing micro-grid solar PV plants can improve social and public services in rural West Bank communities (Ibrik, 2020a). Furthermore, according to Alsamamra and Shoqeir

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(2021), the installation of PV panels on public school rooftops in Palestine could move the country closer to energy self-sufficiency and increase awareness of green energy among young Palestinians (Salah et al., 2021).

Researchers have attempted to determine optimal locations within the Palestinian territory for PV plant installations, considering factors such as sunshine and humidity levels and distance from residential areas or roads. Hamada and Ghodieh (2021) concluded that the eastern and southern areas of the West Bank exhibit the highest solar energy potential. Similarly, other analyses have highlighted Gaza and the southern West Bank as ideal locations for exploiting PV solar power while recognizing Jericho as the least favorable (Ajlouni and Alsamamra, 2019). Multiple studies have investigated the economic feasibility of solar power plants in the Palestinian territory using the net present value (NPV) methodology. For instance, Palestine emerged as one of the few countries demonstrating a positive NPV in a net-benefit analysis of grid-connected PV plants in the MENA region (Adun et al., 2022). Moreover, Omar and Mahmoud (2018) conducted an economic evaluation of three residential solar systems in Palestine utilizing NPV, the internal rate of return, and the payback period.

Previous research has emphasized the economic benefits of PV systems. One study used NPV and the payback period to determine the feasibility of rooftop solar systems within three Palestinian schools (Ibrik and Hashaika, 2019). Rooftop installation can mitigate the challenge of limited land availability, which is relevant to the Palestinian context. Similar methodologies were used to assess the economic benefits of 128 rooftop PV panels at the Faculty of Medicine in Nablus, in the northern West Bank (Ibrik, 2020b). Additionally, the economic performance of 15 PV systems in Palestine was verified based on the payback period (Khatib et al., 2021), and Natsheh (2016) used the same metric to show that a solar PV system in northern Palestine could be more economically feasible than grid electricity.

Researchers have also employed feasibility and net-benefit analyses to recommend government policies to incentivize PV system installation. Decentralized systems, for instance, could benefit from a bonus associated with energy produced by PV systems and self-consumed, with a separate incentive for storage systems based in developed countries (D'Adamo et al., 2024). Other analyses have assessed the main barriers to PV system installation in developing countries, proposing policies such as accessible loans to reduce initial investments and the tax-free importation of key PV components (Podder et al., 2021). A recent paper highlighted several discouraging policies in the Palestinian territory that limit investment in PV systems (Khatib et al., 2021), such as lower priority for smaller investors and a ban on direct investment from distribution companies. The authors further proposed a certification process for PV system suppliers to facilitate investment in this renewable energy. Another study advised the Palestinian government and energy authorities to review and update all incentives for renewables (Juaidi et al., 2022).

As highlighted by the above-cited research, installing PV systems can support sustainable development in the Palestinian territory. To this end, economic analyses may be helpful (Agyekum et al., 2024; Juaidi et al., 2023). We evaluate the net benefits of a residential PV system with or without net metering, assuming various market conditions, within the Palestinian context. The analysis employs a range of economic indicators, including NPV, the internal rate of return (IRR), discounted payback time (DPBT), and the net-benefit index (NBI). Sensitivity, scenario, and risk analyses assess net benefits under a baseline and alternative scenarios. The work benefited from further discussion and analysis during a Twinning project focused on the Palestinian energy system.

2. The Palestinian framework

The State of Palestine in the Middle East has experienced significant population growth over previous decades, from 2.783 million in 1997 to 5.483 million in 2023. The gross domestic product (GDP) surged from \$3.56 to \$19.11 billion between 2002 and 2022 (World Bank, 2023). Despite this economic growth, Palestine continues to lag behind neighboring countries (i.e., Israel, Egypt, and Jordan) in terms of both GDP and unemployment, which stands at a high of 25.7% (in 2022).

The International Trade Administration (2022) estimated an available electricity capacity (not through direct production) of 1100 MW in the West Bank in 2022, with 80 MW derived from renewable energy sources. Approximately 85% of the total supply came from Israel, while Jordan contributed 15%. The current capacity of the Gaza Power Plant is 140 MW. However, due to the high cost of diesel fuel and sourcing challenges, it typically operates at only half capacity (i.e., 50–80 MW). The resulting energy shortage negatively impacts the accessibility of essential water, health, and sanitation services.

In terms of energy consumption, households and the transport sector accounted for approximately 45% and 40% of total consumption, respectively, in the 2014–2021 period. However, Palestine remains far from energy self-sufficient, with a dependency rate of 87.4% in 2021 (Palestinian Central Bureau of Statistics, 2023). Oil products dominate Palestinian energy resources, constituting 58% of the total supply in 2020, while renewable energy contributes only 13% (Palestinian Central Bureau of Statistics, 2020).

The institutional energy framework advocated by the Palestinian National Authority (Khatib et al., 2021) is based on a net metering policy, which forces distribution companies to trade excess electricity produced by PV systems. This framework allows customers to connect to the grid and withdraw electricity as needed. Over time, the amount of electricity from self-generation and renewable energy has increased from approximately 27 GWh in 2011 to 252 GWh in 2020.

3. Materials and methods

In line with the classification of methods proposed in the literature (Sovacool et al., 2018), the present work possesses the following characteristics:

- local geographic coverage;
- sectoral coverage relating to residential areas;
- a scope relating to the economic outputs of different combinations of energy supply and demand;
- a method based on the simulation of variations in technical and economic variables; and
- a time horizon spanning the entire useful life of the project.

The research aimed to determine the net benefit of a newly installed grid-connected residential PV system in Palestine, situated in a generic region. Net benefits were evaluated using the discounted cash flow (DCF) method, which is well-established in the literature (Alaqeel and Suryanarayanan, 2019; D'Adamo et al., 2022a). NPV, the sum of all future cash flows (inflows and outflows), was used to determine project net benefits, considering the opportunity cost of capital as a function of the plant's useful life. The model included two potential cash inflows: the avoided electricity cost in the bill and the sale of electricity. Cash outflows include investment costs, electrical connection to the grid, maintenance activities, insurance, and taxes. Additionally, the model incorporated inverter replacement during the 10th year, determining a temporary increase in maintenance costs. The model proceeded as follows, according to the literature (D'Adamo et al., 2022a):

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

$$DCI = \sum_{t=1}^{N} \left(w_{self,c} \times E_{Out,t} \times p_t^c + \left(1 - w_{self,c}\right) \times E_{Out,t} \times p_t^s \right) / (1 + r)^t \tag{2}$$

$$E_{Out,t} = t_r \times k_f \times \eta_m \times \eta_{bos} \times A_{cell} \times P_f \times n_f \tag{3}$$

$$E_{Out,t+1} = E_{Out,t} \times (1 - dE_f) \quad (4)$$

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

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

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

In which DCI = discounted cash inflow; DCO = discounted cash outflow; t = period; C_{inv} = investment cost; C_{lcs} = loan capital share cost; and $E_{out,t}$ = energy output of the PV system. In addition, three other economic indicators were calculated: IRR, representing the discount rate at which the investment NPV was equal to zero; DPBT, representing the number of years required for the project to generate sufficient revenue to break even; and NBI, indicating the wealth generated per dollar invested. Table 1 introduces the model inputs. The research assumed that the investment was fully financed through debt capital. According to the literature, the electricity purchase price ranges from 0.16 to 0.20 \$/kWh. Hence, the study considered the average cost of 0.18 \$/kWh as the most likely value of this parameter and 0.28 \$/kWh as a possible future cost. In addition, electricity selling price varies according to the presence or absence of net metering. In the first scenario, it was valued at \$0.13/kWh, while it assumed a value of zero in the second. Consequently, the baseline scenario was divided into four case studies representing different combinations of the market and policy scenarios, as follows:

- low market (p^c = 0.18 \$/kWh) and high market (p^c = 0.28 \$/kWh); and
- no net metering (p^s = 0 \$/kwh) and net metering (p^s = 0.13 \$/kWh).

In addition, the self-consumption parameter was variable, ranging from 0% (all energy produced sold) to 100% (all energy produced self-consumed). Two experts based in the Palestinian territory were consulted to validate the model inputs identified in the literature.

Alternative scenarios were analyzed to ensure the robustness of the results. Critical variables were varied, and the resulting changes in NPV were measured. Specifically, a sensitivity analysis involving altering a single critical variable and a scenario analysis, wherein multiple critical variables were changed simultaneously, were conducted. Finally, a risk analysis using a Monte Carlo simulation was conducted to assign a probability value to NPV.

Table 1
Input data (Adun et al., 2022; D'Adamo et al., 2024; Ismail et al., 2013; MeetMed, 2020; Omar and Mahmoud, 2018).

Acronym	Variable	Value
A_{cell}	Active surface: Area of a single PV panel	7 m^2/kWp
C_{ae}	Administrative/electrical connection cost	179 \$/year
$C_{inv,unit}$	Unitary investment cost	2400 \$/kW
dE_f	Annual decrease in PV system efficiency	0.7%
inf	Inflation rate	2.28%
inf_{el}	Electricity inflation rate	5%
k_f	Optimal solar panel tilt angle	1.6
N	Lifetime of the PV system	20 years
N_{debt}	Loan duration	10 years
η_{bos}	BOS efficiency	85%
n_f	Number of PV modules to install	Function of *S*
η_m	Module efficiency	16%
p^c	Electricity purchase price	0.18–0.28 \$/kWh
p^s	Electricity selling price	0.00–0.13 \$/kWh
P_{Cass}	Insurance cost percentage	1%
P_{Ci}	Inverter cost percentage	15%
P_{Cm}	Maintenance cost percentage	2%
P_{Ctax}	Tax rate	15%
P_f	Nominal power of a PV module	Function of *S*
r	Opportunity cost of capital	7%
r_d	Interest rate on a loan	3%
S	Plant size	5 kW
SP_{el}	Sales of electricity	Function of p^s
t_r	Average annual insolation	1971 kWh/m^2 x y
$TaxD_u$	Unitary tax deduction	Not included
$w_{self,c}$	Electricity self-consumption percentage	0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%
Vat	Value added tax	16%

4. Results

The results section describes the baseline scenario (Section 4.1) and the alternative scenarios (Section 4.2).

4.1. Baseline scenario

Variations in NPV with respect to the share of self-consumption in each of the four cases for the baseline scenario were explored, starting with the model described in Section 3 and the data proposed in Table 1 (Fig. 1, Table S1). The graph shows that a higher share of self-consumption corresponded to a higher NPV for each case. Notably, cases with net metering were consistently profitable, regardless of the share of self-consumption, since their NPV was always greater than zero. On the other hand, contexts in which selling electricity to the grid was not possible were not universally profitable. The break-even point (BEP) analysis indicated that, for the no-net-metering and low-market case, PV installation became profitable at 48% self-consumption, while in the no-net-metering and high-market case, net benefit was achieved at 31% self-consumption.

Further analysis revealed significant NPV variation according to different conditions. For instance, with 30% self-consumption, NPV was equal to 1827 and 3243 \$/kW with net metering, depending on the market context, while it was −1511 and −96 \$/kW without net metering. With 60% self-consumption, all plants were profitable, according to the BEP analysis, with NPVs ranging from 2811 to 5642 \$/kW and 1037–3868 \$/kW with and without net metering, respectively.

The NPV increase of 472 \$/kW in the high market compared to the low-market context was maintained irrespective of net metering, occurring for every 10% increase in self-consumption. For example, with 50% self-consumption, the increase was 2359 \$/kW. Similarly, policy was also a source of variation. Specifically, the impact of net metering on NPV was more pronounced at lower rates of self-consumption, with a

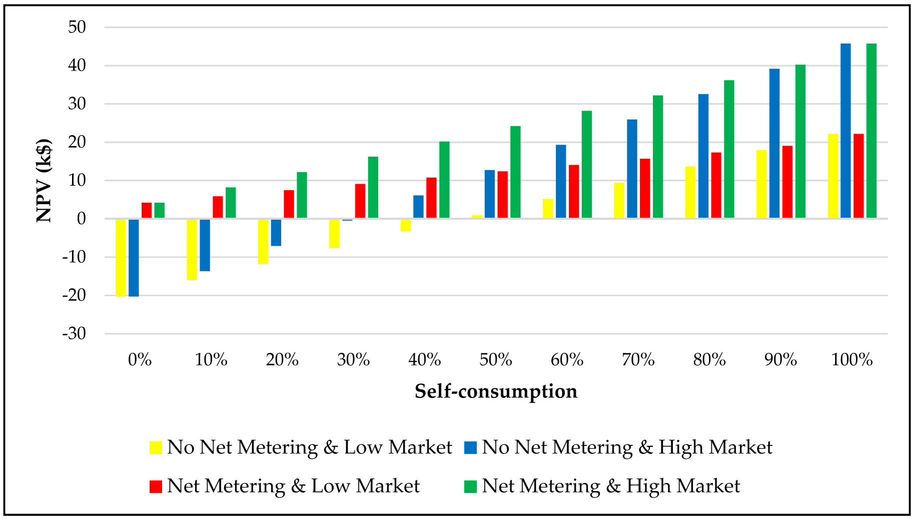

Fig. 1. NPV (k$) – Baseline scenario.

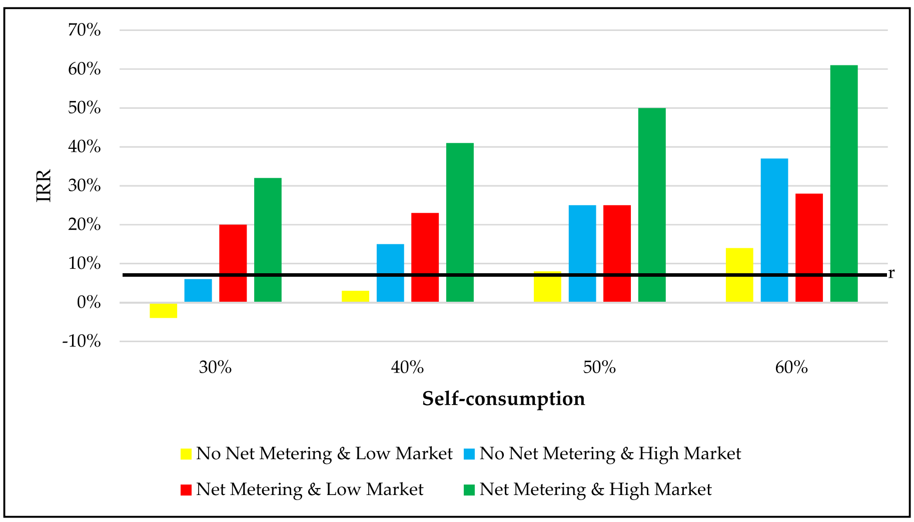

Fig. 2. IRR (%) – Baseline scenario.

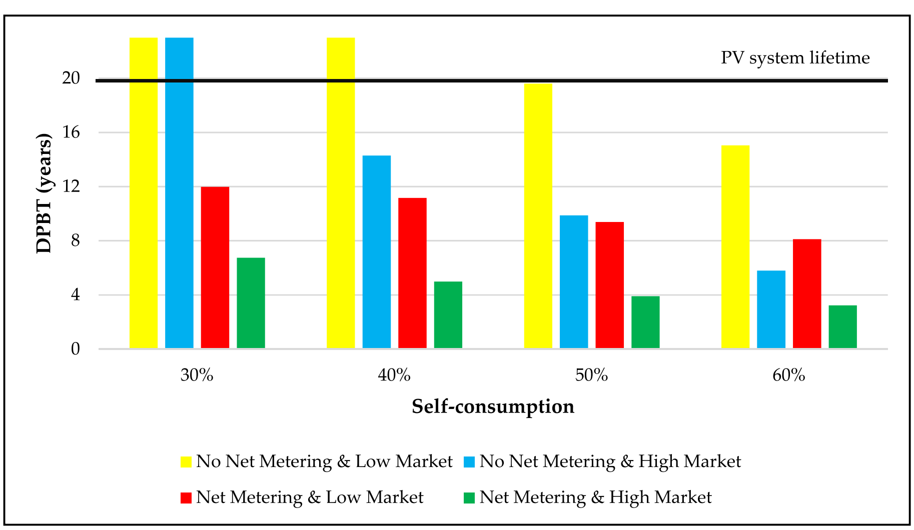

Fig. 3. DPBT (years) – Baseline scenario.

difference of 1774 $/kW at 60% and 3339 $/kW at 30% in the net metering compared to the context without net metering. Another noteworthy observation is that the no-net-metering and high-market case was more profitable than the net metering and low-market case when self-consumption exceeded 50%.

Other economic indicators were calculated to provide a comprehensive view of system net benefits, with a focus on the 30–60% range of self-consumption that is typical for residential PV systems (D'Adamo et al., 2024; Fett et al., 2019; Lang et al., 2016). The first alternative indicator was IRR, for which it was verified that there were no traps for which it could be calculated. The IRR results were consistent with the NPV analysis, confirming that net benefits were not verified in the same three cases. In fact, in the two cases without net metering with 30% self-consumption and a low market with 40% self-consumption, IRR was less than 7% (i.e., the opportunity cost of capital used in this work) (Fig. 2, Table S2). Notably, IRR increased from 41% to 61% in the net metering and high-market case, reaching its peak with self-consumption in the 40–60% range. Conversely, with 30% self-consumption, a lower IRR value emerged relative to the no-net-metering and high-market case with 60% self-consumption.

Fig. 3 (and Table S3) shows the DPBT variations with respect to the share of self-consumption for each case. DPBT exceeded 20 in cases where net benefits were not verified, signifying that the different revenue components were insufficient to offset costs. In the net metering and high-market case, DPBT ranged from 3.2 to 5 years with 40–60% self-consumption. Additionally, it fell below ten years (i.e., half the useful life of the PV system) in the net metering and high-market case with 30% self-consumption, as well as the net metering and low-market case with 50% self-consumption and the no-net-metering and high-market case with 60% self-consumption.

Finally, we considered the NBI, which produced consistent results (Fig. 4, Table S4). In more detail, NBI surpassed 1.0 only in the net metering and high-market case with at least 50% self-consumption, and values below 0 emerged for the three unprofitable cases.

Thus, to summarize the findings, the following values were recorded in the cases for which net benefits were verified:

- NPV: 187–2811 $/kW in the low-market context and 1226–5642 $/kw in the high-market context.
- IRR: 8–28% in the low-market context and 15–61% in the high-market context.
- DPBT: 8.1–19.6 years in the low-market context and 3.2–14.3 years in the high-market context.
- NBI: 0.05–0.64 in the low-market context and 0.30–1.29 in the high-market context.

Particularly noteworthy is the consistency between the NPV and NBI analyses, were the no-net-metering and high-market case proved more profitable than the net-metering and low-market case with 50% self-consumption. On the other hand, the results for the IRR perfectly aligned with the two results, while a similar convergence for DPBT only occurred for 60% self-consumption. The impact of the high-market context intensified with increased self-consumption due to the direct association with the avoided cost in the bill. Conversely, when self-consumption was low, the selling price of energy became a relevant factor distinguishing between the net metering and context without net meterings.

The baseline scenario results align with the findings reported in the literature. In most studies, the percentage of self-consumption has remained constant, typically considering the maximum kW per year that the system can sell to the grid.

First, a study comparing several countries in the MENA region confirmed the net benefits of a PV system in Palestine (Adun et al., 2022). Despite describing a smaller plant (i.e., 3 kW) with additional installation costs (combining PV and thermal technologies), the resulting NPV, at 2557 $/kW, was lower than the typical values obtained in the present study for the net metering baseline cases. In addition, the NPV calculated by other authors for a 5 kW system exceeded 14,000 $/kW (Omar and Mahmoud, 2018), with a DPBT of 5 years and an IRR of approximately 25%. These values align with the present results for the baseline scenario. Further studies have confirmed that the payback period of PV systems in Palestine typically ranges between 5.5 and 7.4 years (Khatib et al., 2021). Other authors considered a larger system (i.e., over 7 kW), estimating approximately 70% self-consumption based on the electricity requirements of the building (Ibrik and Hashaika, 2019) and obtaining an NPV of approximately 11,000 $/kW, comparable to the values obtained for the net metering and low-market case in the present analysis.

4.2. Alternative scenarios

The sensitivity analysis considered the four cases of the baseline scenario, varying a single critical variable and determining NPV across self-consumption levels in the 30–60% range. The critical variables (i.e., unitary investment cost, electricity purchase price, electricity selling price, and average annual insolation) were selected according to the literature (Adun et al., 2022; D'Adamo et al., 2024; Ismail et al., 2013;

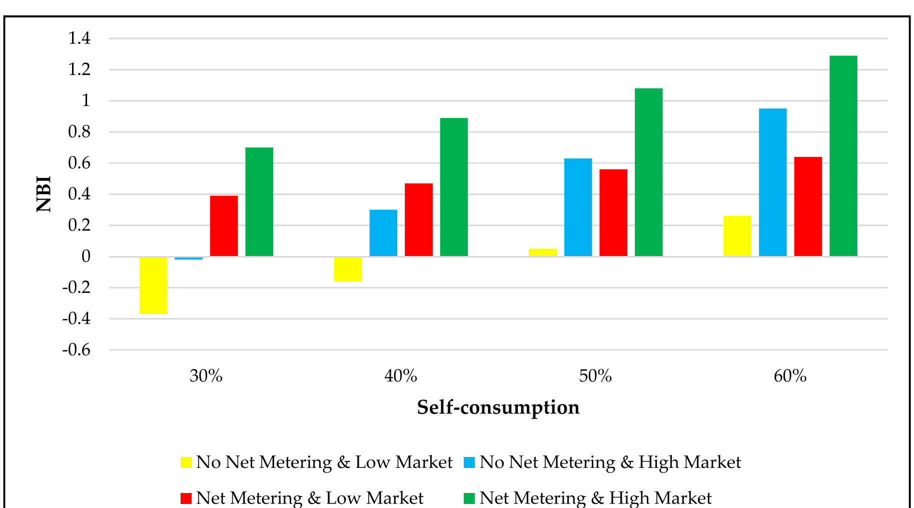

Fig. 4. NBI – Baseline scenario.

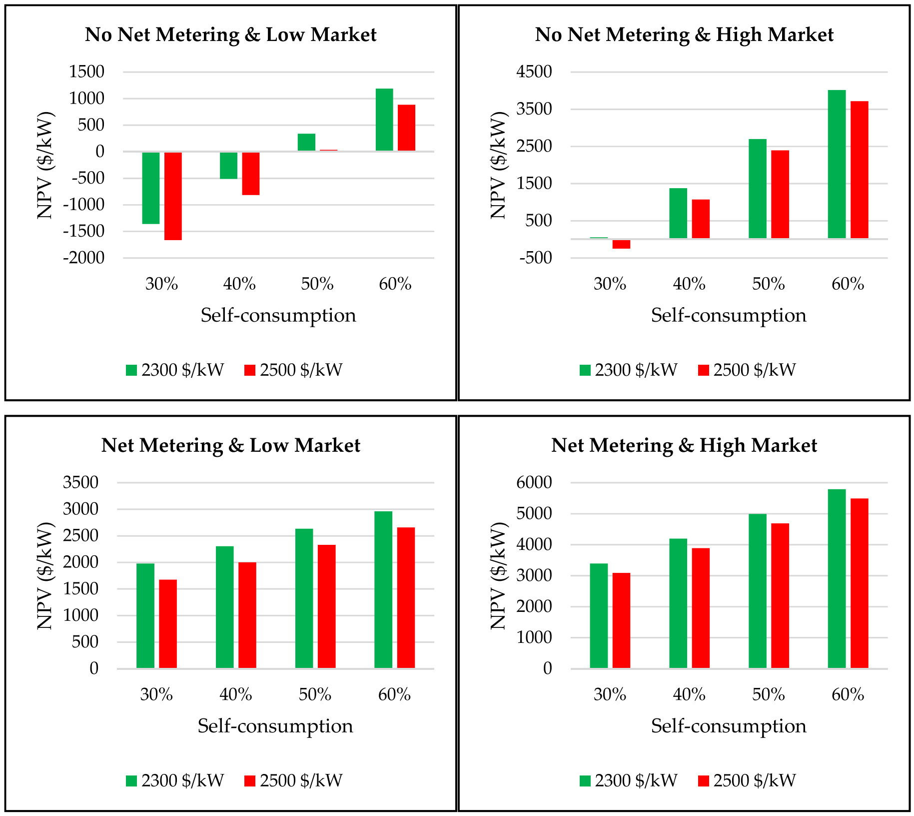

Fig. 5. Sensitivity analysis “unitary investment cost” – NPV ($/kW).

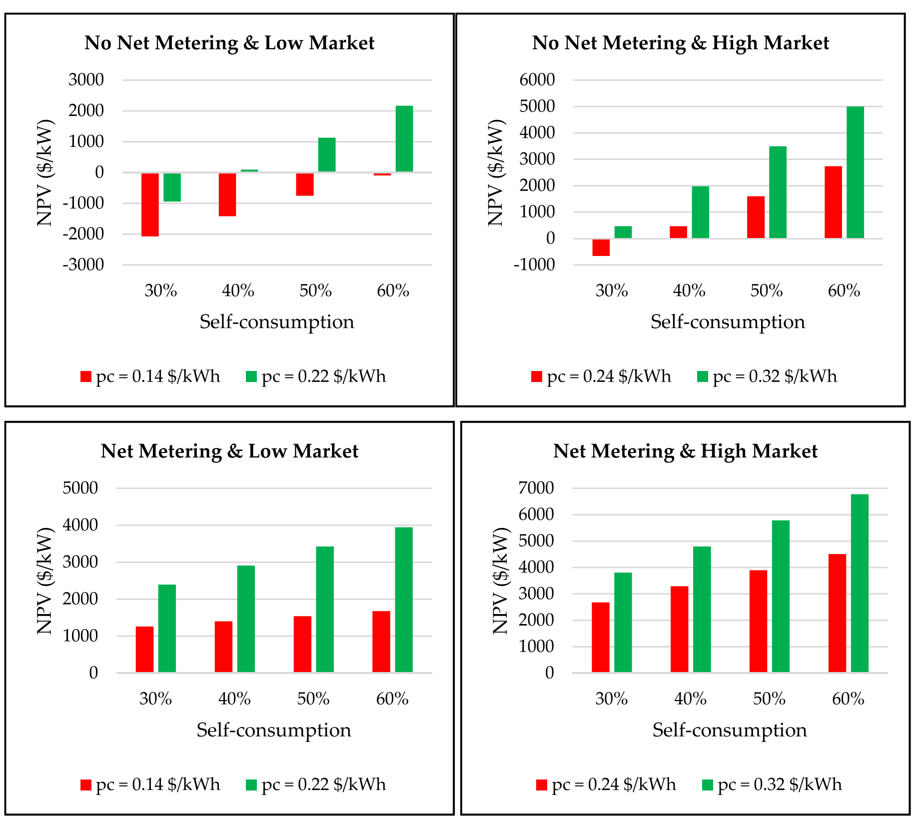

Fig. 6. Sensitivity analysis “purchase price” – NPV ($/kW).

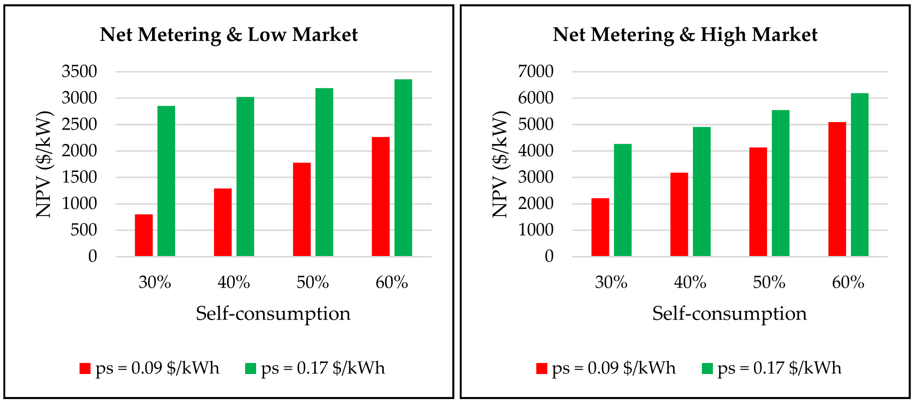

Fig. 7. Sensitivity analysis "electricity selling price" – NPV ($/kW).

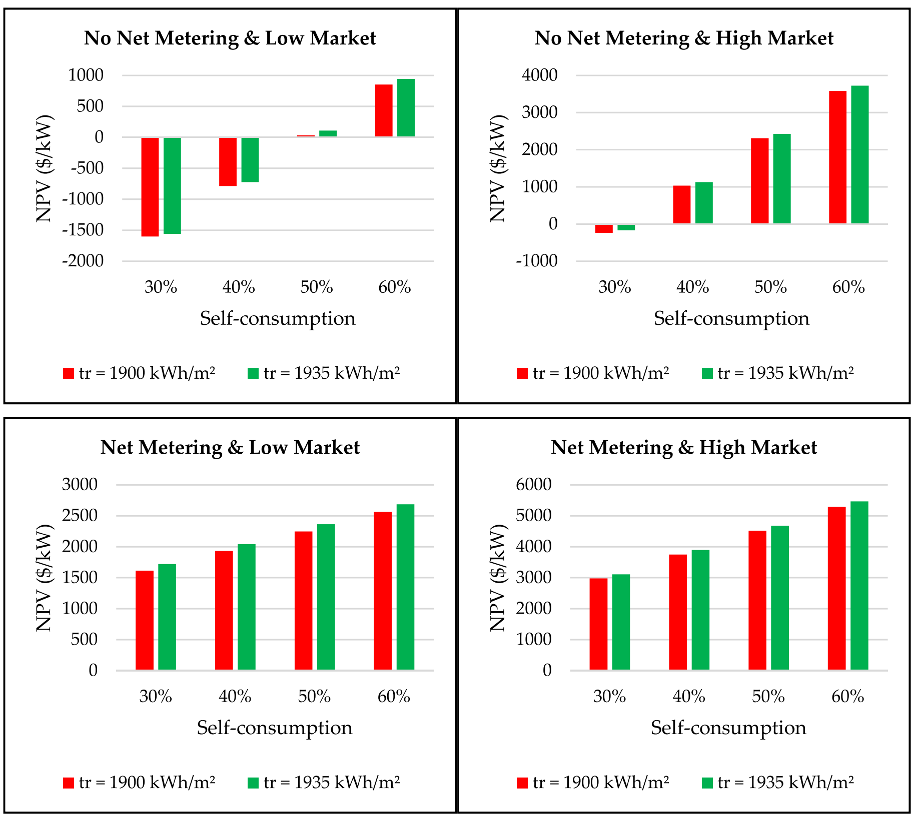

Fig. 8. Sensitivity analysis "insolation level" – NPV ($/kW).

MeetMed, 2020; Omar and Mahmoud, 2018).

In the baseline scenario, the unitary investment cost was 2400 $/kWh, calculated as an average between 2300 and 2500 $/kWh, and the sensitivity analysis considered a 100 $/kWh variation (Fig. 5, Table S5). Variation in the purchase price was determined so that the optimistic low-market context would not coincide with the pessimistic high-market context. Given initial starting prices of 0.18 $/kWh and 0.28 $/kWh, respectively, the selected variation was 0.04 $/kWh (Fig. 6, Table S6). The same variation applied to the electricity selling price, set at 0.13 $/kWh. The analysis did not consider changes in the selling price for the context without net metering (Fig. 7, Table S7). For the insolation level, optimistic (1971 kWh/m^2), pessimistic (1900 kWh/m^2), and intermediate scenarios (1935 kWh/m^2) were considered (Fig. 8, Table S8).

The results indicated consistent net benefits in the net metering context, with NPV ranging from 1676 to 5794 $/kW. Without net metering, net benefits changed in a specific case (30% self-consumption, high market) by 56 $/kW, with a maximum NPV of 4020 $/kW. A 100 $/kW variation in the unitary investment cost determined a 150 $/kW variation in NPV for all cases involving this critical variable.

Changes in purchase prices affected PV plant net benefits. In the net metering context, NPV remained positive across all cases, ranging from 1261 to 6775 $/kW. Conversely, the results deviated from the baseline scenario without net metering. In particular, reducing the purchase price to 0.14 $/kWh, even with 60% self-consumption, led to economic losses. Conversely, at 0.22 $/kWh, NPV became positive at 93 $/kW. Maximum NPV in these scenarios reached 5000 $/kW. In contrast to the critical variable examined above, the change in NPV at this stage of the sensitivity analysis depended on the purchase price and the percentage of self-consumption. Specifically, a change of 0.04 $/kWh resulted in a change in NPV of 566 or 1133 $/kW, depending on whether the percentage of self-consumption was 30% or 60%, respectively.

Variation in the selling price exclusively affected the net metering

Fig. 9. Scenario analysis – NPV ($/kW).

cases, with NPV always positive and in the range of 800–6188 $/kW. Similar to the purchase price, a 0.04 $/kWh change in the selling price led to a NPV variation of 1027 or 546 $/kW when self-consumption was 30% or 60%, respectively.

Concerning insolation level, variation in this critical variable did not significantly impact profitability. NPV ranged from 34 to 3723 $/kW and 1615 to 5465 $/kW for the no-net-metering and net-metering cases, respectively. Summarizing the sensitivity analysis results, NPV proved positive in 85% of the cases. Although a direct comparison between variables was not feasible due to differing deltas of change, the avoided cost in the bill and the percentage of self-consumption emerged as key variables. The subsequent step in the analysis comprised a scenario analysis, simultaneously introducing changes to multiple variables. Two scenarios (optimistic and pessimistic) were considered to evaluate variable trends in both directions. This analysis included the three economic variables from the sensitivity analysis (i.e., unitary investment cost, electricity purchase price, and electricity selling price) within the previously proposed ranges. However, insolation was not included, as only a pessimistic scenario was analyzed. Similarly, to ensure the completeness of the analysis, insurance and maintenance unit costs, which varied by 0.5% from the baseline scenario, were included (Fig. 9, Table S9).

The scenario analysis revealed a novel result: a negative NPV in one net metering case. Specifically, this case described a pessimistic low-

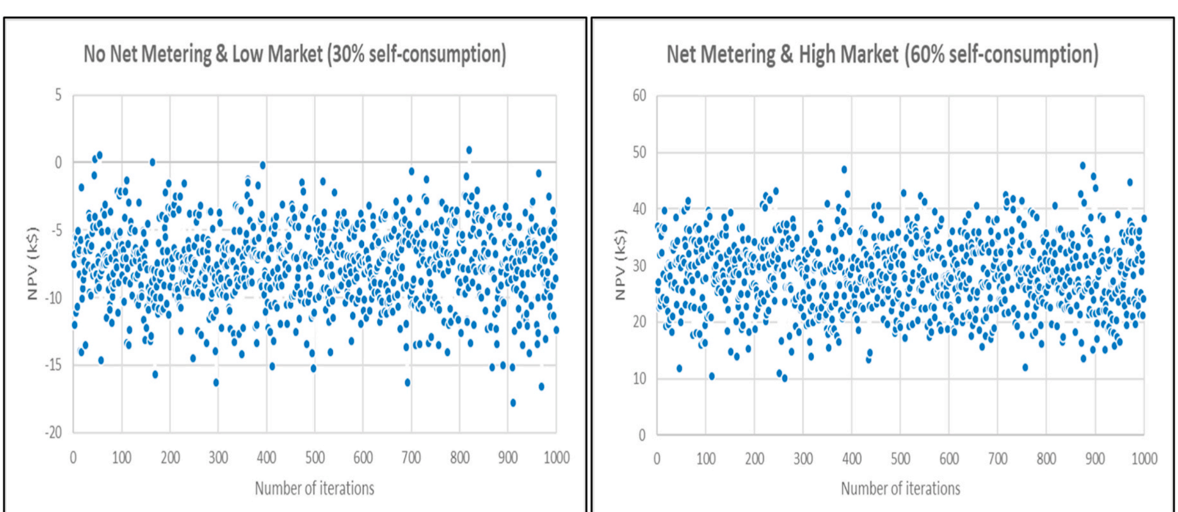

Fig. 10. Risk analysis – NPV ($).

market context with 30% self-consumption. In the other cases, NPV ranged from 17 to 7809 $/kW. For the no-net-metering cases, variations emerged, with the optimistic high-market scenarios yielding a positive NPV even with 30% self-consumption and the pessimistic high-market scenarios with 40% self-consumption generating a negative NPV. Additionally, NPV was positive in the low-market scenario with 40% self-consumption, yet negative in the different pessimistic scenarios, even with 60% self-consumption. The NPV in the profitable scenarios ranged from 581 to 5488 $/kW.

A BEP analysis was again conducted across the different cases to provide deeper insights. Net metering in the optimistic scenarios generated a positive NPV in the energy-only case, while in the pessimistic scenarios, BEP emerged as 15% and 21% self-consumption in the high and low-market contexts, respectively. Of note, in the baseline scenario, NPV was always positive. For no net metering, the BEP in the baseline scenario was 31% self-consumption in the high-market context and 24% and **40**% in the optimistic and pessimistic scenarios, respectively. In the low-market context (48% baseline value), the BEP for self-consumption was 34% and 69%, respectively. Profitability was verified in 75% of the cases considered in the scenario analysis. However, a further risk analysis was needed to obtain a comprehensive characterization of probability. For this purpose, 1000 iterations of NPV were calculated using the Monte Carlo method. Three variables were involved: unitary investment cost, electricity selling price, and electricity purchase price. Mean values were assumed to be equal to those of the baseline scenario, with standard deviations mirroring the range used for the sensitivity and scenario analyses. The two extreme values for self-consumption considered in the alternative scenarios (i.e., 30%, 60%), applied to the four contexts, were considered for the two extreme cases (Fig. 10) and the others (Figure S1).

Aggregating the iterations and the risk analysis results (Fig. 11) reinforced that the percentage of self-consumption and a high avoided cost in the bill (i.e., high market) were the most significant variables. Regardless of the net metering policy context, these variables consistently led to project net benefits. However, the probability of achieving a positive NPV in the other three cases varied between 94.4 and 99.4%. Considering a context without net metering and 30% self-consumption, a higher probability of net losses emerged, with a positive NPV predicted 42.5% of the time in the high-market context and 0.4% of the time in the low-market scenario.

5. Conclusions and policy Suggestions

Renewable energies (including solar energy) have the potential to shed light on civil society's goals involving sustainability. Although energy concerns affect citizens and businesses, geopolitical risks often complicate the energy landscape. The case of Palestine is emblematic in this respect.

The present study confirmed the potential net benefits of a residential PV system (5 kW) in the Palestinian territory, with NPV ranging between 937 and 14,056 $/kW in a low-market context and 6128 to 28,212 $/kW in a high-market context. Complementary economic indicators provided further support, with the following values: IRR between 8 and 61%, DPBT between 3.2 and 19.6 years, and NBI between 0.05 and 1.29. The results underscore the importance of the percentage of self-consumption and the avoided cost in the bill, in line with the literature. Net metering presented a baseline scenario generating consistently positive NPV, while 48% and 31% self-consumption were identified as BEPs for zero NPV in the low and high-market context without net metering. The analyses of alternative scenarios extended the cases to different contexts, indicating that all net metering cases could achieve a positive NPV of at least 94.4%, reaching 100% in the high-market context with 60% self-consumption. A similar pattern was observed for the context without net metering with 60% self-consumption. However, no net metering with 30% self-consumption and a low market reduced the probability to 0.4%. Of note, even in the developing market of Palestine, increased self-consumption appears to be associated with higher profit.

SDG7 is particularly relevant in geographic areas with energy dependency on foreign countries. In Palestine, interruption of the supply chain (i.e., poor service quality based on indicators such as the SAIDI [System Average Interruption Duration Index] and SAIFI [System Average Interruption Frequency Index]) may have serious repercussions for both industrial and residential sectors, with further negative impacts on the national economy. With this in mind, the Palestinian territory (in the absence of conflict) should self-produce energy and, in so doing, embrace renewable energies (especially solar) as part of a sustainable development program. Alongside the realization of large-scale plants, green development requires the support of prosumers who can mitigate the costs of energy bills, safeguard ecosystems, and foster social models such as energy communities. Based on previously demonstrated net benefits, The results provide a forward-looking vision of prosumer development to promote three strategic policy goals for Palestine: i) enhanced energy security, ii) energy price reduction for consumers, and iii) improved service quality. Political backing is necessary to realize this transformative shift.

Policies such as net metering and feed-in tariffs should be modified to maximize benefits for renewable energy investors. Importantly, the distribution tariff should be reconsidered. Consumers pay a one-part tariff based only on the energy withdrawn from the grid. Consequently, the increase in self-production due to installing new PV plants would reduce distributor income, disincentivizing PV adoption. Transitioning to a two- or three-part tariff and incorporating consumers' payment of one or more fixed components could neutralize the impact of

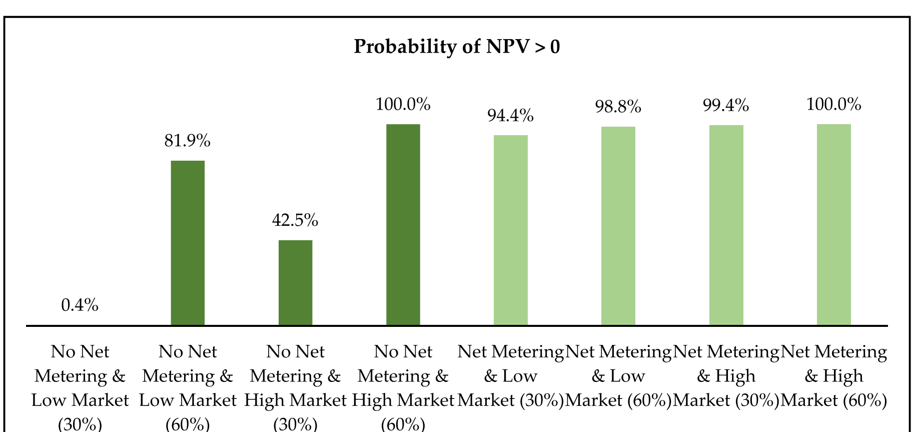

Fig. 11. Risk analysis – Probability of net benefits.

self-production on distributors. This policy would diminish opposition to PV adoption and align with fair regulatory principles.

Furthermore, the regulatory framework should incentivize maximal self-consumption of the distributed energy rather than using the distribution grid as virtual storage. This policy may help alleviate grid congestion and diminish the need for investment in grid reinforcement. Storage technologies should be investigated to optimize self-consumption from PV distributed generation. Finally, Palestinian electricity providers should implement support schemes for demand-side management applications, which rely on prosumers to optimize energy imports and exports to the grid according to real-time supply and demand.

Future analyses should explore consumer energy habits and preferences for particular energy sources to address gaps in the current research. In addition, the present study demonstrates two further limitations. The first concerns its location-specific findings, as different areas of Palestine have distinct contexts of political stability. The second concerns the assumption of ground-mounted PV systems (which are preferable from a sustainable perspective), which require the net benefits of the investment to be deducted from the cost of the land.

International research collaboration facilitates knowledge exchange that may contribute to developing sustainable communities that consider human knowledge a central pillar. Such a cooperative effort is aligned with SDG7, promoting clean and affordable forms of energy, including solar energy.

CRediT authorship contribution statement

Alberto Biancardi: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Idiano D'Adamo:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Franco D'Amore:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Raimond Moretti:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jup.2024.101730.

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