

Toward SDG 7: A Quantitative Sustainability Framework for Evaluating PV+BES Systems in the Low-Carbon Transition

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Abstract—Sustainability in the energy sector requires a pragmatic and interdisciplinary approach. This study analyses the economic profitability and environmental effectiveness of photovoltaic (PV) systems integrated with battery energy storage (BES) systems through a quantitative framework based on Net Present Value analysis, sensitivity analysis, Least Absolute Shrinkage and Selection Operator regression, and greenhouse gas emission reduction value, using a shopping mall in Rome as a case study. By applying uniform percentage changes to economic and environmental variables, the study identifies the critical factors that influence profitability in different self-consumption scenarios. The results show that, in PV systems, the avoided cost in the electricity bill (energy purchase price) is the most significant lever, especially in contexts with high self-consumption, while the sale price becomes more important when self-consumption is low. In BES systems, increased self-consumption remains the main factor improving profitability, although investment costs continue to have a significant impact. Tax deductions have less impact, especially in mature markets. From an environmental point of view, the reduction in emissions depends heavily on the composition of the fossil fuel mix replaced, with a limited additional environmental impact from BES. The results offer operational guidance for prosumers, energy managers, and investors to achieve Sustainable Development Goal 7 by optimizing self-consumption rate, electricity purchase price, PV+BES investment cost, and the fossil-fuel mix replaced to improve the economic and environmental performance of PV+BES systems.

Key words: Battery energy storage (BES), economic analysis, environmental analysis, photovoltaic (PV), sustainable development.

1. INTRODUCTION

THE transition toward a green economy presents a critical challenge for corporate leadership. This transition marks the dawn of a sustainability age, where priorities must be reorganized, and the industrial model reinvented to ensure continued growth that benefits both humanity and the environment. In this age, energy managers and

investors are increasingly tasked with aligning business operations with sustainability targets, which involves a fundamental tradeoff between making green investments and ensuring their economic viability [1]. One pragmatic approach involves providing quantitative assessments to support the different perspectives of sustainability and the role of prosumers [2], [3], [4]. In addition, educational research shows that greater knowledge of the Sustainable

Development Goals (SDGs), supported by schools and effective educational models, increases environmental awareness and the propensity to adopt sustainable behaviors [5].

This dilemma is fundamental in the energy sector, where companies seek to reduce their carbon footprint and increase energy independence through renewable energy adoption [6]. Integrated photovoltaic (PV) systems, often paired with battery energy storage (BES) systems, have emerged as an effective solution, combining environmental responsibility and potential long-term cost savings for businesses [7], [8], [9]. However, the decision to invest significant capital in such projects requires rigorous assessment from a management perspective. The evaluation of PV and BES investments is complex. For managers, the primary concern is the economic sustainability of the project, which depends on various interconnected factors [10]. These include not only the initial capital expenditures for PV modules, inverters, and batteries, but also fluctuating operational factors, such as grid electricity purchase prices, the sale price of surplus energy, and maintenance costs [11]. A key factor to consider in this scenario is the on-site self-consumption rate, as it directly determines the level of savings and the project's overall profitability [12]. Furthermore, financial viability is often shaped by policy instruments, such as tax deductions and subsidies, which can significantly alter the economic feasibility of this solution [13], [14]. Existing research shows that load flexibility improves the economic viability of PV-battery systems, favoring larger PV capacities and smaller batteries [15]. Several studies provide an overview of this topic, considering the many variables that influence decision-making across different analytical perspectives.

This multidimensional approach integrates economic, environmental, social, and strategic aspects, offering a more complete and comparable assessment of available options [16], [17], [18]. In literature, the Net Present Value (NPV) is the most widely adopted metric for assessing similar projects. Numerous studies have applied NPV analysis to various contexts, confirming the general profitability of such systems under specific conditions [19], [20], [21].

Beyond economic considerations, an environmental analysis is fundamental for managers to fully appreciate the benefits of adopting PV+BES systems. This involves evaluating the reduction in carbon emissions achieved through the displacement of fossil fuel-generated electricity with renewable sources [22]. An integrated PV+BES system, based on increased self-consumption, reduced emissions, and economic benefits, contributes directly to the achievement of SDG 7 [23]. However, a gap persists in identifying which of the numerous input variables most critically influence the financial and environmental outcomes in diverse operational scenarios. Consequently, managers often lack a clear, prioritized framework to determine which factors to evaluate first before committing capital to PV+BES investments. This study fills this gap through an in-depth case study of an integrated PV+BES system at a commercial shopping mall in Rome. A shopping mall represents a particularly relevant setting for decision-making, as it represents high and highly variable energy loads, diverse stakeholder interests, and complex operational dynamics common to large-scale assets. Initially, the NPV of the system for this specific case is evaluated using literature-based data, followed by a multidimensional sensitivity analysis to identify the key variables affecting both financial and

environmental performance. For the PV system, which involves many economic parameters, the analysis includes scenarios for low, medium, and high self-consumption rates and uses both sensitivity analysis and a least absolute shrinkage and selection operator (LASSO) regression to provide a robust assessment on the influence of the drivers analyzed. For the BES system, the economic sensitivity analysis examines the impact of unit investment cost and tax deductions across four self-consumption increase scenarios. Finally, an environmental sensitivity analysis evaluates how changes in fossil fuel sources within the local energy mix over two different timeframes affect the overall emission reduction potential of the combined PV+BES system.

The objectives of this article are to provide evidence-based answers to the following research questions: Which economic variables most critically impact the financial viability of a PV system under different self-consumption scenarios? How do the unit investment cost and tax incentives for a BES system affect its economic contribution at varying levels of self-consumption increase? Which fossil fuel sources within a regional energy mix have the most significant environmental impact on a PV+BES system's emission reduction potential?

By answering these questions, this work provides an original contribution with direct managerial, methodological, and sustainability implications, reflecting the increasing demand for practice-oriented insights [24]. The rest of this article is structured as follows. Section 2 describes the methodology employed. Section 3 presents the results of these analyses. Finally, Section 4 concludes this article.

2. METHODOLOGY

The sustainability analysis of an integrated PV+BES system is typically carried out using NPV. This indicator is widely adopted in the literature as a key metric for assessing the economic viability of PV+BES systems [19], [20], [21]. The NPV model employed in this work is adapted from existing literature and considers various variables impacting both revenues and costs over the project's lifetime [23]. The general formula for NPV is given by

$$NPV = \sum_{t=0}^n \frac{C_t}{(1+r)^t} \quad (1)$$

where C_t is the net cash flow during a single period t , r is the discount rate (opportunity cost of capital), and n is the number of periods (project lifetime). The case study examines a shopping mall located in Rome. Initial attention is focused solely on the PV system, considering the impact of the share of self-consumption that plays a key role in the economic assessment of PV systems [25], [26], [27]. Self-consumption is the share of locally produced electricity that is used on-site to meet local loads, rather than being fed into the grid.

Three distinct levels of self-consumption are considered: starting from the baseline self-consumption rate of 43.1%, two additional scenarios were defined to represent low and high self-consumption conditions, namely, 20% and 65%, respectively. These values cover a realistic and sufficiently wide operating range of self-consumption levels observed in commercial PV applications and discussed in the literature. Table S1 of the Supplementary Material, available online shows the input data used for this study [21], [23], [28], [29], [30], [31], [32], in which it should be noted that a single purchase price of 0.275 €/kWh (i.e., the average between 0.20 and 0.35 €/kWh, which have

been identified as ranges based on the shopping center's energy bills) is considered. For the sensitivity analysis, a pessimistic scenario was considered by adjusting the base values of the economic variables by 5%. Specifically, cost variables were increased by 5%, while revenue variables were decreased by 5% to assess their impact on NPV.

To further validate the findings and provide a robust assessment of the drivers' influence on NPV, a LASSO regression analysis was conducted [33]. LASSO regression is particularly suitable for this study as it performs both variable selection and regularization, which helps prevent overfitting and improves the interpretability of the model when dealing with a relatively large number of correlated predictor variables, but requires a preliminary step on variable scaling to have the same magnitude for the different units of measurement of the variables [34]. Although LASSO may exhibit instability in variable selection when predictors are highly correlated, our results are interpreted in terms of the relative importance and ranking of drivers. This mitigates potential concerns related to multicollinearity. In this article, the z-score normalization approach was employed. The dependent variable (Y) for the LASSO regression was defined as the difference in NPV between the base case scenario (for each of the three self-consumption levels) and the new NPV resulting from a 5%, 8%, and 10% pessimistic variation in a single economic parameter. While the 5% variation represents the magnitude adopted in the previous sensitivity analysis [21], the additional 8% and 10% variations were introduced as stress-test scenarios to assess the robustness and stability of the ranking of the economic drivers under different conditions. This approach allows for a direct quantification

of each variable's impact on profitability relative to a baseline and enables verification that the relative importance of the drivers is not sensitive to the specific magnitude of the parameter perturbation.

In the BES analysis, the reported values of 0%, 10%, 20%, and 30% represent incremental increases in self-consumption relative to the baseline PV self-consumption rate of 43.1%, rather than absolute self-consumption levels [21]. In this case, the analysis focuses on specific variables that are involved in the economic evaluation of a PV+BES and that were not analyzed previously in the PV system. The scenario-based parameter perturbations (comprising three variations across 15 parameters for three self-consumption levels, yielding a total of 135 simulated scenarios) served as the input dataset for the LASSO regression. The results of these simulations (and used as data for the LASSO regression) are presented in Table S2 of the Supplementary Material, available online. To estimate the λ parameter used in the LASSO regression, a K-fold cross validation approach (with $K = 10$) was employed. The details on the Lambda estimation used in this work are reported in Figure S1 of the Supplementary Material, available online. The optimal λ estimated and used in this work is 0.3563.

Regarding the environmental aspect, the reduction in emissions is calculated using a clean kWh obtained from PV compared to a kWh obtained from a mix of fossil fuels [23]. The reduction in emissions is calculated as the difference between a mix of fossil fuels and nuclear, obtained based on an energy mix in accordance with the shopping mall's utility bills and the emissions associated with a PV system. The emission values associated with energy sources, including PV+BES

technologies, are shown in Table S3 of the Supplementary Material, available online together with the percentage of the energy mix (PEM) relating to fossil fuels [35], [36], [37]. In this analysis, consistent with the approach adopted for economic factors, the pessimistic scenario was defined by applying a 5% percentage change to the variables considered. In the environmental context, a pessimistic scenario corresponds to a lower overall reduction in emissions. This condition can occur in two cases: 1) when the unit emission values associated with fossil fuels and nuclear power are lower, reducing the environmental benefit of the comparison, or 2) when the unit emission values of the PV source

are higher, increasing the emission level of the renewable system. As regards the PEM, it was decided not to vary it individually (since the variation of one source would have determined at least the variation of another variable) but to analyze two distinct cases belonging to the shopping center's bills relating to a different time period.

3. RESULTS

The analysis of the impact of economic driver variables is divided between the PV system and the BES system. Therefore, the first part will illustrate the variables analyzed in relation to PV (see Section 3.1), followed by those analyzed in relation

to BES (see Section 3.2). The environmental perspective allows for the assessment of changes in terms of emission reductions (see Section 3.3), and finally some points of discussion will be proposed (see Section 3.4).

3.1 PV System—Economic Sensitivity Analysis The results are presented by describing the value of the variable in the initial and final contexts, followed by the NPV/Size in the final and initial contexts, showing how the output varies in percentage terms. Table 1 considers self-consumption in the base scenario, while Tables 2 and 3 consider alternative contexts.

Table 1. Variable Economic Impact Analysis for Self-Consumption at 43.1%.

Variable	Initial value	Final value	New NPV (€/kW)	Percentage delta	Base NPV (€/kW)
Administrative costs (€)	1000	1050	1189	≈0%	1189
Unit cost of PV investment (€/kW)	1500	1575	1105	-7.06%	
Inverter cost (€)	7000	7350	1186	-0.25%	
Decrease in efficiency (%)	0.88	0.92	1179	-0.84%	
Inflation (%)	2	2.1	1188	-0.08%	
Electricity inflation (%)	3	2.85	1153	-3.03%	
Energy purchase price (€/kWh)	0.275	0.26125	1072	-9.84%	
Energy sale price (€/kWh)	0.08	0.076	1160	-2.44%	
Insurance percentage (%)	2	2.1	1168	-1.77%	
Maintenance percentage (%)	1	1.05	1179	-0.84%	
Tax cost percentage (%)	35	36.75	1173	-1.35%	
Opportunity cost of capital (%)	5	5.25	1147	-3.53%	
Loan interest rate (%)	3	3.15	1172	-1.43%	
PV tax deduction (%)	50	47.5	1157	-2.69%	
VAT (%)	10	10.5	1182	-0.59%	

Table 2. Variable Economic Impact Analysis for Self-Consumption at 20%.

Variable	Initial value	Final value	New NPV (€/kW)	Percentage delta	Base NPV (€/kW)
Administrative costs (€)	1000	1050	167	0%	167
Unit cost of PV investment (€/kW)	1500	1575	82	-50.9%	
Inverter cost (€)	7000	7350	164	-1.8%	
Decrease in efficiency (%)	0.88	0.92	160	-4.19%	
Inflation (%)	2	2.1	166	-0.6%	
Electricity inflation (%)	3	2.85	143	-14.37%	
Energy purchase price (€/kWh)	0.275	0.26125	112	-32.93%	
Energy sale price (€/kWh)	0.08	0.076	126	-24.55%	
Insurance percentage (%)	2	2.1	146	-12.57%	
Maintenance percentage (%)	1	1.05	156	-6.59%	
Tax cost percentage (%)	35	36.75	145	-13.17%	
Opportunity cost of capital (%)	5	5.25	147	-11.98%	
Loan interest rate (%)	3	3.15	150	-10.18%	
PV tax deduction (%)	50	47.5	135	-19.16%	
VAT (%)	10	10.5	159	-4.79%	

The results highlight that the variables that have the greatest impact on the percentage change in NPV are the unit investment cost of PV and the purchase price of energy, with variations of approximately 7% and 10%, respectively. Also worth noting is the impact of other variables such as the opportunity cost of capital, electricity inflation, and tax deductions on PV, which account for approximately 3% of the results. It should be noted that the variation in administrative costs tends to be even more minimal when considering the NPV per unit of size. The baseline scenario suggests that improving on-site electricity utilization and carefully monitoring grid purchase prices are more effective profitability levers than marginal reductions in administrative or maintenance costs.

When the percentage of self-consumption is low, a larger share of electricity is exported to the grid. Consequently, the sale price of electricity becomes a more relevant component of total revenues, together with the purchase price and the investment cost variables. In this context, percentage variations are substantially wider because of the relatively low baseline NPV value, with reductions of approximately 51% and 33% associated with the

PV investment cost and the purchase price, respectively. Conversely, in the high self-consumption scenario, percentage variations are more limited, with impacts of approximately 4% and 8% associated with the PV investment cost and the purchase price. Overall, the analysis shows that, starting from the baseline scenario, the impact of the electricity purchase price on profitability becomes greater than that of the PV investment cost. It can therefore be concluded that the critical variables may vary depending on the percentage of self-consumption and that, in accordance with the literature [21], [38], [39], [40], in mature markets (i.e., context characterized by widespread deployment of PV technologies, declining capital costs, relatively stable regulatory frameworks, and a progressive reduction in the dependence on investment subsidies and tax deduction schemes) with incentive structures, such as low tax deductions, the percentage of self-consumption and the purchase price of energy are the two critical variables. The LASSO regression results presented in Figure 1 are consistent with the previously presented sensitivity analyses. Specifically, the unit cost of the inverters and the unit PV investment cost show significant negative coefficients, indicating that an

increase in these costs reduces the NPV. Conversely, the energy purchase price displays a high positive coefficient, suggesting that a higher purchase price positively impacts the NPV. Similarly, the energy sale price shows a positive coefficient, which aligns with the positive effect of selling surplus energy on profitability, particularly in low self-consumption scenarios. The regression also highlights the strong positive coefficient associated with the self-consumption rate (a higher self-consumption rate produces a higher NPV).

3.2. BES System: Economic Sensitivity Analysis The BES analysis shows that, starting from a self-consumption percentage set equal to the baseline scenario (43.1%), the adoption of this technology will lead to an increase in the self-consumption percentage following three distinct increments (10%, 20%, and 30% relative to the baseline, as shown in Section 2), alongside a 0% increment case representing the most negative (and least realistic) scenario, which is not characterized by any increase (see Table 4).

The results clearly show a significant increase in NPV with the greatest

Table 3. Variable Economic Impact Analysis for Self-Consumption at 65%.

Variable	Initial value	Final value	New NPV (€/kW)	Percentage delta	Base NPV (€/kW)
Administrative costs (€)	1000	1050	2158	-0.05%	2159
Unit cost of PV investment (€/kW)	1500	1575	2074	-3.94%	
Inverter cost (€)	7000	7350	2156	-0.14%	
Decrease in efficiency (%)	0.88	0.92	2145	-0.65%	
Inflation (%)	2	2.1	2158	-0.05%	
Electricity inflation (%)	3	2.85	2110	-2.27%	
Energy purchase price (€/kWh)	0.275	0.26125	1981	-8.24%	
Energy sale price (€/kWh)	0.08	0.076	2140	-0.88%	
Insurance percentage (%)	2	2.1	2138	-0.97%	
Maintenance percentage (%)	1	1.05	2148	-0.51%	
Tax cost percentage (%)	35	36.75	2149	-0.46%	
Opportunity cost of capital (%)	5	5.25	2094	-3.01%	
Loan interest rate (%)	3	3.15	2141	-0.83%	
PV tax deduction (%)	50	47.5	2127	-1.48%	
VAT (%)	10	10.5	2151	-0.37%	

variation as the increase in self-consumption grows. In all contexts, the investment cost of the BES emerges as a determining variable, but it should be noted that its weight becomes less significant when the increase in self-consumption becomes more substantial (in fact, the NPV varies from 16% to 3% in the two extreme scenarios of self-consumption increase considered). The same applies to the tax deduction on the BES, which varies from 8% to 1%. This figure, like the previous one on the PV system,

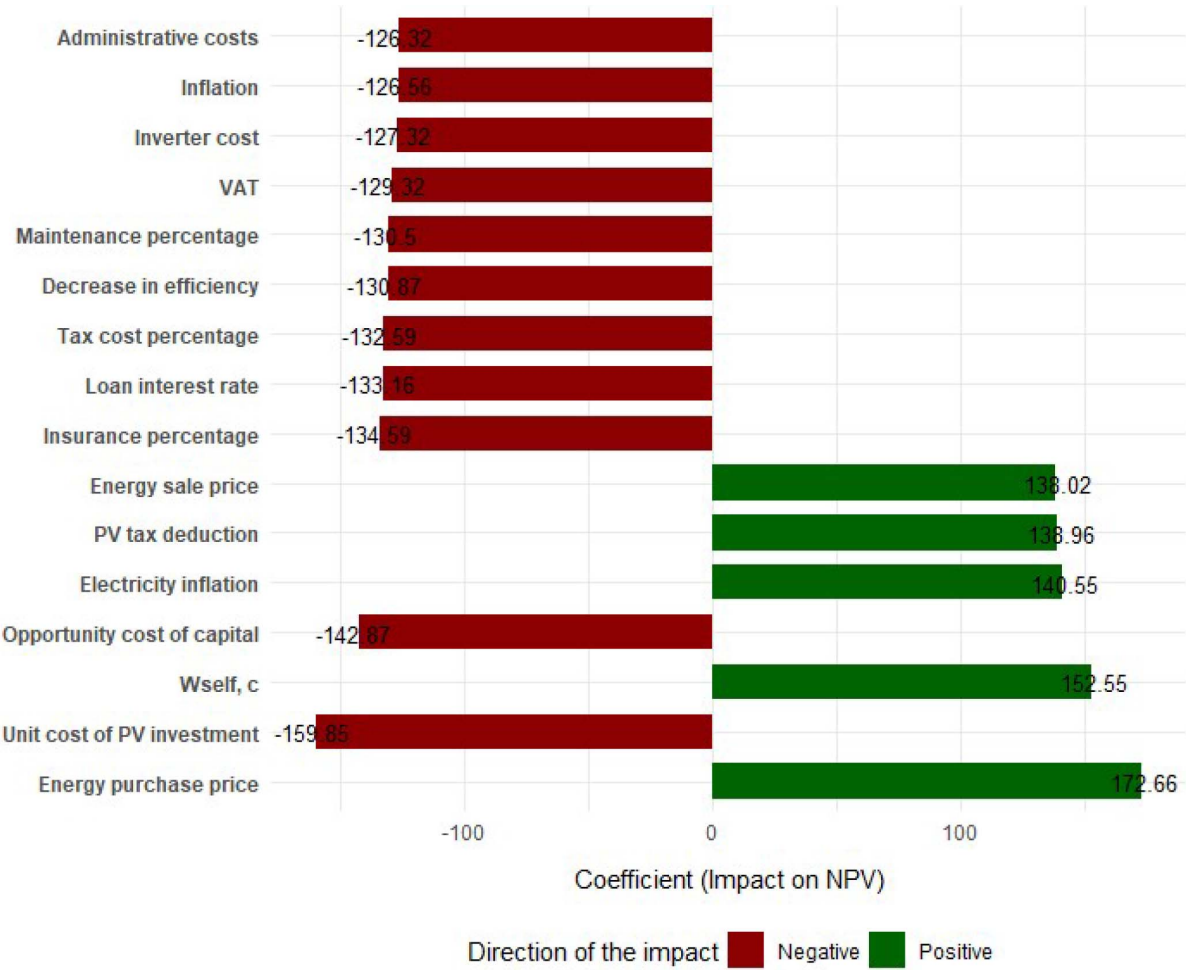


Figure 1. LASSO Regression coefficients based on z-score-standardized inputs. Note: the intercept has been removed to improve the interpretability of the impacts. Positive coefficients indicate variables associated with an increase in Δ NPV, while negative coefficients indicate variables associated with a decrease in Δ NPV.

Table 4. Variable Economic Impact Analysis for Self-Consumption at 43.1% and a Different Increase in Self-Consumption.					
Variable	Initial value	Final value	New NPV (€/kW)	Percentage delta	Base NPV (€/kW)
Increase in self-consumption 0%					
Unit cost of BES investment (€/kWh)	700	735	244	-16%	289
BES tax deduction (%)	50	47.5	265	-8%	
Increase in self-consumption 10%					
Unit cost of BES investment (€/kWh)	700	735	687	-6%	732
BES tax deduction (%)	50	47.5	708	-3%	
Increase in self-consumption 20%					
Unit cost of BES investment (€/kWh)	700	735	1129	-4%	1174
BES tax deduction (%)	50	47.5	1150	-2%	
Increase in self-consumption 30%					
Unit cost of BES investment (€/kWh)	700	735	1572	-3%	1617
BES tax deduction (%)	50	47.5	1593	-1%	

shows a lower impact associated with this policy instrument in terms of economic profitability.

From an operational perspective, BES becomes particularly attractive in commercial applications characterized by high daytime PV production combined with significant evening or peak-hour electricity demand, as these conditions maximize the increase in self-consumption.

It is important to emphasize that a greater number of simulations could be conducted using techniques, such as risk analysis, whose robustness is based precisely on the identification of critical variables, which is the objective of this work [21],[23].

3.3 PV+BES System: Environmental Sensitivity Analysis

The environmental analysis focuses on the integrated PV+BES system. The starting assumption is that the energy mix consists solely of fossil fuels and nuclear, and, consequently, the

percentage of the energy mix only concerns these sources (i.e., 0.6771 indicates that natural gas accounts for 67.71% of the energy mix). The analysis is proposed for two distinct contexts: the data obtained from the energy bill at the start of the project (2024 - Table 5) and that obtained at the end of the project (2025 – Table 6).

The results show that the percentage change is negative, as emissions are lower in the scenario analyzed than in the baseline scenario. It should be noted that there are no significant differences between the two case studies, but this was to be expected given that the two PEMs were not so different. It appears that the result is not influenced by a single factor: natural gas is the least polluting source compared to oil and coal, but since it is very present in the PEM, it has an impact of 3.3 %–3.4%; coal, on the other hand, is the source with the highest emissions and therefore, although it accounts for about one third of natural gas, it has an impact on the

final result of about 2.4%–2.5%. It should be noted that the BES contributes a higher additional embodied emission factor than the PV system when comparing the respective life-cycle emission values adopted in this study. However, despite this additional environmental burden, the overall impact of BES on total emission reduction remains limited in percentage terms (approximately 1.1%), while PV-related variations remain around 0.6%.

3.4. DISCUSSION

These results from integrated PV+BES systems must be viewed within a broader context, in which the specific context must be studied. The issue has been examined through an appropriate review of the economic dimension [41], but the analyses must be interpreted in different contexts. Some analyses show the important role of investment costs [42],[43], while others focus on the percentage of self-consumed energy [44]. To this end, break-even analyses are

Table 5. Variable Environmental Impact Analysis—Initial Project.

Variable	Initial value	Final value	PEM	New RECD (tCO ₂ eq/year)	Percentage delta	Base RECD (tCO ₂ eq/year)
PV (gCO ₂ eq/kWh)	42	44.1	-	76.39	-0.6%	76.82
Oil (gCO ₂ eq/kWh)	518	492.1	0.0296	76.66	-0.2%	
Coal (gCO ₂ eq/kWh)	927	880.65	0.1928	74.96	-2.4%	
Natural gas (gCO ₂ eq/kWh)	372	353.4	0.6771	74.2	-3.4%	
Nuclear (gCO ₂ eq/kWh)	78	74.1	0.0302	76.8	-0.03%	
Other (gCO ₂ eq/kWh)	644	611.8	0.0702	76.35	-0.6%	
BES (kgCO ₂ eq/kWh)	110	115.5	-	75.97	-1.1%	

Note: PEM stands for percentage of energy mix

Table 6. Variable Environmental Impact Analysis – Final Project.

Variable	Initial value	Final value	PEM	New RECD (tCO ₂ eq/year)	Percentage delta	Base RECD (tCO ₂ eq/year)
PV (gCO ₂ eq/kWh)	42	44.1	-	77.47	-0.6%	77.9
Oil (gCO ₂ eq/kWh)	518	492.1	0.0177	77.81	-0.1%	
Coal (gCO ₂ eq/kWh)	927	880.65	0.2038	75.94	-2.5%	
Natural gas (gCO ₂ eq/kWh)	372	353.4	0.6703	75.31	-3.3%	
Nuclear (gCO ₂ eq/kWh)	78	74.1	0.0322	77.88	-0.03%	
Other (gCO ₂ eq/kWh)	644	611.8	0.0757	77.40	-0.6%	
BES (kgCO ₂ eq/kWh)	110	115.5	-	77.05	-1.1%	

Note: PEM stands for percentage of energy mix

conducted on investment costs [25], [45] as well as on the increase in the percentage of self-consumption [21], [23]. These analyses serve to avoid contexts in which BES becomes uneconomical [46]. However, it should be noted that many other variables could be considered: the location of the plant and the size of the integrated plant [47], [48]. In fact, correct sizing through an optimization process has a positive impact on economic output [49]. The sizing of plants, together with the reduction of investment costs, is highlighted in other analyses [50], to which technical aspects must be added, such as the power and charge states of the BES [51] and battery degradation over time [52]. Electricity tariffs play an important role in energy sharing [53], but the use of policy choices on the BES could also push for an increase in self-consumption [40], and different applications of tax deductions could induce prosumers to invest in such projects [23]. The framework proposed in this study provides managers and investors with a replicable model to evaluate the critical variables identified. From a policy and managerial perspective, the Rome shopping-mall case highlights that economic performance is primarily associated with operational variables directly linked to self-consumption dynamics. In particular, the results show that electricity purchase prices, self-consumption rates, and PV+BES investment costs are more influential than tax deduction schemes in mature market conditions. These findings suggest that policy measures aimed at facilitating higher self-consumption and reducing upfront investment costs may be more effective in supporting the diffusion of PV+BES systems in commercial buildings. In fact, correct sizing is necessary not only to increase self-consumption but also to minimize pollutant emissions [54]. The environmental analysis indicates that the emission-reduction potential of PV+BES systems

remains strongly dependent on the composition of the displaced fossil-fuel mix, particularly the relative role of natural gas and coal. Applying a cost to emissions would link the economic component to the environmental component [55], [56]. The literature pays a lot of attention to variations in the value of emissions associated with BES [57], [58], [59]. However, what emerges is that it is essential to measure environmental performance in relation to fossil fuels [23], and the future will be desirable when renewable energy plants have a lower impact on emissions because it will mean that the least polluting fossil fuels will be used. Evidence further confirms that BES profitability depends primarily on increases in self-consumption, supported by favorable policy conditions and lower investment costs, while Monte Carlo analyses show that demand management strategies have a greater impact on economic performance than equivalent reductions in investment costs [2].

From the societal point of view, the results suggest that sustainability requires social innovation [60], [61] and the involvement of young professionals in the energy transition [62]. Individuals are more supportive of projects when the benefits are perceived as advantageous for the local community, highlighting the importance of local involvement [63]. Citizens prioritize self-consumption over government incentives and proximity benefits, highlighting the central role of personal behavior in the adoption of renewable energy. Understanding social dynamics is essential for developing policies that encourage engagement and support a socially driven transition towards SDG 7 [18].

4. CONCLUSION

Sustainability is a complex challenge that requires an interdisciplinary approach to bring together different

perspectives. The concept of pragmatic sustainability draws attention to the use of quantitative methods to demonstrate the conditions under which a project supports the energy transition toward low-carbon solutions. This work has several implications.

From a methodological point of view, it shows how all variables are modified by the same amount to identify those that can be considered critical. This approach can be repeated for different forms of energy and is the basis for conducting sensitivity, scenario and risk analyses that give stability to the results. The use of statistical methods further reinforces what has been achieved.

From an operational point of view, it emerges that in a PV system, the cost avoided in the bill is the variable that most affects the NPV. However, the investment cost of the plant is always significant, but the percentage of self-consumption should not be overlooked, as it rewards virtuous behavior even from an economic perspective. Finally, the sale price is critical in contexts with a low percentage of self-consumption. Regarding BES, it emerges that the increase in self-consumption is the main factor improving economic profitability. In addition, the incidence of the investment cost also assumes significant importance. Both of these analyses showed a lower incidence of tax deductions. This aspect will become increasingly significant in markets where investment costs tend to decrease. From an environmental point of view, the analysis shows that the reduction in emissions resulting from the adoption of a PV+BES system is closely linked to the composition of the reference fossil energy mix. Although BES introduces its own environmental impact, it can contribute significantly to the overall reduction of emissions, especially in the presence of a high penetration of high-emission fossil sources (e.g., coal). Therefore, the

managerial implications suggest that prosumers should pay attention to these variables that affect the economic dimension of the project.

From a sustainability point of view, the policy implications indicate that citizens need to be supported in implementing consumption patterns that are synchronized with production, but the choice to keep purchase prices low could, on the one hand, reduce the attractiveness of PV systems but, on the other hand, prevent energy poverty. Sustainability is called upon to balance this solution, making the ecological transition accessible to all citizens. Tax deductions are a tool that can support those with fiscal capacity, while for families in energy poverty, capital account deduction schemes should be explored to reduce the impact of investment costs, which, in any case, weigh on the profitability of the project. To summarize, the results suggest the following managerial priorities for PV+BES investments:

- 1) assess the expected self-consumption rate before investment, as it is the primary driver of PV and PV+BES profitability;

- 2) prioritize accurate forecasts of grid electricity purchase prices and the selling price of electricity;
- 3) carefully evaluate PV and BES technology investment costs, particularly in low self-consumption or early-market conditions;
- 4) treat incentive schemes and tax deductions as secondary economic levers whose relevance decreases in mature markets; and
- 5) align PV+BES sizing with load profiles to optimize economic returns and emission reductions.

This study is subject to limitations related to its single-case application and to the use of scenario-based parameter variations that may not capture all sources of real-world uncertainty. Future research could extend the framework to multiple case studies across different countries and sectors, integrate stochastic modelling of price dynamics, and explicitly account for battery degradation and operational strategies.

To address these limitations and assess the generalizability of the

findings, it is worth noting that although the empirical application refers to a shopping mall in Rome, the proposed framework is transferable to other geographical contexts. However, the relative importance of the identified drivers is expected to vary depending on market maturity, electricity tariff structures, and incentive regimes. In markets with high retail electricity prices and limited subsidies, self-consumption and avoided energy costs are likely to dominate profitability, whereas in emerging markets or highly incentivized contexts, upfront investment costs and policy support mechanisms may play a more prominent role.

In this perspective, the study contributes directly to the implementation of SDG 7 by linking concrete policy levers to clean energy access. By integrating environmental and economic dimensions, this work delivers a practical, replicable quantitative framework that allows prosumers and policymakers to effectively prioritize interventions, balancing long-term profitability with sustainable energy transition goals.

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