Energy Nexus 21 (2026) 100612

Contents lists available at ScienceDirect

Energy Nexus

journal homepage: www.elsevier.com/locate/nexus

# Green restaurants: An economic assessment of solar photovoltaics and energy storage systems

Idiano D'Adamo [a], Simone Di Leo [a], Massimo Gastaldi [b,*], Anna Chiara Maccallini [c]

[a] *Department of Computer, Control and Management Engineering, Sapienza University of Rome, 00185 Rome, Italy*
[b] *Department of Industrial and Information Engineering and Economics, University of L'Aquila, 67100 L'Aquila, Italy*
[c] *Sapienza University of Rome, Italy*

ARTICLE INFO

*Keywords:*
Economic analysis
Photovoltaic
Prosumer
Storage
Sustainable development

## ABSTRACT

The transition to sustainable business models in the catering sector requires the integration of environmental innovation with economic feasibility. Restaurants, as energy-intensive businesses, represent a strategic context for assessing the financial viability of renewable energy technologies. This study evaluates the economic viability of photovoltaic (PV) and battery energy storage (BES) systems in Italy. The analysis evaluates the project under different policy conditions, with and without public incentives (40 % capital deduction on investment costs), and identifies the key factors that influence their profitability. A comprehensive methodology combining financial and sensitivity analysis, scenario analysis, LASSO regression, break-even point and Monte Carlo simulations was applied to assess economic performance and risk. The results show that the PV system is profitable in both contexts, although incentives significantly improve returns: from 425 to 1590 €/kW. Profitability depends mainly on specific production, the cost of purchasing electricity and the percentage of self-consumption. For the BES, profitability only occurs when self-consumption increases by at least 22–25 % with incentives and 30–35 % without them. Overall, the results emphasise that policy support and management strategies to optimise self-consumption are key to ensuring financial profitability. This work enables restaurant owners to identify the variables that most strongly influence the final outcome, helping them mitigate risks and maximise returns, while supporting more informed decisions that contribute to long-term sustainable development.

## 1. Introduction

The transition from fossil fuels to renewable sources is a cornerstone of the energy transition outlined in the Clean Energy for All Europeans legislative package and the RED II directive. The adoption of sustainable practices is essential to achieving energy independence, a strategic objective of the European Union, by encouraging the active participation of prosumers [1,2]. In this context, Renewable Energy Communities emerge as tools capable of generating economic value for prosumers while promoting collective well-being, for example through investments in public infrastructure or support for vulnerable families, reinforcing the principles of sustainable development [3]. These aspects are part of the growing attention that energy infrastructure is receiving in the European context [4].

The spread of photovoltaic (PV) systems goes beyond purely technical or regulatory considerations: it represents an overall strategy to align decarbonisation objectives with social well-being and community resilience [5–7]. The theme is highlighted in its environmental [8], social [9] and technological [10] dimensions and in its optimisation analysis techniques [11,12].

Economic analyses of PV systems are widely covered in the literature, aimed at understanding the dynamics of adoption and the factors influencing their diffusion [13,14]. Several studies also propose a technical-economic approach [15,16]. However, the intermittency of PV systems represents a critical limitation. The issue of storage plays a crucial role [17]. In fact, battery energy storage (BES) systems, particularly lithium-ion batteries, offer viable solutions, as evidenced by numerous technical-economic analyses [18,19]. Some studies highlight the relevance of environmental aspects [20,21]. Similarly, the recycling of PV modules is also carefully evaluated [22].

The installation of PV systems alone may discourage the subsequent adoption of BES [23], but integration does not always result in economic benefits [24]. From an economic point of view, the integration of BES systems increases the percentage of self-consumed energy [25], but

---

* Corresponding author.
*E-mail address:* massimo.gastaldi@univaq.it (M. Gastaldi).

https://doi.org/10.1016/j.nexus.2025.100612
Received 28 October 2025; Received in revised form 5 December 2025; Accepted 8 December 2025

investment costs remain high [26–28]. Therefore, the economic viability of PV+BES systems depends on multiple factors. The economic savings do not always offset the investment costs of batteries, even in contexts with favourable tariffs [29]. Other scenarios with net metering show favourable economic conditions [30]. Strategic decisions should be informed by the identification of effective approaches for the optimal sizing of PV+BES systems [31], taking into account the diverse energy profiles and consumption patterns of different building types [32].

The payback periods for integrated PV+BES systems can be similar to or longer than those for photovoltaic systems alone, making public subsidies necessary to encourage their adoption [33]. Temporary subsidies for energy storage systems are crucial to promote the adoption of clean technologies [34], while self-consumption legislation can incentivize the use of BES to maximise on-site PV electricity use [35]. Nonetheless, challenges persist - such as investment returns, regulatory uncertainty, safety, and limited public awareness [36] - with tariff structures remaining key to the economic viability of both standalone and storage-integrated PV systems [33].

It is crucial to quantify the required increase in self-consumption for BES integration to become more advantageous than a stand-alone PV system. This parameter, along with the associated savings on electricity bills, is fundamental when evaluating applications in public [37], residential [38], and industrial [39] buildings. The findings highlight that prosumers play a key role in advancing sustainable urban development and achieving SDG 7 [38], with integrated PV+BES systems representing a form of green innovation [39]. Moreover, assessing different policy scenarios is essential to determine their economic feasibility [37].

Recent research in the catering sector shows that sustainable values and corporate social responsibility perceptions strongly influence consumer attitudes and intentions [40]. When customers view operators' actions as genuinely altruistic, this enhances the perceived sustainable value and increases their willingness to pay a premium price [41]. Although some analyses propose specific analyses for restaurants [42], in general these investments fall within the category of commercial buildings, which are closely monitored in relation to economic and political factors [31,37].

This work has two main objectives. First, an in-depth literature review will be conducted to establish the state of the art regarding the economic feasibility of PV/BES in the commercial sector, highlighting critical research gaps and policy implications. Second, the objective of this research is to assess the economic viability of a sustainable restaurant project through an economic analysis of PV and PV+BES systems. The study aims to determine the financial viability of PV and PV+BES configurations in different policy scenarios (with or without capital deduction), identifying the key variables that most influence profitability through LASSO modelling and sensitivity analysis. The ultimate goal is to define the condition (such as incentive schemes, investment costs, and self-consumption levels) under which the integration of storage technologies becomes economically advantageous, supporting informed decision-making and the development of effective energy transition policies.

## 2. Literature review

Recent literature emphasises the central role of energy storage in enabling flexible and reliable renewable energy systems. Several studies examine current storage technologies and their relevance to modern energy systems [43]. Research also focuses on decarbonisation strategies and optimisation methods for industrial applications, including energy-conscious production planning [44] and hybrid models for renewable resource integration [45].

Advances in forecasting and optimisation further support system performance, as demonstrated by artificial intelligence-based modelling [46]. Technical-economic analyses highlight the feasibility of photovoltaic systems combined with batteries in various contexts, from grid-connected configurations [47] to residential scenarios with peer-to-peer sharing [48] and university campuses [49]. Broader sustainability perspectives, including circular economy principles [50] and global environmental strategies [51], reinforce the need for integrated energy solutions.

The economic analysis of photovoltaic systems combined with battery energy storage has increasingly gained attention in the literature last years. A Systematic Literature Review (SLR) was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [52] to have a full picture of this topic. This procedure was complemented by a bibliometric thematic analysis, as suggested by [53], to integrate quantitative mapping with a qualitative interpretation of research trends.

The literature search was carried out in the Scopus database on 16 October 2025. The initial query, applied to all searchable fields, was formulated as follows:

"photovoltaic" OR "solar" OR "PV" AND "economic analysis" OR "profitability" AND "battery energy storage" OR "BES" AND "model" AND "NPV" OR "net present value"

This preliminary search yielded a total of 430 documents. Two exclusion criteria were then applied:

- E1: The publication was not an article or review.
- E2: The publication was not written in English.

After applying these criteria, the number of articles and reviews was reduced to 362. Given the high number of retrieved documents, a thematic mapping analysis [54] was conducted to have an overview of the main research directions and conceptual clusters in the field, following the approach proposed by [53]. The results of the thematic mapping, based on the 362 articles identified in the initial query, are presented in Fig. 1. In Fig. 1, the four quadrants are based on the research themes centrality (relevance, on the x axis) and density (development on the y axis). There are the motor theme quadrants (high density, high centrality) on the upper right corner, Basic theme quadrant (low density, high centrality) on the lower right corner, Niche theme quadrant (high density, low centrality) on the high left corner and emerging/declining theme quadrant (low density, low centrality) on the bottom left corner.

It should be noted that the most central and mature topics, i.e. those driving scientific development in the field, are renewable energy and techno-economic analysis. These topics combine technical and economic aspects, demonstrating the growing importance of assessing not only technological efficiency but also the economic sustainability of energy solutions. However, smart grids and sensitivity analyses emerge on the borderline with niche topics and basic themes, as does photovoltaics with economic analysis, showing the combination linked to the topic and the methodological step used. One niche topic is optimisation, such as NPV itself; finally, it can be observed that more classic terms such as battery and energy storage are considered, while battery storage is proposed as a niche. Therefore, research tends to integrate technological, economic and sustainability aspects, with a gradual shift towards more integrated and intelligent energy solutions.

Based on the initial thematic mapping, the search strategy was refined to focus more precisely on the core research objective. The previously presented query was limited to the article title, abstract, and keywords fields, resulting in a final set of 23 articles retrieved. Following full-text screening, a total of 19 articles were ultimately selected for inclusion. All stages of the SLR process are presented in the PRISMA flow diagram shown in Fig. S1. The next parts of this section present the main findings from the 19 selected articles, focusing on the three key factors that can affect PV+BES economic sustainability: policy and economic drivers, investment costs and contextual factors, and technical factors.

### 2.1. Policy and economic drivers of PV-BES profitability

The literature sustain that the economic viability of PV+BES solution is highly dependent on economic, technical, and regulatory variables.

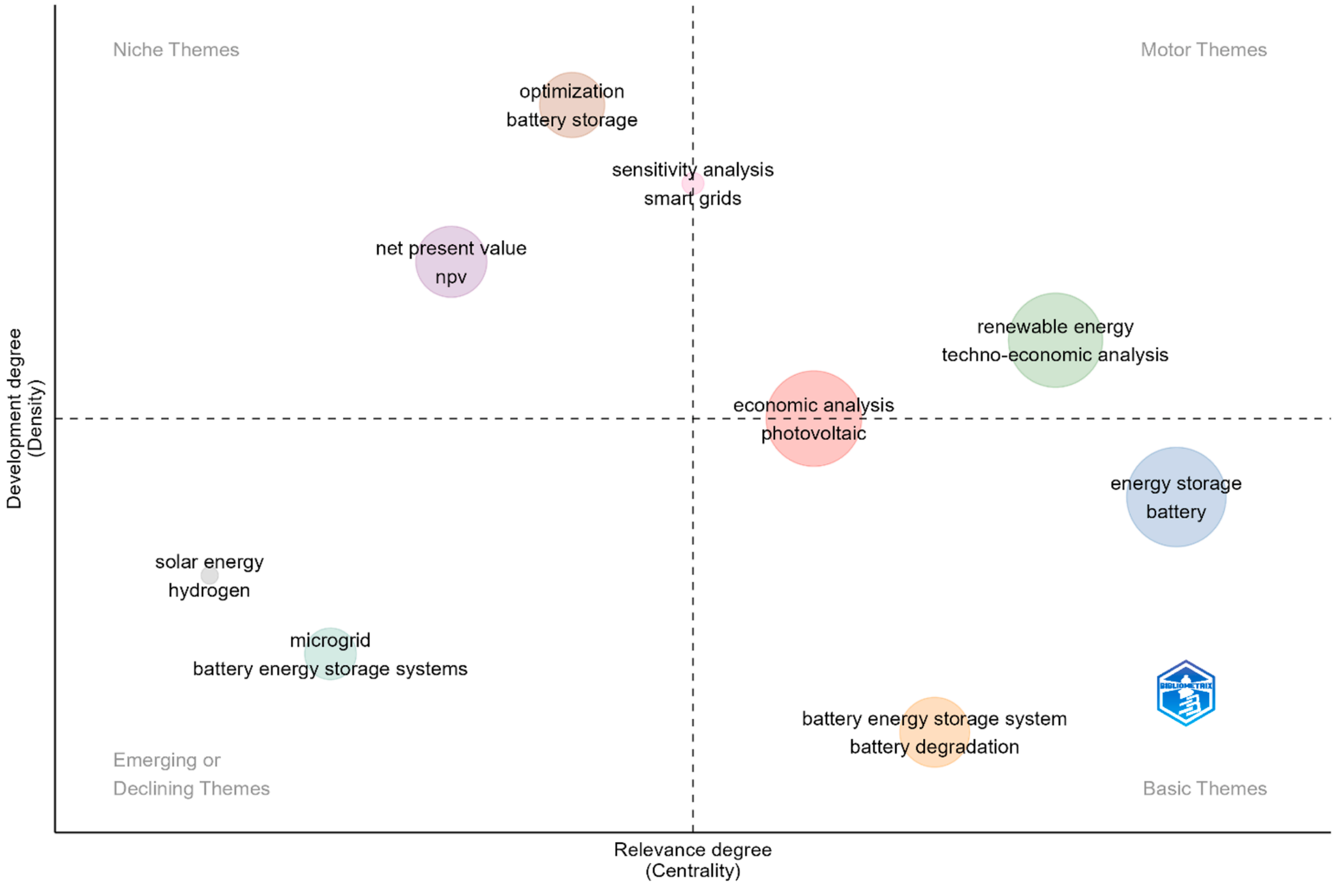

**Fig. 1.** Thematic Map: colors represent the different thematic clusters and bubble size represents theme importance.

Fundamentally, the integration of these systems significantly increases sustainability, particularly through the growth of self-consumption and the application of incentive policies such as tax breaks [38]. Studies consistently identify self-consumption as the most decisive factor for enhancing the profitability of PV-BES systems [38,55]. Furthermore, the economic advantage is often contingent on regulatory frameworks, where the absence of remuneration for surplus energy can make the combined system unprofitable [56–59]. Smart energy management, such as the implementation of Home Energy Management Systems and flexible State-of-Charge management, also demonstrates a clear path to improved profitability and system lifespan [60–62].

### 2.2. *Investment costs and contextual feasibility*

A significant factor emerged from the literature is the necessity of balancing technology choices between cost and performance [63]. Specifically, the cost of storage is recognized as a critically variable factor [64,65]. The economic feasibility of PV+BES systems varies considerably based on geographical and regulatory contexts [59]. Many studies conclude that a sharp reduction in battery prices is required for widespread profitability, although rising electricity prices or a reduction in battery costs can rapidly accelerate the competitiveness of these systems [66,67]. The need to validate models using real-world data and considering the specific context of the installation is also stressed [68].

### 2.3. *Technical factors: sizing, degradation, and management*

Technical considerations are fundamental in model accuracy. The correct sizing of both PV and BES systems is central for maximizing both economic returns and technical efficiency [64]. A rigorous economic models must include the effects of component degradation and replacement to prevent the overestimation of NPV and ensure realistic long-term projections [69,70]. This requires the use of realistic aging models for both PV and BES components, relying on realistic hypotheses if possible. Furthermore, literature suggest that innovative solutions, such as the use of second-life batteries, and the benefits of combining different energy sources can provide economic advantages respect to classical BES [71,72].

## 3. Methodology

Investment strategies can be analysed using a variety of approaches. Markov decision-making identifies strategies that optimise the use of an action policy [73], while other analyses follow a more traditional approach based on comparing revenues and costs [74]. Among investment evaluation tools, the discounted cash flow method plays a central role in the evaluation of long-term projects, as it assumes that the value of a project corresponds to the sum of its future cash flows, discounted to take into account the cost of capital and investment risk [3,75].

The methodological approach adopted in this study integrates deterministic and stochastic analyses to assess the economic feasibility and robustness of photovoltaic and photovoltaic + BES systems in the restaurant case study. The workflow includes an economic model (Section 3.1) and input data (Section 3.2). Subsequently, a LASSO (Least Absolute Shrinkage and Selection Operator) regression model was used to identify the most influential variables explaining the changes in NPV ($\Delta$NPV) compared to the baseline configuration. NPV is a key indicator for assessing the economic sustainability of PV + BES projects [37,76].

### 3.1. *Model*

The indicators typically used are Net Present Value (NPV), which measures the profits achieved by the project; Internal Rate of Return (IRR), which measures the percentage return on the project; Discounted Payback Time (DPBT), which quantifies the time period in which the project pays for itself; Profitability Index (PI), which quantifies the profits per unit of investment cost; and NPV/SIZE, which relates profits to the size of the project.

The technical data was simulated using PVsyst 8.0.15 software for a 24 kW system located on the roof of a restaurant in Rome. The system covers approximately 135 m$^2$, with a 30° tilt and 0° (south) orientation. The simulation yielded a net annual production of 32,773 kWh, corresponding to a specific production of 1366 kWh/kW. Instead, the last year will be equal to 28,678 kWh due to the degradation of PV plant.

The economic model of reference is that proposed in the literature [37] and is modified according to two political scenarios:

- one with a non-repayable capital deduction of 40 % (PI scenario);
- one without any grant (NPI scenario).

The political variable in this model has a direct impact on costs, reducing their amount. The cash flow analysis encompasses several components. In particular, the annual cash flows generated by the PV system (for each year t, where t ∈ {0,1,…,20}) can be attributed to the following categories. On the revenue side, the main inflows derive from avoided energy costs, representing the savings from self-consumption, and from the sale of surplus energy fed into the grid. However, the latter is expected to decrease when a storage system is implemented, as it allows for more efficient energy management and higher self-consumption. On the cost side, investment costs financed by third-party capital stand out, while maintenance and insurance costs are notable among operating costs. Following the literature [77,78], BES capacity is sized proportionally to the PV system. This work adopts a BES-to-PV ratio of 1.5, as this configuration is widely used in similar techno-economic studies and typically maximises the increase in self-consumption while keeping costs manageable [38]. Analytically, Eq. (1) proposes the NPV and Eqs. (2)–(4) describe the revenue components, separating the savings from self-consumption and the revenues from electricity sold to the grid. Eqs. (5)-(6) proposes the energy production and Eqs. (7)–(8) summarise the structure of investment, O&M, and financial costs, which together determine the discounted outflows. Finally, Eq. (9) describes the policy tool applied to the investment cost.

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

$$\mathrm{DCI(PV)} = \sum_{t=1}^{N} \frac{\mathrm{ECA_t}}{(1+r)^{\mathrm{t}}} + \sum_{t=1}^{N} \frac{\mathrm{SP_{el,t}}}{(1+r)^{\mathrm{t}}} \tag{2}$$

$$\mathrm{ECA_t} = \mathrm{w_{self,c}} \cdot \mathrm{E_{out,t}} \cdot \mathrm{p_{c,t}} \text{ with } \mathrm{p_{c,t}} = \mathrm{p}_{\mathrm{c},t=1} \cdot (1 + \mathrm{inf_{el}})^{t-1} \tag{3}$$

$$\mathrm{SP_{el,t}} = \left(1 - \mathrm{w_{self,c}}\right) \cdot \mathrm{E_{out,t}} \cdot \mathrm{p_{s,t}} \text{ with } \mathrm{p_{s,t}} = \mathrm{p}_{\mathrm{s},t=1} \cdot (1 + \mathrm{inf_{el}})^{t-1} \tag{4}$$

$$\mathrm{E_{out,t}} = \mathrm{P_{PV}} * \mathrm{S} \tag{5}$$

$$\mathrm{E}_{\mathrm{out},t+1} = \mathrm{E_{out,t}} \cdot \left(1 - \mathrm{dE_f}\right) \tag{6}$$

$$\begin{aligned}\mathrm{DCO(PV)} = \mathrm{C_{ae}} &+ \sum_{t=1}^{N} \frac{\mathrm{p_m} \cdot \mathrm{C_{inv}} \cdot (1+\mathrm{inf})^{t-1} + \mathrm{p_a} \cdot \mathrm{C_{inv}} \cdot (1+\mathrm{inf})^{t-1} + \left(\mathrm{SP_{el,t}} \cdot \mathrm{p_{cTax}}\right)}{(1+r)^{\mathrm{t}}} \\ &+ \sum_{t=0}^{\mathrm{N_{debt,PV}}-1} \frac{\left(\frac{\Delta \mathrm{C_{inv,PV}}}{\mathrm{N_{debt,PV}}}\right) + \left(\Delta \mathrm{C_{inv,PV}} - \mathrm{C_{lcs,t}}\right) \cdot \mathrm{r_d}}{(1+r)^{\mathrm{t}}} + \frac{\mathrm{C_{inv,I}}}{(1+r)^{10}}\end{aligned} \tag{7}$$

$$\mathrm{C_{inv,PV}} = \mathrm{C_{inv,PV,u}} \cdot \mathrm{S} \cdot (1 + \mathrm{Vat}) \tag{8}$$

$$\Delta \mathrm{C_{inv,PV}} = \mathrm{C_{inv,PV}} * (1 - \Delta \mathrm{P}\ (\mathrm{PV})) \tag{9}$$

Focusing on the storage system, its size is typically defined in proportion to the PV system, with B and S representing the BES and PV capacities, respectively. This relationship is fundamental because it determines the associated increase in self-consumption [55,79]. To enhance self-consumption, a BES capacity of 36 kWh was selected, corresponding to a BES-to-PV ratio of 1.5. Given a battery lifespan of ten years, replacement is required after the first decade of operation. The economic assessment of the BES mainly depends on the increase in self-consumption it provides, which must justify the investment. As for the PV system, discounted cash inflows related to the BES are computed through analogous relationships. Eqs. (10)–(13) details the extension of the economic model considering BES, where costs and revenues are dependent on the increase in self-consumption. Also in this case, Eq. (14) shows the role of policy tool applied to the investment cost.

$$\mathrm{NPV(BES)} = \mathrm{gross\ NPV(BES)} + \sum_{t=1}^{N} \frac{\left(\Delta \mathrm{w_{self,c}} \cdot \mathrm{E_{out,t}} \cdot \mathrm{p_{c,t}}\right)}{(1+r)^{\mathrm{t}}} \tag{10}$$

$$\mathrm{gross\ NPV(BES)} = -\mathrm{DCO(BES)} \tag{11}$$

$$\begin{aligned}\mathrm{DCO(BES)} = &\sum_{t=1}^{N} \frac{\left(\mathrm{p_{m,BES}} \cdot \mathrm{C_{inv}} \cdot (1+\mathrm{inf})^{t-1} + \mathrm{p_{a,BES}} \cdot \mathrm{C_{inv}} \cdot (1+\mathrm{inf})^{t-1}\right.}{(1+r)^{\mathrm{t}}} \\ &+ \sum_{t=0}^{\mathrm{N_{debt,BES}}-1} \frac{\left(\frac{\Delta \mathrm{C_{inv,BES}}}{\mathrm{N_{debt,BES}}}\right) + \left(\Delta \mathrm{C_{inv,BES}} - \mathrm{C_{lcs,t}}\right) \cdot \mathrm{r_d}}{(1+r)^{\mathrm{t}}}\end{aligned} \tag{12}$$

$$\mathrm{C_{inv,BES}} = \mathrm{C_{inv,BES,u}} \cdot \mathrm{B} \cdot (1 + \mathrm{Vat}) \tag{13}$$

$$\Delta \mathrm{C_{inv,BES}} = \mathrm{C_{inv,BES}} * (1 - \Delta \mathrm{P}\ (\mathrm{BES})) \tag{14}$$

Finally, the overall NPV initially allows the profitability of the first technology (PV) to be measured and then assesses whether the integrated system (PV+BES) is more cost-effective than the PV system alone (Eq. (15)). The other indicators used in this work are presented in Eqs. (16)-(19).

$$\mathrm{NPV(PV+BES)} = \mathrm{NPV(PV)} + \mathrm{NPV(BES)} \tag{15}$$

$$\sum_{t=0}^{N} \frac{\mathrm{I_t} - \mathrm{O_t}}{(1 - \mathrm{IRR})^{\mathrm{t}}} = 0 \tag{16}$$

$$\sum_{t=0}^{\mathrm{DPBT}} \frac{\mathrm{I_t} - \mathrm{O_t}}{(1+r)^{\mathrm{t}}} = 0 \tag{17}$$

$$\mathrm{PI} = \frac{\mathrm{NPV}}{\mathrm{C_{inv}}} \tag{18}$$

$$\mathrm{NPV} \Big/ \mathrm{SIZE} = \frac{\mathrm{NPV}}{\mathrm{S}} \tag{19}$$

### 3.2. *Input data*

This section outlines the rationale behind the selection of several variables used in the economic model. It begins with the two main parameters for discounting cash flows: a useful life of 20 years and an opportunity cost of capital of 5 %. These values were defined based on the relevant literature and subsequently validated through consultation with two experts.

A restaurant's electricity consumption depends on both its operational scale and the number of customers served, as larger sizes and higher customer numbers correspond to higher energy loads. For this scope, the restaurant's annual electricity consumption was set at 30,000 kWh based on data from a sample of restaurants in Rome. Consumption data must be compared with production data, which in turn depends on the location and size of the plant, so it is also essential to understand the space available for installation. According to production data, it is possible to estimate a self-consumption percentage of 40 %; in fact, this estimate was calculated taking into account energy consumption with production peaks that are higher in the summer months. It should also be noted that in a city with a strong tourist vocation, both in terms of religious and cultural sites, there is also high demand at lunchtime. The large number of tourists also makes restaurant opening hours very flexible. Based on data from the restaurants examined and evaluating the data reported on Eurostat, the purchase price of energy was estimated at 0.26 €/kWh, while the sale price was estimated at 0.11 €/kWh according to GSE data. The unit cost of PV investment is 1450 €/kW and that of BES is 650–750 €/kWh. In addition, inverter cost is assumed equal to 15 % of the investment cost. Table 1 reports all input data of this work [3,37–39,80–84].

### 3.3. LASSO regression

To identify the variables that most significantly influence ΔNPV, this study employed the LASSO regression method originally introduced by [85]. The LASSO regression was applied various simulated scenarios, generated by varying the case study parameters within the ranges reported in Table S2. Each observation corresponds to an alternative PV or PV+BES configuration defined by different productivity levels, cost assumptions, policy conditions and self-consumption values. This ensures that variable selection reflects the behaviour of the case study. LASSO performs simultaneous coefficient estimation and variable selection by imposing an L1-penalty on the regression coefficients, leading to sparse solutions where many coefficients are exactly zero. Its optimization problem is defined as:

**Table 1**
Input data.

| Variable | Acronym | Value | Unit |
|---|---|---|---|
| BES size | $B$ | 36 | kWh |
| Adminstrative/Electrical connection cost | $C_{ae}$ | 1300 | € |
| Investment cost (BES) | $C_{inv,BES}$ | $f\ (B,\ C_{inv,BES,u})$ | € |
| Investment cost (PV) | $C_{inv,PV}$ | $f\ (S,\ C_{inv,PV,u})$ | € |
| BES unit investment cost | $C_{inv,BES,u}$ | 650–750 | €/kWh |
| Investment cost (inverters) | $C_{inv,I}$ | $f\ (C_{inv,PV})$ | € |
| Unitary investment cost (PV) | $C_{inv,PV,u}$ | 1450 | €/kW |
| Discounted cash inflows | DCI | $f\ (I_t,\ r,\ N)$ | € |
| Discounted cash outflows | DCO | $f\ (O_t,\ r,\ N)$ | € |
| Decreased efficiency of the system | $dE_f$ | 0.7 | % |
| Energy output | $E_{out}$ | 28,678–32,773 | kWh/y |
| Avoided energy cost | ECA | - | € |
| Cash inflows | $I_t$ | - | € |
| Rate of inflation | Inf | 2.5 | % |
| Rate of energy inflation | $inf_{el}$ | 2 | % |
| Useful life of the plant | $N$ | 20 | Y |
| Lifetime of a BES system | $N_B$ | 10 | Y |
| Period of loan (BES) | $N_{debt,BES}$ | 5 | Y |
| Period of loan (PV) | $N_{debt,PV}$ | 10 | Y |
| Inverter useful life | $N_I$ | 10 | Y |
| Cash outflows | $O_t$ | - | € |
| Percentage of assurance (PV) | $p_a$ | 1 | % |
| Percentage of assurance (BES) | $p_{a,BES}$ | 1 | % |
| Electricity purchase price | $p_c$ | $f\ (p_{c,t=1}; inf_{el})$ | €/kWh |
| Electricity purchase price ($t = 1$) | $p_{c,t=1}$ | 0.26 | €/kWh |
| Percentage of taxes cost | $p_{cTax}$ | 40 | % |
| Productivity (PV) | $P_{PV}$ | 1366 | kWh/kW |
| Percentage of maintenance (PV) | $p_m$ | 2 | % |
| Percentage of maintenance (BES) | $p_{m,BES}$ | 1 | % |
| Electricity selling price | $p_s$ | $f\ (p_{s,t=1}; inf_{el})$ | €/kWh |
| Electricity selling price ($t = 1$) | $p_{s,t=1}$ | 0.11 | €/kWh |
| Opportunity cost of capital | R | 5 | % |
| Interest rate on the loan | $r_d$ | 3 | % |
| Plant size | S | 24 | kW |
| Sale of produced energy | $SP_{el}$ | - | € |
| Value-added tax | Vat | 10 | % |
| Percentage of self-consumption | $w_{self,c}$ | 40 | % |
| Investment cost net of capital deduction (BES) | $\Delta C_{inv,BES}$ | $f\ (\Delta P\ (BES);\ C_{inv,BES})$ | € |
| Investment cost net of capital deduction (PV) | $\Delta C_{inv,PV}$ | $f\ (\Delta P\ (PV);\ C_{inv,PV})$ | € |
| Capital deduction (BES) | $\Delta P\ (BES)$ | 40 | % |
| Capital deduction (PV) | $\Delta P\ (PV)$ | 40 | % |
| Delta percentage of self-consumption | $\Delta w_{self,c}$ | 10–30 | % |

$$\widehat{\beta}^{LASSO} = \operatorname{argmin}\left\{\frac{1}{2n}\sum_{i=1}^{n}\left(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j\right)^2 + \lambda\sum_{j=1}^{p}\left|\beta_j\right|\right\} \tag{20}$$

where ($y_i$) is the response variable, $x_{ij}$ are the predictors, $\beta_j$ are the regression coefficients, $n$ is the number of observations, and $\lambda$ is the regularization parameter controlling the strength of penalization. When $\lambda = 0$, the method is equal to the standard OLS regression; as $\lambda$ increases, coefficients are shrunk toward zero, and less influential variables are eliminated from the model [86]. LASSO was selected over standard OLS regression for various reasons. First, it enables automatic variable selection and model regularization, providing interpretable results even when the number of predictors is relatively large compared to the number of scenarios analyzed [85]. Second, by penalizing large coefficients, LASSO reduces overfitting and improves generalization performance on unseen data [87]. Third, it effectively handles multicollinearity, since the L1 penalty tends to retain only one variable among a group of correlated predictors while setting the others to zero. Lastly, the method aligns with the managerial objective of identifying the most critical decision levers that predominantly drive the economic outcome. The LASSO model was implemented using the glmnet package (Friedman et al., 2010), which applies coordinate descent optimization for efficient computation. The regularization parameter $\lambda$ was selected via 10-fold cross-validation, following the standard procedure of minimizing the mean squared prediction error.

## 4. Results

The sustainable restaurant project is not limited to introducing innovative environmental solutions, but also requires verification that these choices are supported by solid economic sustainability. This work analyses the baseline scenario for a PV system (Section 4.1) and then describes the LASSO analysis (Section 4.2) and evaluation of alternative scenarios for this technology (Section 4.3). The next step consists of evaluating the BES (Section 4.4) and the related LASSO analysis (Section 4.5).

### 4.1. PV base scenario analysis

The installation of a 24 kW PV system was subjected to an in-depth financial analysis in order to assess whether the investment is capable of generating adequate returns and reducing exposure to energy cost risks. The economic viability of a PV system does not depend solely on technical and financial parameters, but also on the political and institutional context in which the investment is made. It should be noted that self-consumption is set at 40 %. In this regard, a comparative analysis of two scenarios was developed in order to appropriately assess the economic viability of this investment (Table 2):

**Table 2**
Financial indicators in the PI and NPI scenarios.

| | PI scenario | NPI scenario |
|---|---|---|
| NPV | 38,175 € | 10,212 € |
| DPBT | 5 years 2 months | 15 years 5 months |
| IRR | 40 % | 9 % |
| PI | 0.90 | 0.20 |
| NPV/SIZE | 1590 €/kW | 425 €/kW |

- the scenario with capital contribution - political with incentives (PI), which provides for a capital contribution equal to 40 % of the initial investment
- the alternative scenario without contribution - political no incentives (NPI), which represents the case in which the company must bear the entire investment cost.

The results show that in both cases the investment is profitable, but with very different levels of profitability. In the PI scenario, the NPV reaches 38,175 €, while in the NPI scenario it drops to 10,212 €, with a loss of profitability of over 28,000 €. There are therefore significant differences in profitability. An analysis of the entire 20-year useful life of the system shows that without the public incentive, the DPBT moves beyond 15 years: this means that most of the period would be absorbed only by the recovery of initial costs, leaving little margin for producing actual economic benefits. On the contrary, with the non-repayable grant, the return on investment occurs in about 5 years, i.e. in just over a quarter of the total duration. This means that, for a restaurant, the system would start to generate net benefits very early on, making the operation much safer and more cost-effective. In terms of relative profitability, the PI scenario achieves an IRR of 40 %, well above the opportunity cost of capital, while in the NPI scenario, the IRR stands at 9 %, which, although positive, reduces the attractiveness of the project. Similarly, the PI drops from 0.90 to 0.20, signalling a drastic reduction in the return per euro invested. The return per unit of power (NPV/SIZE) in the incentivised scenario reaches 1590 €/kW, while without the subsidy the value drops to only 425 €/kW: a difference that confirms the decisive impact of public support policy. Therefore, although the plant is profitable even without subsidies, state support allows for a substantial improvement in all financial indicators. This not only increases economic convenience, but also reduces the risk perceived by the company, shortening payback times and guaranteeing returns significantly higher than the market benchmark. It is therefore clear that the current policy scenario is an effective tool for accelerating the energy transition and encouraging private investment in the renewable energy sector.

The distribution of cash flows allows for the breakdown of inflows and outflows (Table S1) over the useful life. In the case with a subsidy, the total discounted revenues amount to approximately 72,633 €, of which the majority, 65 %, derives from savings on bills thanks to self-consumption of energy, while the remaining 35 % comes from the sale of energy fed into the grid. This data confirms that the economic advantage of the system is mainly linked to its ability to replace the purchase of electricity from the grid, given that the unit purchase price (0.26 €/kWh) is significantly higher than the sale price (0.11 €/kWh). On the other hand, the total discounted costs amount to approximately 34,458 €. The breakdown shows that the most significant item is capital costs, which account for approximately 40 % of the total, followed by maintenance, taxes and insurance costs, which account for 26.5 %, 16.6 % and 10.2 % respectively. Interest costs (2.5 %) and electricity connection costs (3.8 %) are more marginal. Without the subsidy, revenues side remains unchanged; in fact, the economic model used in this study assumes that the capital grant has a direct impact on reducing investment costs. Instead, the cost situation changes significantly. The total discounted costs amount to approximately 62,421 €, with capital costs accounting for more than half of the total (55.8 %), followed by maintenance costs (24.4 %). Therefore, with the non-repayable grant, the weight of the initial capital is significantly reduced and the cost structure is more balanced.

### 4.2. LASSO PV analysis

In order to assess the soundness of the results obtained in greater depth, it is not sufficient to analyse only the distribution between costs and revenues, which provides a static snapshot of economic convenience. Instead, it is necessary to understand how the NPV can vary as the main technical and economic variables change, in order to highlight which parameters, have the greatest impact on overall profitability. With this in mind, a quantitative analysis based on the LASSO method was applied, with the aim of identifying the most relevant variables that influence the change in the net present value of the investment (ΔNPV). Starting from the fourteen independent variables relating to technical and economic parameters (e.g. production per kW, electricity purchase cost, unit investment, self-consumption, maintenance, etc.) and their ranges of variation – Table S2, Fig. 2 shows the results of this analysis (with the optimal $\lambda = 0.00514$).

The LASSO analysis highlighted a clear distinction between relevant and negligible variables relating to the PI scenario. Specific production per kW was found to be the most relevant parameter: even small variations have a marked effect on ΔNPV. An increase in production, linked to above-average levels of insolation, translates into improved profitability, while a reduction has the opposite effect. A second determining factor is the cost of purchasing electricity. When the price of energy rises, self-production becomes relatively more advantageous, resulting in an increase in ΔNPV. Conversely, lower prices reduce the economic benefit associated with the system. An equally important role is played by the self-consumption share, which reflects the restaurant's ability to directly use the energy produced. The higher the self-consumption, the lower the dependence on the grid and the higher the profitability. Alongside these three main variables, the unit investment is also highly relevant, ranking among the top four variables influencing ΔNPV. Increases in the initial cost significantly reduce the economic viability of the system. Further impacts derive from the variables of energy sales and opportunity cost of capital.

In the NPI scenario, the LASSO analysis shows (Fig. S2) that production per kW remains the most decisive variable, followed most significantly by the unit investment cost, indicating that in the absence of public incentives, the initial outlay becomes a critical lever for the economic sustainability of the plant. The cost of purchased electricity and the share of self-consumption are also confirmed as relevant, but the opportunity cost of capital and the energy sales tariff are also critical. Finally, the variables emerging as dominant in the LASSO model (specific production, energy purchase cost, and self-consumption) are precisely those generating the largest variations in the sensitivity analysis, confirming the internal coherence of the results.

Table 3.

### 4.3. Alternative PV scenarios

#### 4.3.1. Sensitivity analysis

The degree of stability of the results is examined in greater detail below through a sensitivity analysis, modifying the most critical parameters individually:

- the opportunity cost of capital (+2 %, +4 %), which reflects macroeconomic conditions and directly influences the discounting of cash flows;
- the energy sales tariff (+0.01 €/kWh, +0.02 €/kWh) and the purchase cost (±0.02 €/kWh, ±0.04 €/kWh), which represent the main items of revenue and savings and are subject to significant market fluctuations;
- specific production per kW (±5 %, ±10 %), a technical parameter that depends on climatic conditions and the geographical location of the plant.

The results show that an increase in opportunity cost leads to a significant reduction in profitability. The NPV falls from 1590 €/kW to 1267 €/kW and 1018 €/kW, highlighting that an increase in opportunity cost from 5 % to 7 % leads to a reduction of 323 €/kW and a further 249 €/kW when it reaches 9 %. Consequently, in these contexts, future cash flows weigh less heavily and the profitability of the project decreases.

As regards the reduction in the energy sales tariff of 0.01 €/kWh, this leads to a decrease in profitability of 59 €/kW and 114 €/kW when it is

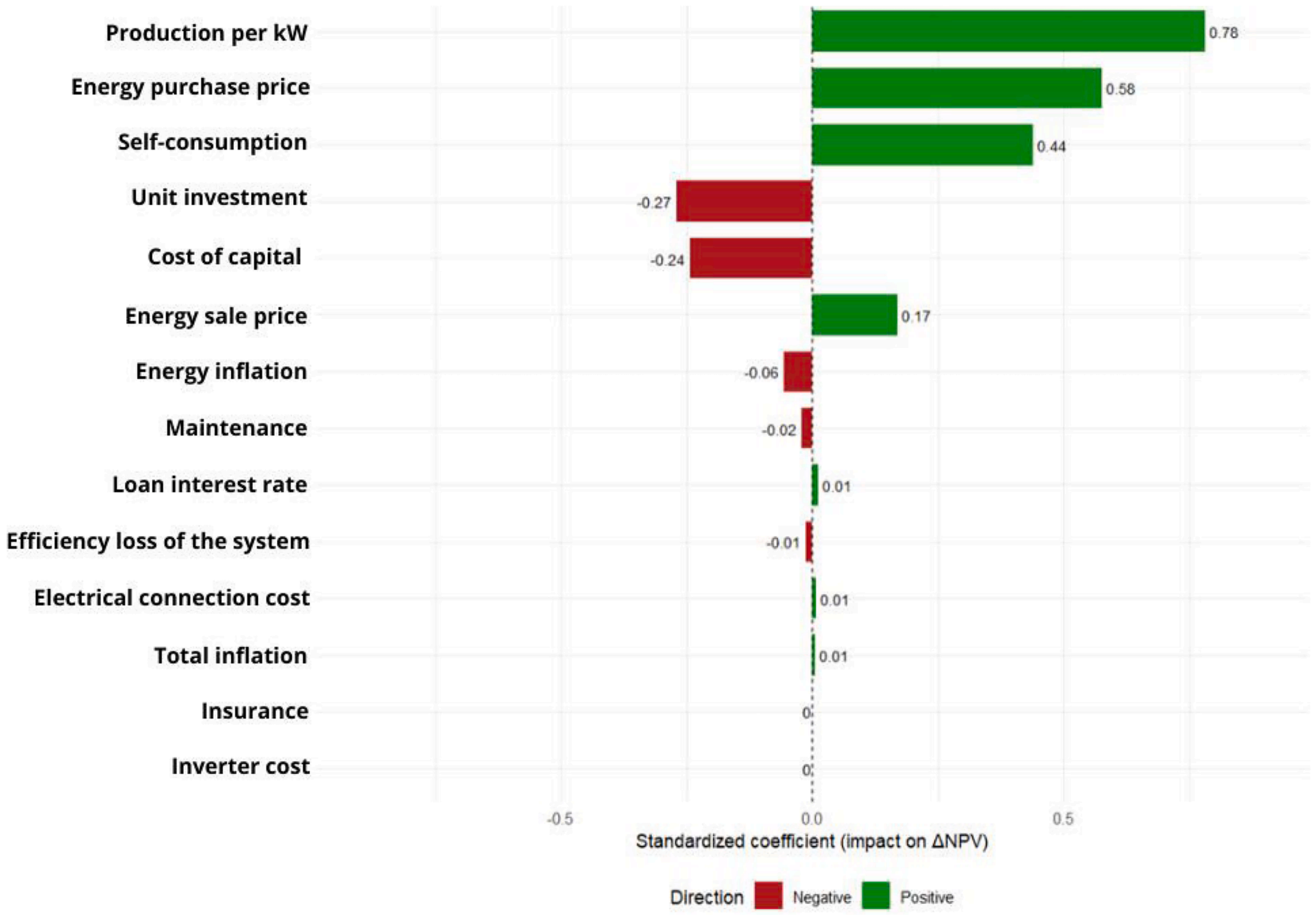

**Fig. 2.** Results of the LASSO analysis for the PI scenario – PV system.

**Table 3**
Sensitivity analysis – NPV in the PI scenario.

| Case study | Value | NPV (€) | NPV/SIZE (€/kW) |
|---|---|---|---|
| Base scenario | | 38,175 | 1590 |
| Opportunity cost | 7 % | 30,410 | 1267 |
| | 9 % | 24,422 | 1018 |
| Energy sales tariff | 0.10 €/kWh | 36,790 | 1531 |
| | 0.09 €/kWh | 35,300 | 1417 |
| Energy purchase cost | 0.22 €/kWh | 30,927 | 1289 |
| | 0.24 €/kWh | 34,551 | 1440 |
| | 0.28 €/kWh | 41,799 | 1742 |
| | 0.30 €/kWh | 45,423 | 1893 |
| Production per Kw | 1229 kWh/kW | 31,883 | 1328 |
| | 1297 kWh/kW | 35,029 | 1460 |
| | 1433 kWh/kW | 41,321 | 1722 |
| | 1502 kWh/kW | 44,467 | 1853 |

reduced by 0.02 €/kWh. This confirms that, although energy sales contribute positively to the economic result, their weight is lower than the savings obtained from self-consumption. The variation in this variable is affected by market mechanisms and public policies. It should be noted that a reduction in this variable could encourage greater self-consumption but could penalise those who are not in a position to implement virtuous behaviour.

The cost of purchasing electricity has also been varied in optimistic scenarios, as this value tends to fluctuate greatly and can vary over time depending on the market. The results show that the impact of the purchase cost is very significant: for every variation of ±0.02 €/kWh, the NPV undergoes a deviation of 3624 €, equal to approximately 150 €/kW. This confirms that the cost-effectiveness of the project is strongly linked to the price on the bill and that favourable market scenarios (reduction in purchase cost) reduce profitability, while unfavourable scenarios (increase in cost) increase it. This effect is due to the logic of self-consumption: the higher the cost of avoided energy, the greater the benefit for the company.

The variable production per kW depends on the level of insolation, a parameter that varies naturally depending on climatic conditions, and given the criticality that emerged from LASSO, it is varied in optimistic and pessimistic scenarios. Each 5 % increase in production results in an increase in NPV of 3146 €, equal to approximately 131 €/kW. Similarly, a reduction in production generates a negative impact of a similar magnitude. This result highlights the advantages of those territories favoured by their location, but underlines the strategic role of technology in design choices. However, some phenomena will not depend on the designers but on phenomena linked to climate change, which can accentuate variability: periods with greater solar radiation increase profitability, while adverse weather conditions reduce it.

The same sensitivity analysis was replicated for the alternative political scenario without incentives. In this case, the absolute NPV values are significantly lower than in the base scenario, highlighting lower economic robustness. Despite this, the dynamics of variation follow a consistent trend: the same variables have a greater impact on profitability, albeit with different intensities. A negative NPV emerges when the opportunity cost of capital is set at 9 % - Table S3.

### 4.3.2. *The percentage of self-consumption*

The percentage of self-consumption is a crucial variable for the profitability of the investment, since the direct use of the energy produced allows for the maximisation of economic benefits. It varies from

0 % (sale-only scenario) to 100 % (self-consumption-only scenario) with a range of 10 % in both policy scenarios – Tables 4 and S4.

The results show that every 10 % increase in self-consumption corresponds to a systematic increase in NPV/SIZE. In the scenario with subsidies, the indicator rises from around 67 €/kW in the case of sales only to 3605 €/kW with total self-consumption, with an average increase of around 355 €/kW for every 10 % of self-consumption. In the scenario without subsidies, the values for NPV/SIZE are negative up to 20 % self-consumption and only become positive from 30 % onwards, reaching 2329 €/kW at 100 %. In this case, the average increase is approximately 350 €/kW for every 10 % of self-consumption. A comparison of the two scenarios shows that, for the same self-consumption, the PI scenario guarantees on average around 1000–1200 €/kW more than the NPI scenario. The comparison between the two scenarios shows that the contribution significantly improves profitability, bringing forward the break-even point (which becomes immediate) and raising the overall NPV values. However, the trend in marginal variations remains similar: in both cases, self-consumption guarantees maximum incremental benefits up to 50–60 %. These results have important management implications. Self-consumption should not be interpreted solely as a technical parameter, but as a genuine management behaviour. The restaurant's ability to synchronise its consumption with solar production is in fact the key to maximising economic benefits. With this in mind, targeted business strategies, such as scheduling energy-intensive consumption during peak sunlight hours, can significantly increase economic returns. Furthermore, it should be noted that actual self-consumption also depends on external factors, such as seasonality of demand and weather conditions, which influence solar production and consumption profiles. Looking ahead, the introduction of storage systems or demand side management techniques could make it possible to go beyond the identified threshold of convenience, reducing the loss of value associated with diminishing marginal returns.

### 4.3.3. Scenario analysis

After performing sensitivity analyses on individual variables, a scenario analysis was developed with the aim of assessing the impact of a change in several critical parameters (Table S5). This approach allows for the simulation of a pessimistic-realistic situation, in which the project is confronted with less favourable conditions in terms of both costs and revenues, making it possible to verify the overall soundness of the investment (Table 5).

When only the variables related to revenues are modified, it becomes clear that these play a crucial role in determining overall profitability. With a 40 % public contribution, the project remains very solid: the NPV remains above 33 k€ and the IRR falls slightly but remains high (34 %). In other words, even assuming less favourable conditions on the revenue side, the investment continues to guarantee attractive returns. The situation changes significantly in the absence of a contribution. In this case, the NPV falls to 5 k€ and the IRR to 7 %. These values indicate that the project is still profitable, but with extremely limited margins.

To construct a more comprehensive pessimistic cost scenario, the analysis incorporates variations not only in the investment cost but also in maintenance and insurance. Although the LASSO results did not identify the last as critical, their cumulative impact on the overall cost structure justifies their inclusion for the risk assessment. The results show that the NPV is reduced to around 35 k€ and the IRR remains high (36 %). Without the subsidy, however, profitability is significantly lower: the NPV is around 4 k€ and the IRR is 7 %. The scenario without public funding appears much more critical. It should be noted that this does not indicate that costs have a greater impact than revenues, but depends on the input values assumed for revenues, which show a smaller reduction between the two pessimistic scenarios assumed in the sensitivity analysis, and on the greater weight that investment costs have in the NPI scenario. Finally, when there is a simultaneous change in both revenues and costs, the NPV is reduced to 30 k€ in the PI context, but the same changes lead to a sharp deterioration in economic indicators in an NPI context, resulting in a non-profitable situation.

**Table 4**
Sensitivity analysis of the impact of self-consumption on NPV/SIZE (PI vs NPI).

| | PI scenario (€/kW) | NPI scenario (€/kW) |
|---|---|---|
| 0 | 67 | −1098 |
| 10 | 448 | −717 |
| 20 | 829 | −336 |
| 30 | 1210 | 45 |
| 40 | 1591 | 425 |
| 50 | 1972 | 801 |
| 60 | 2353 | 1161 |
| 70 | 2731 | 1493 |
| 80 | 3082 | 1806 |
| 90 | 3396 | 2120 |
| 100 | 3605 | 2329 |

### 4.3.4. Break-even point PV analysis

The break-even point (BEP) analysis was carried out with the aim of identifying the minimum conditions that guarantee the economic sustainability of the project, i.e. those that bring the NPV to zero (Table 6).

The first variable considered was the percentage of self-consumption. The analysis only concerned the alternative policy scenario, since in the baseline policy scenario (PI) the plant is profitable even with zero self-consumption and therefore no critical threshold is recorded. The results show that, in the scenario without public subsidies, the NPV is zero when self-consumption is around 29 %. The analysis was then applied to the purchase price of electricity, which shows a value of 0.049 €/kWh and 0.204 €/kWh in the two respective policy scenarios. Therefore, in the base policy scenario, unprofitability occurs with exceptionally low prices, which are unlikely to be observed in practice. Conversely, in the alternative policy scenario (NPI), the break-even threshold proposes a value that is much more sensitive to potential real conditions. The last variable considered is production per kW. Here too, the results confirmed the different robustness of the two scenarios: in the PI, the critical threshold is around 545 kWh/kW, a level well below the average reference production (1365 kWh/kW), indicating that the investment maintains ample safety margins. In the NPI, on the other hand, the critical value is approximately 1146 kWh/kW: this means that economic viability is only maintained if the plant achieves production levels close to the expected average, making the investment more exposed to the risk of possible reductions in insolation or efficiency.

### 4.3.5. PV risk analysis

The Monte Carlo analysis was carried out with a thousand iterations to estimate the variability of the overall economic results (Fig. S3–4). Starting from each base scenario (PI and NPI), variations were introduced on the main critical variables: r productivity (−5 % and +5 %), energy price (from 0.26 €/kWh to 0.24 €/kWh), self-consumption level (30 % and 50 % compared to the base value of 40 %) and opportunity cost of capital (from 5 % base to 7 % and 9 %). For each configuration, three probabilities were calculated: i) the probability that the NPV is greater than zero; ii) the probability that the NPV exceeds the base NPV value of the reference scenario; and iii) the probability that the NPV exceeds the minimum NPV value, corresponding to the most unfavourable but positive condition emerging from the sensitivity analysis - Table 7.

In the PI Scenario, all the scenarios examined show a consistently positive NPV, confirming the soundness of the investment. In the base case, the probability of exceeding the reference NPV (38,175 €) is 50.9 %, with results distributed in a balanced manner. Compared to the minimum value identified in the sensitivity analysis (24,422 €), the probability of exceeding it remains 100 %, indicating safety margins even in the worst-case scenarios. Productivity has a decisive impact: with −5 %, the probability of exceeding the base NPV drops to 3.9 % and that of exceeding the minimum to 96.2 %; with +5 %, the values reach

**Table 5**
Pessimistic scenario analysis on financial indicators (PI vs NPI).

| | PI revenues | PI costs | PI revenues + costs | NPI revenues | NPI costs | NPI revenues + costs |
|---|---|---|---|---|---|---|
| NPV | 33,113 € | 35,113 € | 30,052 € | 5123 € | 4133 € | −1286 € |
| DPBT | 5 years 8 months | 5 years and 7 months | 6 years and 1 month | 17 years 8 months | 18 years 2 months | >20 years |
| IRR | 34 % | 36 % | 31 % | 7 % | 7 % | 4.5 % |
| PI | 0.80 | 0.82 | 0.72 | 0.15 | 0.14 | - |
| NPV/SIZE | 1379 €/kW | 1463 €/kW | 1252 €/kW | 213 €/kW | 172 €/kW | - |

**Table 6**
BEP analysis in the two policy scenarios.

| Variable | PI | NPI |
|---|---|---|
| Percentage of self-consumption | – | 28.8 |
| Energy purchase price | 0.049 €/kWh | 0.204 €/kWh |
| Specific production per kW | 545 kWh/kW | 1146 kWh/kW |

99.9 % and 100 % respectively. Self-consumption is also decisive: by reducing it to 30 %, the probability of exceeding the base NPV drops to 0.6 % and that of exceeding the minimum to 88.1 %; with 50 %, on the other hand, it rises to 96.9 % and 100 %. The price of energy, on the contrary, has a marginal impact. Far more significant is the opportunity cost of capital: at 7 %, the probability of exceeding the base value falls to 2.2 % (93.4 % on the minimum), and at 9 % – a highly unlikely scenario, almost double the reference value – the probability of exceeding the base NPV falls to 0 % and that on the minimum to 52.6 %. Therefore, all case studies are profitable: even in the worst-case scenario, the project remains viable, albeit with reduced margins.

In the base case of the NPI scenario, the probability of a positive NPV is not total but remains high (94.6 %). Compared to the reference value (10,212 €), the probability of exceeding it is 49.5 %, while compared to the minimum NPV (2964 €), it stands at 88.9 %. Already here, a greater fragility emerges compared to the PI scenario. Productivity confirms its central role: with −5 %, the probability of a positive NPV falls to 84.8 % (27.4 % >base; 74.2 % >minimum), while with +5 %, the values reach 99.9 % (93.1 % >base; ~100 % >minimum). The price of energy has limited effects, while self-consumption is decisive: at 30 %, the probability of positive NPV falls to 56.3 % (6.1 % >base; 38.7 % >minimum), indicating a high risk. This scenario is particularly critical because it may not result from management decisions, but from restaurant usage patterns (e.g., more evening than daytime traffic). Conversely, with 50 % self-consumption, the probabilities return to very high levels (99.8 % >0; 91.5 % >base; 98.9 % >minimum). The opportunity cost has a similar impact to the PI Scenario: at 7 %, the NPV remains positive in 95.9 % of cases (39.6 % > base; 86.3 % > minimum), but at 9 %, the scenario becomes less interesting (48 % > 0; 2.9 % > base; 25.5 % > minimum). Unlike the PI Scenario, here the values do not fall to zero, but remain very low. Therefore, the NPI Scenario is profitable but more vulnerable.

### *4.4. Base scenario analysis BES*

The NPV indicator was used for the economic evaluation of the storage system (BES) of 36 kWh, calculated as the difference between the discounted revenues generated by the increase in self-consumption and the discounted costs of the investment. The costs considered include initial capital costs, financial charges, maintenance costs and insurance costs. Revenues, on the other hand, were estimated as the product of the increase in self-consumption (Δwself), the annual production of the PV system and the price of electricity, updated annually to take inflation into account. Initially, the Gross NPV (BES) is calculated, which does not included revenues linked to the increase in self-consumption, in order to assess the criticality of this variable. This indicator is calculated for both policy scenarios based on two distinct BES investment costs (650 €/kWh and 750 €/kWh) - Table 8.

As expected, in both cases the Gross NPV is negative, highlighting the poor cost-effectiveness of the investment if the increase in self-consumption is not taken into account. In fact, the capital contribution alone results in a NPV of approximately 10 k€ and 11.5 k€ higher in the two investment contexts, but the indicator remains negative. At this point, it becomes essential to consider the increase in terms of potential self-consumption values. There can be multiple combinations that identify the different case studies, so to generalise, three different levels of increase in self-consumption (Δwself = 10 %, 20 %, 30 %) are considered, which also depend heavily on the relationship between the size of the BES-PV system.

For example, Table 8 shows that in the PI scenario with a unit investment of 650 €/kWh, the Gross NPV (BES) is −25,367 €. Considering a 20 % increase in self-consumption, the NPV (BES) becomes −1811 € (Table 9). Consequently, this amount of energy produced by the PV system and used through BES technology is valued at a purchase price of 0.26 €/kWh over its entire useful life, but cannot cover the entire share of additional costs.

The results show that with a 10 % increase, the NPV remains negative in all scenarios, and the same is true with a 20 % increase. Finally, when analysing the 30 % increase, the NPV is positive in the PI scenario,

**Table 8**
Gross NPV (BES).

| BES unitary investment | PI (€) | NPI (€) |
|---|---|---|
| 650 €/kWh | −25,367 | −35,317 |
| 750 €/kWh | −29,270 | −40,751 |

**Table 7**
Probability of exceeding the NPV thresholds in the two policy scenarios. All data in percentage.

| | PI scenario | | | NPI scenario | | |
|---|---|---|---|---|---|---|
| | >0 | >NPVbase (38,175 €) | >NPVmin (24,422 €) | >0 | >NPVbase (10,212 €) | >NPVmin (2964 €) |
| Base | 100 | 50.9 | 100 | 94.6 | 49.5 | 88.9 |
| Productivity −5 % | 100 | 3.9 | 96.2 | 84.8 | 27.4 | 74.2 |
| Productivity +5 % | 100 | 99.9 | 100 | 99.9 | 93.1 | 99.9 |
| Energy price 0.24 | 100 | 50.0 | 100 | 85.2 | 27.9 | 73.1 |
| Self-consumption 30 % | 100 | 0.6 | 88.1 | 56.3 | 6.1 | 38.7 |
| Self-consumption 50 % | 100 | 96.9 | 100 | 99.8 | 91.5 | 98.9 |
| Opportunity cost 7 % | 100 | 2.2 | 93.4 | 95.9 | 39.6 | 86.3 |
| Opportunity cost 9 % | 100 | 0.0 | 52.6 | 48.0 | 2.9 | 25.5 |

**Table 9**

NPV (BES) for different scenarios of increase in self-consumption.

| BES unitary investment | PI (€) | NPI (€) |
|---|---|---|
| **ΔWself =10 %** | | |
| 650 €/kWh | −13,589 | −23,539 |
| 750 €/kWh | −17,492 | −28,973 |
| **ΔWself =20 %** | | |
| 650 €/kWh | −1811 | −11,761 |
| 750 €/kWh | −5714 | −17,194 |
| **ΔWself =30 %** | | |
| 650 €/kWh | 9967 | 17 |
| 750 €/kWh | 6065 | −5416 |

both with a unit cost of 650 €/kWh (9967 €) and with a unit cost of 750 €/kWh (6065 €) and marginally also in the NPI context with a unit cost of 650 €/kWh (17 €). This result therefore highlights the fundamental role played by the actual increase in self-consumption following the adoption of BES.

Although the previous case studies indicate where profitability is verified, it is considered useful to compare the integrated PV+BES system with the PV system alone. Where NPV (PV+BES) > NPV (PV), the integrated system is also more cost-effective from an economic perspective (Table 10).

Analysis of these results shows that the political context affects the final result and also the cost of BES technology, but the factor that seems to have the greatest impact is the increase in self-consumption.

The BEP analysis allows us to identify the minimum increase in self-consumption (Δwself) necessary for the investment in the storage system to become economically profitable (NPV = 0) – Table 11.

The previous analysis showed that the increase in self-consumption was <30 % in the PI scenario, while it was higher than this percentage in the NPI scenario. The BEP results confirm these aspects: 22–25 % emerges in the PI scenario and 30–35 % in the NPI scenario. The two policy contexts show very different values, highlighting how the presence or absence of a capital grant affects the final result. On the other hand, the cost of the BES appears to be less significant, varying from 3 % in the two PI scenarios to 5 % in the two NPI scenarios.

### *4.5. LASSO BES analysis*

To strength the results obtained, the LASSO model was applied, which made it possible to highlight which variables have the greatest impact on ΔNPV, evaluating the context in four different scenarios: the two extreme increases in self-consumption (10 % and 30 %) and the two political scenarios. The analyses were conducted using a penalization parameter $\lambda = 0.00948$ for the 10 % self-consumption increase case and $\lambda = 0.00522$ for the 30 % self-consumption increase case. The analyses were conducted on ten critical variables (Table S6) varying by ±5 % and ±10 %. For the investment cost of BES, the most pessimistic value of 750 €/kWh was chosen. This choice highlights the variable's importance, as the LASSO results identifies the BES unit cost as a highly significant factor influencing ΔNPV (Figs. 3, 4, S5, S6). This confirms that the economic viability of this technology depends on this variable. This variable has a more significant impact on both the cost of purchasing energy and PV production. The only exception is the scenario of a significant increase in self-consumption with capital grants, highlighting how the multiplicity of analyses in these projects is fundamental. In fact, there are individual case studies where significant variations occur: if self-consumption increases significantly and there is a political scenario that makes the investment cost less relevant, even when this parameter has a higher value, it is not the most decisive variable. Similarly, its technological development, economies of scale and experience can lead to clear competitive advantages. Among the other variables, the maintenance cost of the BES deserves particular attention.

**Table 10**

NPV (PV+BES). Data in €.

| Investment cost BES | 10 % Increase of self-consumption | 20 % increase in self-consumption | 30 % increase in self-consumption | PI scenario |
|---|---|---|---|---|
| 650 €/kWh | 24,586 | 36,364 | 48,142 | 38,175 |
| 750 €/kWh | 20,683 | 32,461 | 44,240 | |
| Investment cost BES | 10 % Increase in self-consumption | 20 % increase in self-consumption | 30 % increase in self-consumption | NPI scenario |
| 650 €/kWh | −13,327 | −1549 | 10,229 | 10,212 |
| 750 €/kWh | −18,761 | −6982 | 4796 | |

**Table 11**

– BEP analysis results BES in terms of increase in self-consumption. Data in percentage.

| BES unitary investment | PI | NPI |
|---|---|---|
| 650 €/kWh | 22 | 30 |
| 750 €/kWh | 25 | 35 |

## 5. Discussion

The environmental perspective shows that replacing one kWh produced by a PV plant with one obtained from a fossil fuel plant allows for a reduction of 451.5 $gCO_2eq/kWh$ [37]; however, when the inclusion of a BES is considered, its benefit is reduced. Some analyses have identified an emissions value of 110 $kgCO_2eq/kWh$ [88]. The economic analysis of a PV system is considered useful only for investors. However, the literature presented in the first two sections has highlighted how decision-making processes tend to be multidisciplinary. In this context, the economic aspect is not only one of the three dimensions of sustainability but also provides guidance for optimising the decision-making process. The analyses are conducted at an international level, where NPV tends to be widely used: 10.35 million yuan [89]; (−26,477)–289,328 R$ [90]; 10,000–510,000 USD/$m^2$ [91]; 9100–22,000 $ [92]; 2.37 US$/$m^2$ [93]; 81,996 € [94] and 31,019–232,644 € [84]. Other analyses suggest a payback period of 13.6 years [95], and some are specific to restaurants with utility savings of 7381,929 RM [42]. Analyses applied to the Italian context suggest 457–4013 €/kW in a commercial building applying a 50 % tax deduction [37], 318–2583 €/kW in an industrial context [39], 1535–6703 €/kW in a residential context with a 70 % tax deduction [38] and 2706–6309 €/kW in a context of incentives characterised by renewable energy communities [3]. These analyses highlight how it is possible to observe multiple values, which depend on variations in critical variables, and this is why a decision-making process necessarily requires the presence of baseline and alternative scenarios. The application of storage is also given a lot of attention in the literature. Several studies have focused on analyzing the cost structure and economic performance of BES systems in order to evaluate the financial feasibility and long-term viability of this technology: 400 €/kWh [65]; 150 €/kWh [96]; 200 CNY/kWh [57]; 150–200 €/kWh [82] and 250–500 €/kWh [97]. Large PV–BES systems may represent impractical investments in Greece and Italy, while Cyprus, thanks to its higher solar potential and electricity prices, makes hybrid PV–BES a more viable option for public buildings: 124–175 k€ for Greece, 217–286 k€ for Italy and 258–338 k€ for Cyprus [31]. However, other analyses show that the economic benefits have not been verified [98], while it is verified in other studies with a payback period of 6–7 years [30] and 3 years [99].

A key variable is the percentage of self-consumption, where the following values emerge: 17–23 % and 9–12 % with a 70 % tax deduction and 22–27 % and 11–15 % with a 50 % tax deduction depending on the purchase price of energy [38]; 13–17 % with a purchase price of 0.35 €/kWh and 26–35 % with a price of 0.20 €/kWh with a 50 % tax deduction [37]; 15–20 % and 27–36 % again depending on the purchase price of energy in a context without a favourable tax

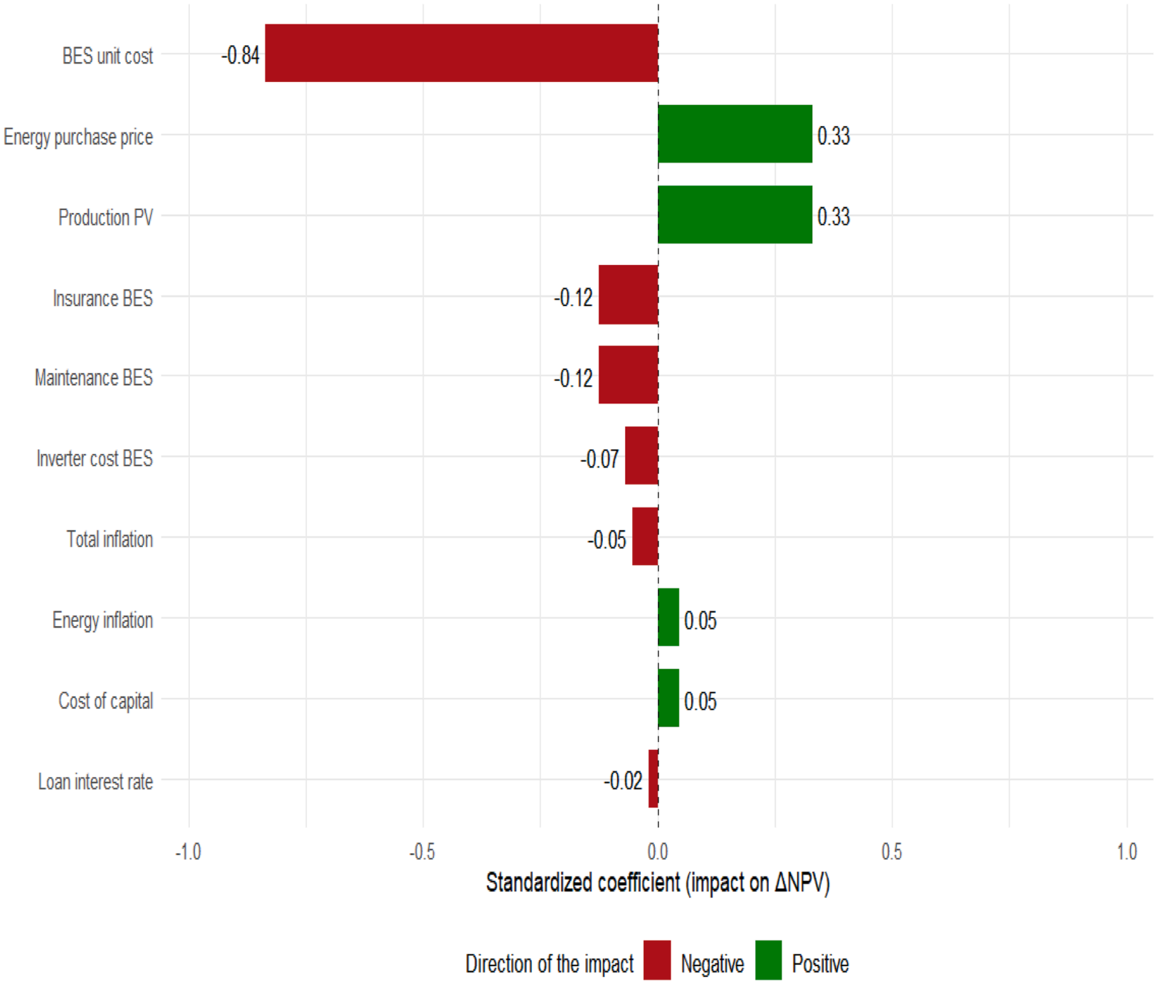

**Fig. 3.** Results of the LASSO analysis PI scenario – BES plant (PI case + 10 % increase in self-consumption).

deduction [39]. Other analyses have shown that self-consumption values are concentrated in the 20–30 % and 23–35 % range, depending on whether the ratio between BES and PV size is 1 and 1.5 respectively [55].

Increasing self-consumption is a key objective for improving the energy efficiency and economic sustainability of PV+BES systems. In restaurants, however, achieving high levels of self-consumption depends not only on the demand profile of the individual business, but also on external factors and shared energy management models. In this context, the creation of energy communities or demand aggregation systems can enable a better match between production and consumption, maximising the local use of the energy produced and reducing the impact on the grid.

From a policy and regulatory perspective, measures need to be introduced to encourage the adoption of these technologies. Incentives are an effective tool, but a distinction must be made between two types of economic support with different effects. Tax relief allows part of the investment to be recovered through tax reductions over several years, offering a gradual benefit over time. Capital allowances, on the other hand, directly reduce the initial cost of the investment, making it more accessible and immediately affordable, especially for small and medium-sized enterprises. An energy policy that combines capital deduction with collective energy management models could effectively promote the spread of PV-BES systems in the catering sector, contributing both to the economic sustainability of businesses and to energy transition objectives.

## 6. Conclusions

The analysis carried out enabled an in-depth evaluation of the economic and financial sustainability of investing in a PV system - either stand-alone or integrated with a BES - within the context of restaurant operations. The methodological approach adopted provided a detailed analysis of the profitability and main risk factors affecting the investment's cost-effectiveness, distinguishing between two different political contexts.

The results of the first research objective highlight the following predominant themes emerging from the SLR: (i) policy and economic drivers of PV-BES profitability; (ii) investment costs and contextual feasibility; and (iii) technical factors related to system sizing, degradation, and management.

The results of the second research objective show that the presence of a capital grant is a determining factor for the economic sustainability of the project. In the case with incentives, all financial indicators are highly positive and exceed the thresholds commonly adopted in the sector confirming that the investment is not only profitable but also offers considerable safety margins. Conversely, in the scenario without subsidies, profitability is drastically reduced; while remaining profitable, the profit is near the limits of economic sustainability for an SME in the catering sector.

The sensitivity analysis highlighted the project's strong dependence on productivity per kW, energy purchase cost and self-consumption share. These parameters confirm the dual nature of the risk: technical, linked to irradiation conditions and plant efficiency, and economic,

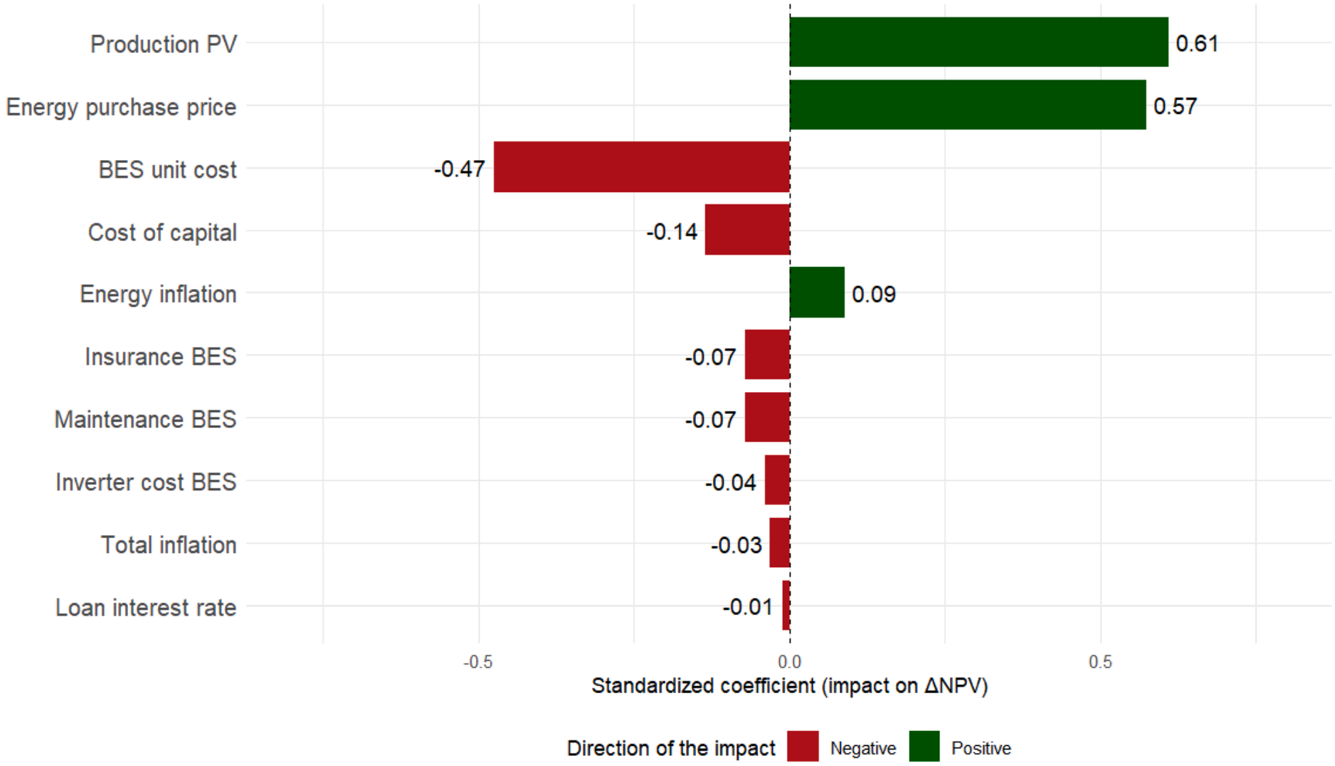

**Fig. 4.** Results of the LASSO analysis for the PI scenario – BES plant (PI case + 30 % increase in self-consumption).

related to energy price trends. Among these, productivity per kW emerges as the most sensitive variable, affecting the overall stability of the project. Similarly, the share of self-consumption is confirmed as a fundamental management lever: increasing it through targeted operational strategies (e.g. scheduling consumption during daylight hours) maximises economic benefits.

A comparison of policy scenarios shows that the presence of an incentive not only increases profitability but also reduces risk exposure. This means that the public incentive acts not only as an economic factor, but also as a financial risk mitigation tool, promoting the bankability of the investment and reducing the uncertainty perceived by operators.

Integration with a storage system (BES) has made it possible to explore technologically advanced but economically more complex scenarios. The results showed that, in the absence of a significant increase in the share of self-consumption, investment in BES is not sustainable: the NPV remains negative in almost all cases. However, when the increase in self-consumption is between 22 % and 25 %, the project becomes profitable in the PI context. This shows that the profitability of BES depends heavily on its ability to valorise the energy produced, while the unit cost of the technology, although significant, is not the main variable in the presence of incentives.

Overall, the study highlights that the economic viability of PV systems for small restaurants depends primarily on self-consumption levels and on the availability of incentives. For restaurants without incentives, self-consumption becomes economically meaningful only above 30 %, informing operational planning and investment timing. Restaurants can improve profitability by shifting energy-intensive activities to high-production hours. When incentives are available, PV systems deliver strong economic returns even with moderate self-consumption, enabling investment even for businesses with limited operational flexibility. The adoption of storage systems is an interesting prospect in terms of energy sustainability and grid independence but still requires cost optimisation and more sophisticated management models to ensure adequate returns. Finally, the robustness of the results in the different scenarios confirms that, despite technical and financial variability, investment in photovoltaics is an effective strategy for reducing energy dependence and contributing to ecological transition objectives, with both economic and environmental benefits.

In this context, the decision analytics approach adopted, integrating quantitative tools such as LASSO regression, break-even analysis and Monte Carlo simulation, has proven particularly effective in supporting investment decisions under conditions of uncertainty. This methodology makes it possible to identify critical variables, quantify risk and provide a rational basis for defining more targeted investment strategies and incentive policies. The application of advanced decision analysis tools thus contributes to transforming energy sustainability from a qualitative objective into a measurable and optimisable process, strengthening the ability of companies to adapt to evolving energy scenarios. This study has several limitations. The analysis relies on a fixed consumption profile, does not model dynamic tariff changes, and focuses on a single restaurant case study. PV and BES degradation are included in simplified form, and the regulatory framework is assumed to remain stable over the plant's lifetime. Future research may extend the model to dynamic load profiles, alternative tariff structures, different business types, and more realistic degradation models. Further future research could be conducted by combining the proposed economic model with optimization or machine learning approaches to support operational decision-making, identifying cost-optimal sizing configurations and adaptive energy management strategies under uncertainty.

In conclusion, the work demonstrates that the political and regulatory framework plays a decisive role in activating investments in renewable energy, reducing payback times and increasing operator confidence. The integration of economic and financial analysis with risk assessment provides a robust approach to support informed investment decisions, laying the foundations for further developments towards more resilient, digitised and self-consumption-oriented energy systems in pursuit of SDG7.

## CRediT authorship contribution statement

**Idiano D'Adamo:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Simone Di Leo:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Massimo Gastaldi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Anna Chiara Maccallini:** 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.

## Acknowledgments

This study was carried out within the PEACE (Protecting the Environment: Advances in Circular Economy) study, which received funding from the "Fund for the National Research Program and Projects of Significant National Interest (PRIN)" Investment M4.C2. 1.1-D.D. 104.02–02–2022, 2022ZFBMA4 funded by the European Union-Next Generation EU. This manuscript reflects only the authors' views and opinions, and the authors can be considered solely responsible for them.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nexus.2025.100612.

## Data availability

Data will be made available on request.

## References

[1] J. López Prol, A. Paul, Profitability landscapes for competitive photovoltaic self-consumption, Energy Policy 188 (2024) 114084, https://doi.org/10.1016/j.enpol.2024.114084.

[2] T. Daglis, M.-A. Katsikogianni, D. Ipsakis, K.P. Tsagarakis, Prosumerism for sustainability, Sustain. Prod. Consum. 55 (2025) 458–469, https://doi.org/10.1016/j.spc.2025.03.002.

[3] P. Basilico, A. Biancardi, I. D'Adamo, M. Gastaldi, V. Stornelli, Socioeconomic dimensions of renewable energy communities: pathways to collective well-being, Util. Policy. 96 (2025) 102000, https://doi.org/10.1016/j.jup.2025.102000.

[4] I. Papamichael, I. Voukkali, K. Vrionides, P. Loizia, M. Stylianou, P. Sospiro, M. C. Liscio, V. Naddeo, A.A. Zorpas, An overview of critical energy infrastructure of the European Defence sector, Energy Nexus. 19 (2025) 100483, https://doi.org/10.1016/j.nexus.2025.100483.

[5] F. Liu, C.W. Su, M. Qin, M. Umar, Is renewable energy a path towards sustainable development? Sustain. Dev. 31 (2023) 3869–3880, https://doi.org/10.1002/sd.2631.

[6] A. Kaab, H. Ghasemi-Mobtaker, M. Sharifi, U. Jørgensen, Evaluating the viability of installing photovoltaic panels on irrigation canals for energy generation and water storage, Energy Nexus. 18 (2025) 100455, https://doi.org/10.1016/j.nexus.2025.100455.

[7] J. Yan, Y. Yang, P.E. Campana, J. He, City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China, Nat. Energy 4 (2019) 709–717, https://doi.org/10.1038/s41560-019-0441-z.

[8] H. Zhang, Y. Song, M. Zhang, Y. Duan, D. Zhao, Ecological environmental impact assessment of photovoltaic and "photovoltaic +" development in China, Renew. Energy 252 (2025) 123509, https://doi.org/10.1016/j.renene.2025.123509.

[9] D. Peñaloza, É. Mata, N. Fransson, H. Fridén, Á. Samperio, A. Quijano, A. Cuneo, Social and market acceptance of photovoltaic panels and heat pumps in Europe: a literature review and survey, Renew. Sustain. Energy Rev. 155 (2022) 111867, https://doi.org/10.1016/j.rser.2021.111867.

[10] A.C. Lazaroiu, M. Gmal Osman, C.-V. Strejoiu, G. Lazaroiu, A comprehensive overview of photovoltaic technologies and their efficiency for climate neutrality, Sustainability. 15 (2023) 16297, https://doi.org/10.3390/su152316297.

[11] N.M Saad, M.Z. Sujod, M.I. Muhammad Ridzuan, M.F. Abas, M.S. Jadin, M. F. Abdul Kadir, A new optimisation framework based on Monte Carlo embedded hybrid variant mean–variance mapping considering uncertainties, Decis. Anal. J. 10 (2024) 100368, https://doi.org/10.1016/j.dajour.2023.100368.

[12] H.A. Kazem, M.T. Chaichan, A.H.A. Al-Waeli, A. Gholami, A systematic review of solar photovoltaic energy systems design modelling, algorithms, and software, Energy Sources, A Recover. Util. Environ. Eff. 44 (2022) 6709–6736, https://doi.org/10.1080/15567036.2022.2100517.

[13] J. López Prol, K.W. Steininger, Photovoltaic self-consumption is now profitable in Spain: effects of the new regulation on prosumers' internal rate of return, Energy Policy 146 (2020) 111793, https://doi.org/10.1016/j.enpol.2020.111793.

[14] G. Aquila, P. Rotella Junior, L.C.S. Rocha, P.P. Balestrassi, E. de Oliveira Pamplona, W.T. Nakamura, Net metering rolling credits vs. net billing buyback: an economic analysis of a policy option proposal for photovoltaic prosumers, Renew. Energy 232 (2024) 121154, https://doi.org/10.1016/j.renene.2024.121154.

[15] M.H. Nabil, J. Barua, U.R.J. Eiva, M.A. Ullah, T.A. Chowdhury, S.M.S. Siddiquee, M.E. Alam, R. Das, Techno-economic analysis of commercial-scale 15 MW on-grid ground solar PV systems in Bakalia: a feasibility study proposed for BPDB, Energy Nexus. 14 (2024) 100286, https://doi.org/10.1016/j.nexus.2024.100286.

[16] S.J. Thomas, S. Thomas, S.S. Sahoo, A.K. G, M.M. Awad, Solar parks: a review on impacts, mitigation mechanism through agrivoltaics and techno-economic analysis, Energy Nexus. 11 (2023) 100220, https://doi.org/10.1016/j.nexus.2023.100220.

[17] L. Malka, A. Daci, A. Kuriqi, P. Bartocci, E. Rrapaj, Energy storage benefits assessment using multiple-choice criteria: the case of Drini River Cascade, Albania, Energies 15 (2022) 4032, https://doi.org/10.3390/en15114032.

[18] S. Dhundhara, Y.P. Verma, A. Williams, Techno-economic analysis of the lithium-ion and lead-acid battery in microgrid systems, Energy Convers. Manage 177 (2018) 122–142, https://doi.org/10.1016/j.enconman.2018.09.030.

[19] G. de Oliveira e Silva, P. Hendrick, Photovoltaic self-sufficiency of Belgian households using lithium-ion batteries, and its impact on the grid, Appl. Energy 195 (2017) 786–799, https://doi.org/10.1016/j.apenergy.2017.03.112.

[20] M. Raugei, P. Winfield, Prospective LCA of the production and EoL recycling of a novel type of Li-ion battery for electric vehicles, J. Clean. Prod. 213 (2019) 926–932, https://doi.org/10.1016/j.jclepro.2018.12.237.

[21] X. Yu, W. Li, V. Gupta, H. Gao, D. Tran, S. Sarwar, Z. Chen, Current challenges in efficient lithium-ion batteries' Recycling: a perspective, Glob. Chall. 6 (2022) 2200099, https://doi.org/10.1002/gch2.202200099.

[22] I. Papamichael, A.A. Zorpas, End-of-waste criteria in the framework of end-of-life PV panels concerning circular economy strategy, Waste Manage Res. 40 (2022) 1677–1679, https://doi.org/10.1177/0734242X221132886.

[23] M. Alipour, E. Irannezhad, R.A. Stewart, O. Sahin, Exploring residential solar PV and battery energy storage adoption motivations and barriers in a mature PV market, Renew. Energy 190 (2022) 684–698, https://doi.org/10.1016/j.renene.2022.03.040.

[24] M. Beuse, M. Dirksmeier, B. Steffen, T.S. Schmidt, Profitability of commercial and industrial photovoltaics and battery projects in South-East-Asia, Appl. Energy 271 (2020) 115218, https://doi.org/10.1016/j.apenergy.2020.115218.

[25] T. Ma, Y. Zhang, W. Gu, G. Xiao, H. Yang, S. Wang, Strategy comparison and techno-economic evaluation of a grid-connected photovoltaic-battery system, Renew. Energy 197 (2022) 1049–1060, https://doi.org/10.1016/j.renene.2022.07.114.

[26] F.M. Camilo, R. Castro, M.E. Almeida, V.F. Pires, Economic assessment of residential PV systems with self-consumption and storage in Portugal, Sol. Energy 150 (2017) 353–362, https://doi.org/10.1016/j.solener.2017.04.062.

[27] J. Klamka, A. Wolf, L.G. Ehrlich, Photovoltaic self-consumption after the support period: will it pay off in a cross-sector perspective? Renew. Energy 147 (2020) 2374–2386, https://doi.org/10.1016/j.renene.2019.10.033.

[28] P. Jivaganont, P. Limthongkul, J. Mongkoltanatas, Profitability of battery energy storage system coupled with photovoltaic at behind-the-meter, J. Energy Storage 121 (2025) 116357, https://doi.org/10.1016/j.est.2025.116357.

[29] C. Cienfuegos, P.M. Rodrigo, I. Cienfuegos, A. Diaz-Ponce, Comparative analysis of battery energy storage systems' operation strategies for peak shaving in industries with or without installed photovoltaic capacity, Renew. Energy Focus 49 (2024) 100574, https://doi.org/10.1016/j.ref.2024.100574.

[30] D. Boruah, S.S. Chandel, Techno-economic feasibility analysis of a commercial grid-connected photovoltaic plant with battery energy storage-achieving a net zero energy system, J. Energy Storage 77 (2024) 109984, https://doi.org/10.1016/j.est.2023.109984.

[31] N.G. Chatzigeorgiou, S. Theocharides, G. Makrides, G.E. Georghiou, Assessment of the economic feasibility of hybrid Photovoltaic – Battery energy Storage Systems in public buildings with flexible load demand: examination study in Southern Europe, Renew. Energy 256 (2026) 124089, https://doi.org/10.1016/j.renene.2025.124089.

[32] H. Li, Q. Chen, T. Zhang, X. Liu, X. Liu, Y. Dai, B. Guan, Can distributed photovoltaic-battery systems power buildings with favorable matching performance and techno-economic feasibility? Energy Convers. Manage 306 (2024) 118260 https://doi.org/10.1016/j.enconman.2024.118260.

[33] Z. Wang, M. Luther, P. Horan, J. Matthews, C. Liu, Technical and economic analyses of PV battery systems considering two different tariff policies, Sol. Energy 267 (2024) 112189, https://doi.org/10.1016/j.solener.2023.112189.

[34] S. Feng, I. Lazkano, Energy storage and clean energy transitions, Energy Policy 198 (2025) 114447, https://doi.org/10.1016/j.enpol.2024.114447.

[35] L. Semmelmann, M. Konermann, D. Dietze, P. Staudt, Empirical field evaluation of self-consumption promoting regulation of household battery energy storage systems, Energy Policy 194 (2024) 114343, https://doi.org/10.1016/j.enpol.2024.114343.

[36] N. Jayaraj, A. Klarin, S. Ananthram, The transition towards solar energy storage: a multi-level perspective, Energy Policy 192 (2024) 114209, https://doi.org/10.1016/j.enpol.2024.114209.

[37] G. Antonini, I. D'Adamo, S. Di Leo, M. Gastaldi, M. Scarcelli, Advancing sustainable development through integrated photovoltaic and battery energy storage systems in commercial buildings: a strategic, economic, and environmental perspective, Sustain. Dev. 33 (2025) 9144–9164, https://doi.org/10.1002/sd.70148.

[38] A. Biancardi, F. Califano, I. D'Adamo, M. Gastaldi, I. Kostakis, A distributed and sustainable model for future cities: a profitability analysis of integrated photovoltaic systems with storage under different incentive policies, Energy Policy 205 (2025) 114691, https://doi.org/10.1016/j.enpol.2025.114691.

[39] G. Ciambellini, I. D'Adamo, M. Gastaldi, M. Smol, Sustainability and competitiveness: economic analysis of a photovoltaic plant with storage in an Italian textile company, Innov. Green Dev. 4 (2025) 100209, https://doi.org/10.1016/j.igd.2025.100209.

[40] W. Mou, S.M. Rasoolimanesh, S.H.-W. Chuah, Beyond taste: examining sustainable value, perceived CSR and consumer behaviour in the restaurant industry, J. Hosp. Tour. Insights 7 (2024) 844–867, https://doi.org/10.1108/JHTI-07-2023-0446.

[41] P. Mahasuweerachai, C. Suttikun, W.H. Bicksler, Green or greed? Generational perspectives of sustainability claims in restaurants, Fam. Consum. Sci. Res. J. 52 (2024) 163–177, https://doi.org/10.1111/fcsr.12500.

[42] M.K. Gunasegaran, M. Hasanuzzaman, C. Tan, A.H. Bakar, V. Ponniah, Energy consumption, Energy analysis, and solar Energy integration for commercial building restaurants, Energies. (Basel) 16 (2023) 7145, https://doi.org/10.3390/en16207145.

[43] E. Enasel, G. Dumitrascu, Storage solutions for renewable energy: a review, Energy Nexus. 17 (2025) 100391, https://doi.org/10.1016/j.nexus.2025.100391.

[44] G.P. Georgiadis, C.N. Dimitriadis, M.C. Georgiadis, Decarbonizing the industry sector: current status and future opportunities of energy-aware production scheduling, Processes 13 (2025) 1941, https://doi.org/10.3390/pr13061941.

[45] G.P. Georgiadis, C.N. Dimitriadis, N. Passalis, M.C. Georgiadis, A hybrid ML-MILP framework for the optimal integration of photovoltaic and battery systems in manufacturing industries, Comput. Chem. Eng. 203 (2025) 109356, https://doi.org/10.1016/j.compchemeng.2025.109356.

[46] E. Gul, G. Baldinelli, J. Wang, P. Bartocci, T. Shamim, Artificial intelligence based forecasting and optimization model for concentrated solar power system with thermal energy storage, Appl. Energy 382 (2025) 125210, https://doi.org/10.1016/j.apenergy.2024.125210.

[47] S. Saurabh, A. Kumar, R. Kumar, Techno economic analysis of grid connected photovoltaic systems with battery energy storage: a comprehensive review, Energy Storage 7 (2025) e70119, https://doi.org/10.1002/est2.70119.

[48] Z. Wang, M. Luther, P. Horan, J. Matthews, C. Liu, Technical and economic analyses of grid-connected residential PV considering batteries and peer-to-peer energy sharing, Renew. Energy 252 (2025) 123494, https://doi.org/10.1016/j.renene.2025.123494.

[49] H. Zhou, J. Bi, Y. Lv, W. Zhao, H. Zhang, T. Du, Techno-economic analysis of solar photovoltaic systems integrated with battery energy storage for university campuses, J. Energy Storage 129 (2025) 117360, https://doi.org/10.1016/j.est.2025.117360.

[50] A.A. Zorpas, The hidden concept and the beauty of multiple "R" in the framework of waste strategies development reflecting to circular economy principles, Sci. Total. Environ. 952 (2024) 175508, https://doi.org/10.1016/j.scitotenv.2024.175508.

[51] A.A. Zorpas, V.J. Inglezakis, I. Papamichael, P. Razis, I. Voukkali, A. Pérez-Gimeno, V. Naddeo, T. Rodríguez-Espinosa, P. Loizia, J. Navarro-Pedreño, Planetary sustainability science and technology: integrating astro-soil, astro-environmental engineering and astro-habitat engineering for space exploration, Sci. Total. Environ. 992 (2025) 179959, https://doi.org/10.1016/j.scitotenv.2025.179959.

[52] M.J. Page, J.E. Mckenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J.M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. Mcdonald, L.A. Mcguinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, (2021) 372. 10.1136/bmj.n71.

[53] A. Avenali, C. Daraio, S. Di Leo, G. Matteucci, T. Nepomuceno, International transactions in operational research systematic reviews as a metaknowledge tool: caveats and a review of available options, Intl. Trans. Op. Res. 30 (2023) 2761–2806, https://doi.org/10.1111/itor.13309.

[54] M.J. Cobo, A.G. López-Herrera, E. Herrera-Viedma, F. Herrera, An approach for detecting, quantifying, and visualizing the evolution of a research field: a practical application to the Fuzzy Sets Theory field, J. Informetr. 5 (2011) 146–166, https://doi.org/10.1016/J.JOI.2010.10.002.

[55] I. D'Adamo, M. Gastaldi, P. Morone, The impact of a subsidized tax deduction on residential solar photovoltaic-battery energy storage systems, Util. Policy. 75 (2022) 101358, https://doi.org/10.1016/j.jup.2022.101358.

[56] A.I. Nousdilis, G.C. Kryonidis, E.O. Kontis, G.A. Barzegkar-Ntovom, I. P. Panapakidis, G.C. Christoforidis, G.K. Papagiannis, Impact of policy incentives on the promotion of integrated PV and battery storage systems: a techno-economic assessment, IET Renew. Power Gener. 14 (2020) 1174–1183, https://doi.org/10.1049/iet-rpg.2019.0797.

[57] B. Bai, S. Xiong, B. Song, M. Xiaoming, Economic analysis of distributed solar photovoltaics with reused electric vehicle batteries as energy storage systems in China, Renew. Sustain. Energy Rev. 109 (2019) 213–229, https://doi.org/10.1016/j.rser.2019.03.048.

[58] L.T. Do, T.N. Nguyen, Q.T. Tran, K.T. Duong, Economic analysis of solar power plant and battery energy storage: case study of Binh Phuoc province, Vietnam, Clean. Eng. Technol. 26 (2025) 100937, https://doi.org/10.1016/j.clet.2025.100937.

[59] A.L.G. Pires, P. Rotella Junior, L.C.S. Rocha, R.S. Peruchi, K. Janda, R.D. C. Miranda, Environmental and financial multi-objective optimization: hybrid wind-photovoltaic generation with battery energy storage systems, J. Energy Storage 66 (2023) 107425, https://doi.org/10.1016/j.est.2023.107425.

[60] A.C. Duman, H.S. Erden, Ö. Gönül, Ö. Guler, Optimal sizing of PV-BESS units for home energy management system-equipped households considering day-ahead load scheduling for demand response and self-consumption, Energy Build. 267 (2022) 112164, https://doi.org/10.1016/j.enbuild.2022.112164.

[61] C. Jamroen, The effect of SoC management on economic performance for battery energy storage system in providing voltage regulation in distribution networks, Electr. Power Syst. Res. 211 (2022) 108340, https://doi.org/10.1016/j.epsr.2022.108340.

[62] C. Rus-Casas, C. Gilabert-Torres, J.I. Fernández, Optimizing energy management and sizing of photovoltaic batteries for a household in Granada, Spain: a novel approach considering time resolution, Batteries. (Basel) 10 (2024) 358, https://doi.org/10.3390/batteries10100358.

[63] B. Laksahapsoro, M. Bird, S. Acha, N. Shah, Optimisation of photovoltaic and battery systems for cost-effective energy solutions in commercial buildings, Appl. Energy 392 (2025) 125907, https://doi.org/10.1016/j.apenergy.2025.125907.

[64] A.A.R. Raouf Mohamed, R.J. Best, X. Liu, D.J Morrow, A comprehensive robust techno-economic analysis and sizing tool for the small-scale PV and BESS, IEEE Trans. Energy Convers. 37 (2022) 560–572, https://doi.org/10.1109/TEC.2021.3107103.

[65] D. Fioriti, L. Pellegrino, G. Lutzemberger, E. Micolano, D. Poli, Optimal sizing of residential battery systems with multi-year dynamics and a novel rainflow-based model of storage degradation: an extensive Italian case study, Electr. Power Syst. Res. 203 (2022) 107675, https://doi.org/10.1016/j.epsr.2021.107675.

[66] M. Świerczyński, D.-I. Stroe, A.-I. Stan, R. Teodorescu, Lifetime and economic analyses of lithium-ion batteries for balancing wind power forecast error, Int. J. Energy Res. 39 (2015) 760–770, https://doi.org/10.1002/er.3278.

[67] O. Alıç, A holistic techno-economic feasibility analysis of residential renewable energy systems: an insight into Turkish case, J. Energy Storage 94 (2024) 112433, https://doi.org/10.1016/j.est.2024.112433.

[68] J.A. Ballesteros-Gallardo, A. Arcos-Vargas, F. Núñez, Optimal design model for a residential PV storage system. An application to the Spanish case, Sustainability 13 (2021) 1–25, https://doi.org/10.3390/su13020575.

[69] M. Sandelic, A. Sangwongwanich, F. Blaabjerg, Impact of power converters and battery lifetime on economic profitability of residential photovoltaic systems, IEEE Open J. Ind. Appl. 3 (2022) 224–236, https://doi.org/10.1109/OJIA.2022.3198366.

[70] P. Lubello, F. Papi, A. Bianchini, C. Carcasci, Considerations on the impact of battery ageing estimation in the optimal sizing of solar home battery systems, J. Clean. Prod. 329 (2021) 129753, https://doi.org/10.1016/j.jclepro.2021.129753.

[71] X. Han, Y. Liang, Y. Ai, J. Li, Economic evaluation of a PV combined energy storage charging station based on cost estimation of second-use batteries, Energy 165 (2018) 326–339, https://doi.org/10.1016/j.energy.2018.09.022.

[72] A.K. Kumar, A. Verma, R. Talwar, Optimal techno-economic sizing of a multi-generation microgrid system with reduced dependency on grid for critical health-care, educational and industrial facilities, Energy 208 (2020) 118248, https://doi.org/10.1016/j.energy.2020.118248.

[73] M. Voorneveld, M. de Groot, Optimal investment strategy on data analytics capabilities of startups via Markov decision analysis, Decis. Anal. J. 10 (2024) 100438, https://doi.org/10.1016/j.dajour.2024.100438.

[74] M. Molinos-Senante, A. Maziotis, R. Sala-Garrido, M. Mocholi-Arce, An investigation of productivity, profitability, and regulation in the Chilean water industry using stochastic frontier analysis, Decis. Anal. J. 4 (2022) 100117, https://doi.org/10.1016/j.dajour.2022.100117.

[75] J. Zhang, H. Cho, R. Luck, P.J. Mago, Integrated photovoltaic and battery energy storage (PV-BES) systems: an analysis of existing financial incentive policies in the US, Appl. Energy 212 (2018) 895–908, https://doi.org/10.1016/j.apenergy.2017.12.091.

[76] E. Gul, G. Baldinelli, P. Bartocci, F. Bianchi, D. Piergiovanni, F. Cotana, J. Wang, A techno-economic analysis of a solar PV and DC battery storage system for a community energy sharing, Energy 244 (2022) 123191, https://doi.org/10.1016/j.energy.2022.123191.

[77] Y. Wu, Z. Liu, B. Li, H. Liu, R. Liu, L. Zhang, Optimal storage capacity for building photovoltaic-energy storage systems considering energy flexibility management, Energy Build. 338 (2025) 115757, https://doi.org/10.1016/j.enbuild.2025.115757.

[78] J. Hossain, A.F.A. Kadir, H. Shareef, R. Manojkumar, N. Saeed, A.N. Hanafi, A grid-connected optimal hybrid PV-BES system sizing for Malaysian commercial buildings, Sustainability. 15 (2023) 10564, https://doi.org/10.3390/su151310564.

[79] R. Luthander, J. Widén, D. Nilsson, J. Palm, Photovoltaic self-consumption in buildings: a review, Appl. Energy 142 (2015) 80–94, https://doi.org/10.1016/j.apenergy.2014.12.028.

[80] M.A.M. Ramli, A. Hiendro, K. Sedraoui, S. Twaha, Optimal sizing of grid-connected photovoltaic energy system in Saudi Arabia, Renew. Energy 75 (2015) 489–495, https://doi.org/10.1016/J.RENENE.2014.10.028.

[81] G. Cerino Abdin, M. Noussan, Electricity storage compared to net metering in residential PV applications, J. Clean. Prod. 176 (2018) 175–186, https://doi.org/10.1016/J.JCLEPRO.2017.12.132.

[82] F. Chiacchio, F. Famoso, D. D'Urso, L. Cedola, Performance and economic assessment of a grid-connected photovoltaic power plant with a storage system: a comparison between the north and the south of Italy, Energies. 12 (2019) 2356, https://doi.org/10.3390/en12122356.

[83] R. Luthander, J. Widén, J. Munkhammar, D. Lingfors, Self-consumption enhancement and peak shaving of residential photovoltaics using storage and curtailment, Energy 112 (2016) 221–231, https://doi.org/10.1016/J.ENERGY.2016.06.039.

[84] D.L. Talavera, E. Muñoz-Cerón, J. De La Casa, M.J. Ortega, G. Almonacid, Energy and economic analysis for large-scale integration of small photovoltaic systems in buildings: the case of a public location in Southern Spain, Renew. Sustain. Energy Rev. 15 (2011) 4310–4319, https://doi.org/10.1016/j.rser.2011.07.119.

[85] R. Tibshirani, Regression shrinkage and selection via the lasso, J. R. Stat. Soc. Ser. B. 58 (1996) 267–288, https://doi.org/10.1111/j.2517-6161.1996.tb02080.x.

[86] T. Hastie, R. Tibshirani, M. Wainwright, Statistical learning with sparsity, Monogr. Stat. Appl. Probab. 143 (2015) 8.

[87] J.H. Friedman, T. Hastie, R. Tibshirani, Regularization paths for generalized linear models via coordinate descent, J. Stat. Softw. 33 (2010) 1–22, https://doi.org/10.18637/jss.v033.i01.

[88] J.F. Peters, M. Baumann, B. Zimmermann, J. Braun, M. Weil, The environmental impact of Li-ion batteries and the role of key parameters – A review, Renew. Sustain. Energy Rev. 67 (2017) 491–506, https://doi.org/10.1016/j.rser.2016.08.039.

[89] L. Zhang, J. Yu, Q. Shi, Q. Kong, An evaluation of the economic benefits of rooftop distributed photovoltaic projects in the whole county in China, J. Clean. Prod. 432 (2023) 139744, https://doi.org/10.1016/j.jclepro.2023.139744.

[90] T.C. Silva, G.M. Pinto, T.A.Z. de Souza, V. Valerio, N.M. Silvério, C.J.R. Coronado, E.C. Guardia, Technical and economical evaluation of the photovoltaic system in Brazilian public buildings: a case study for peak and off-peak hours, Energy 190 (2020) 116282, https://doi.org/10.1016/j.energy.2019.116282.

[91] M.J. Sorgato, K. Schneider, R. Rüther, Technical and economic evaluation of thin-film CdTe building-integrated photovoltaics (BIPV) replacing façade and rooftop materials in office buildings in a warm and sunny climate, Renew. Energy 118 (2018) 84–98, https://doi.org/10.1016/j.renene.2017.10.091.

[92] M. Emmanuel, D. Akinyele, R. Rayudu, Techno-economic analysis of a 10 kWp utility interactive photovoltaic system at Maungaraki school, Wellington, New Zealand, Energy 120 (2017) 573–583, https://doi.org/10.1016/j.energy.2016.11.107.

[93] C. Koo, T. Hong, K. Jeong, C. Ban, J. Oh, Development of the smart photovoltaic system blind and its impact on net-zero energy solar buildings using technical-economic-political analyses, Energy 124 (2017) 382–396, https://doi.org/10.1016/j.energy.2017.02.088.

[94] J. Lee, B. Chang, C. Aktas, R. Gorthala, Economic feasibility of campus-wide photovoltaic systems in New England, Renew. Energy 99 (2016) 452–464, https://doi.org/10.1016/j.renene.2016.07.009.

[95] B. Ghaleb, M. Asif, Assessment of solar PV potential in commercial buildings, Renew. Energy 187 (2022) 618–630, https://doi.org/10.1016/j.renene.2022.01.013.

[96] G.A. Barzegkar-Ntovom, N.G. Chatzigeorgiou, A.I. Nousdilis, S.A. Vomva, G.C. Kryonidis, E.O. Kontis, G.E. Georghiou, G.C. Christoforidis, G.K. Papagiannis, Assessing the viability of battery energy storage systems coupled with photovoltaics under a pure self-consumption scheme, Renew. Energy 152 (2020) 1302–1309, https://doi.org/10.1016/j.renene.2020.01.061.

[97] S. Schopfer, V. Tiefenbeck, T. Staake, Economic assessment of photovoltaic battery systems based on household load profiles, Appl. Energy 223 (2018) 229–248, https://doi.org/10.1016/j.apenergy.2018.03.185.

[98] G. Zhao, J. Clarke, J. Searle, R. Lewis, J. Baker, Economic analysis of integrating photovoltaics and battery energy storage system in an office building, Energy Build. 284 (2023) 112885, https://doi.org/10.1016/j.enbuild.2023.112885.

[99] Y. Guo, Y. Xiang, Cost–benefit analysis of photovoltaic-storage investment in integrated energy systems, Energy Rep. 8 (2022) 66–71, https://doi.org/10.1016/j.egyr.2022.02.158.