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# Optimal Sizing of Photovoltaic System and Battery Storage in Self-Consumption Applications under Contemporary Regulatory Conditions

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**Abstract.** Photovoltaic systems integrated with battery storage are increasingly implemented within self-consumption schemes. Nevertheless, system sizing is frequently based on installed capacity limits rather than on a comprehensive techno-economic assessment of long-term performance. This paper investigates the optimal sizing of photovoltaic and battery storage systems for a small industrial consumer operating under current regulatory conditions in Slovenia, where battery storage integration is mandatory due to low-voltage network constraints. Several combinations of photovoltaic system power and battery storage system capacity are evaluated using key economic indicators, including payback period and cumulative profit over a twenty-year operating period. Investment costs are derived from representative market-based component prices, and the national self-consumption billing framework is incorporated into the assessment. The results show that increasing battery storage capacity improves long-term profitability for small photovoltaic installations, while for larger systems, higher storage capacities reduce cumulative profit due to increased investment costs. The findings confirm that minimizing payback period does not necessarily correspond to maximizing long-term profit and emphasize the importance of balanced system sizing.

**Key words.** photovoltaic system, battery storage system, payback period, optimal sizing, electrical energy production

## 1. Introduction

Photovoltaic systems (PV) currently represent one of the fastest-growing segments of renewable energy generation, particularly in self-consumption. Due to their rapid deployment, the early stages of development were often not focused on determining the optimal system size. Instead, system design was primarily aimed at achieving the maximum possible installed capacity based on the available rooftop area and grid connection capacity. As a result, the annual electrical energy production of many PV systems exceeded the annual consumption of end users, mainly due to systematic oversizing. This approach has, in many cases, led to inefficient utilization of low-voltage network capacity, thereby limiting the integration of additional residential consumers and production units. With the increasing penetration of PV systems, European power systems are experiencing situations where generation exceeds demand, requiring congestion management and measures such as curtailment or export limitations for grid integration [1, 2]. However, a similar pattern can also be observed in BSS integration, where oversizing is often used to increase energy security and reduce the risk of additional electrical energy procurement costs. Nevertheless, under the increasingly dynamic operating conditions of modern power systems and evolving electricity market structures, such oversized configurations are becoming economically inefficient and less profitable in the long term.

In recent years, research has increasingly focused on systematic approaches to the optimal sizing of PV and BSS to overcome the limitations of conventional oversizing practices. Several studies have demonstrated that properly dimensioned systems often achieve higher economic efficiency than oversized configurations. In particular, the authors in [3] showed that under grid export constraints, well-sized PV-only systems may outperform combined PV–BSS solutions, while [4] proposed an iterative techno-economic framework to reduce grid dependency in buildings as storage costs decline.
Beyond purely economic considerations, recent research has emphasized the importance of accounting for uncertainty in system design. The [5] introduced probabilistic and robust stochastic optimization frameworks that incorporate variability in solar production, electrical energy demand, and BBS degradation, leading to more resilient and reliable sizing strategies. These approaches demonstrate that uncertainty-aware models provide more realistic results than conventional deterministic methods.

Advanced optimization techniques have also played a central role in recent studies. The authors in [6] and [7]

applied genetic algorithms to determine optimal PV and BSS capacities for critical infrastructure and domestic prosumers, respectively, achieving improved reliability and cost performance. Complementing these methods, [8] presented a practical simulation-based approach using professional design tools, highlighting the importance of detailed loss modeling and performance forecasting.
Furthermore, operational and data-related aspects have been shown to significantly influence optimal system sizing. The [9] demonstrated that temporal resolution strongly affects BSS degradation assessment and economic outcomes, while [10] confirmed that an appropriately sized BSS can reduce curtailment and improve forecasting accuracy in large-scale PV plants.

In addition to the findings reported in the literature, the regulatory framework also plays an important role. In Slovenia, the regulatory framework for self-consumption and network tariff calculation has changed considerably in recent years. The shift from annual net-metering to a more dynamic billing scheme, together with the introduction of a new tariff methodology based on agreed and excess power [11], has directly influenced the economic performance of PV and BSS systems. Report [12] indicate that the current framework promotes higher self-consumption while limiting the benefits of excessive grid injection. Consequently, system configurations that rely on oversizing are becoming less favourable compared to solutions based on more accurate capacity sizing.

Overall, the reviewed literature consistently indicates that systematic oversizing of PV and BSS rarely leads to optimal technical or economic performance. Instead, integrated optimization frameworks that combine economic evaluation, uncertainty modeling, operational strategies, and grid constraints represent the most effective approach to sustainable system design. However, comprehensive analyses that quantify the long-term impacts of oversizing under dynamic market and regulatory conditions remain limited.

This paper aims to address this gap by performing a comprehensive techno-economic assessment of PV and BSS sizing for an industrial consumer. The objective is to determine optimal capacity combinations based on payback period and cumulative profit over a twenty-year horizon, while accounting for the current self-consumption billing framework.

## 2. Methodology

This section presents the methodology used to determine the optimal size of the PV system and BSS. The optimal configuration was evaluated based on key economic indicators, primarily the payback period and the total profit achieved after twenty years of system operation [13-15]. The optimization procedure was carried out using a case study of a small industrial consumer. In this context, the applied methodology incorporated the calculation framework for industrial electricity costs as well as the national self-consumption financing and billing scheme, which includes both the PV system and the BSS. In Slovenia, as of 2024, BSS integration is recommended when installing a PV system, primarily due to the current overloading and rising voltage levels in the low-voltage network. The annual electrical power consumption profile and the structure of electrical energy costs for a small industrial consumer are presented in Figures 1 and 2, respectively.

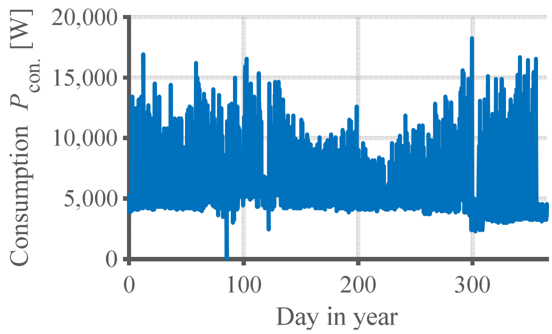

Fig. 1. Annual electrical power consumption profile with 15-minute time resolution.

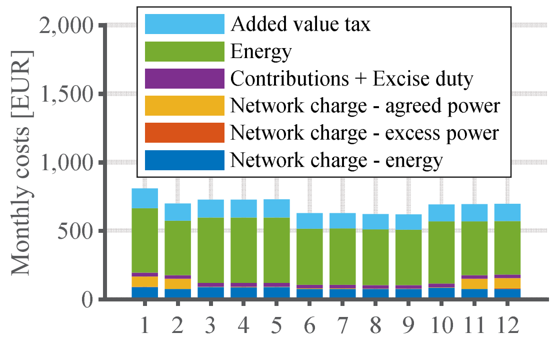

Fig. 2. Structure of electrical energy costs for an industrial consumer.

Fig. 1 shows that the electrical energy consumption corresponds to a small industrial consumer with a relatively constant load throughout the year. The demand rarely falls below approximately 5 kW, primarily due to the continuous operation of IT systems and the constant preparation of process sanitary hot water. The average demand is approximately 5.9 kW, resulting in a total annual electrical energy consumption of 51.72 MWh. Based on the annual consumption profile, the total annual electrical energy cost is approximately 8,274 EUR and remains nearly constant throughout the year due to the relatively stable load pattern. The cost calculation methodology follows the provisions of the Act on the Methodology for Charging Network Charges for Electricity Operators, which defines the network tariff structure [11]. In accordance with this act, the network charge is divided into three components: capacity-related charges for agreed power, excess-power charges, and energy-based network charges. Furthermore, the applied contribution fees, as well as excise duty, were determined based on official data published by the Ministry of the Environment, Climate and Energy of the Republic of Slovenia [16]. The electricity supply price was assumed as a uniform tariff of 0.1 EUR/kWh. A static analysis approach was adopted, assuming constant values of all tariffs, contributions, and electricity prices throughout the entire analyzed period. The electrical energy production

profile of the PV system was estimated using an established methodology based on the geometric relationships between the Sun and the Earth [12]. In addition, the treatment of electrical energy exported to the grid was analyzed using a credit note-based scheme available from one of the Slovenian electricity suppliers. Under this scheme, the prosumer receives a 0.05 EUR/kWh credit note for each kilowatt hour of electrical energy exported to the grid. The accumulated credit can be used in subsequent months to reduce electrical energy costs or can be settled through a payout at the end of the year. The control algorithm for the BSS is defined so that the electrical energy produced by the PV system is first used to cover the industrial consumer's internal consumption. Any surplus electrical energy produced by the PV system is initially stored in the BSS and is exported to the grid only subsequently. In situations where electrical energy consumption exceeds PV production (e.g., due to low solar irradiance or nighttime operation), the BSS is discharged first, and only the remaining deficit is supplied by the low-voltage network.
The core problem addressed in this paper, as outlined in the introduction, is determining the optimal sizes of the PV system and the BSS. The considered capacity values for the industrial consumer are presented in Table I.

Table I. – Ratio of BSS capacity to PV system power.

| BSS capacity [kWh] | | PV system power [kW] | | | | |
|---|---|---|---|---|---|---|
| | | 4.95 | 14.85 | 19.8 | 30.15 | 37.8 |
| BSS capacity factor | 1 | 4.95 | 14.85 | 19.8 | 30.15 | 37.8 |
| | 1.5 | 7.425 | 22.275 | 29.7 | 45.225 | 56.7 |
| | 2 | 9.9 | 29.7 | 39.6 | 60.3 | 75.6 |
| | 2.5 | 12.375 | 37.125 | 49.5 | 75.375 | 94.5 |
| | 3 | 14.85 | 44.55 | 59.4 | 90.45 | 113.4 |

## 3. Results

Based on the presented methodology and the PV and BSS capacity values defined in Table I, this section presents the results of the economic performance indicators for all possible combinations of both system sizes. The capacity values and corresponding investment costs of the PV system and the BSS were determined using representative market-based reference components, including PV modules, inverters, BSS, and associated equipment currently available on the market. Table II presents the total investment cost as a function of BSS capacity and PV system power.

Table II. – Investment cost as a function of BSS capacity and PV system power.

| Investment price [EUR] | | PV system power [kW] | | | | |
|---|---|---|---|---|---|---|
| | | 4.95 | 14.85 | 19.8 | 30.15 | 37.8 |
| BSS capacity factor | 1 | 10180 | 30540 | 40720 | 62006 | 77739 |
| | 1.5 | 12547 | 37643 | 50191 | 76427 | 95819 |
| | 2 | 14915 | 44746 | 59661 | 90848 | 113899 |
| | 2.5 | 17282 | 51848 | 69131 | 105269 | 131979 |
| | 3 | 19650 | 58951 | 78602 | 119690 | 150059 |

In this paper, degradation of both the PV and the BSS was neglected. Similarly, changes in the state of health were not considered, as they are difficult to predict reliably and strongly depend on operational patterns. The twenty-year time horizon was selected based on the assumption that both the PV system and the BSS can operate reliably over this period, which also represents the average expected service lifetime for such systems. Fig. 3 and Table III present the profit after 20 years of system operation as a function of BSS capacity and PV system power.

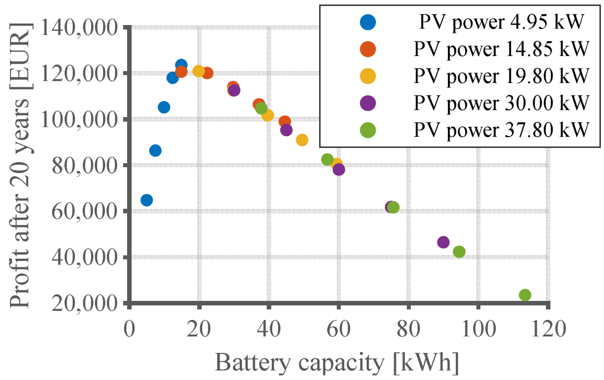


Fig. 3. Profit after twenty years as a function of BSS capacity and PV system power.

Table III. – Profit after twenty years as a function of BSS capacity and PV system power.

| Profit after 20 years [EUR] | | PV system power [kW] | | | | |
|---|---|---|---|---|---|---|
| | | 4.95 | 14.85 | 19.8 | 30.15 | 37.8 |
| BSS capacity factor | 1 | 64776 | 120609 | 120864 | 112573 | 104657 |
| | 1.5 | 86294 | 119998 | 112567 | 95238 | 82484 |
| | 2 | 105157 | 113873 | 101720 | 78065 | 61597 |
| | 2.5 | 117949 | 106401 | 90950 | 61722 | 42318 |
| | 3 | 123488 | 98823 | 80449 | 46390 | 23460 |

Figure 3 and Table III clearly show that the economic benefit strongly depends on the combination of PV system size and BSS capacity. For the smallest considered PV system (4.95 kW), the cumulative profit after twenty years increases with increasing BSS capacity. This indicates that, for small PV installations, additional storage improves self-consumption and reduces costly electrical energy purchases from the grid. The observed trend is mainly driven by the difference between the feed-in tariff and the retail electricity price, where the export price is lower than the purchase price. Consequently, shifting electrical energy consumption to periods of high PV production remains economically advantageous. In contrast, for larger PV systems combined with increasing BSS capacities, the graph reveals a pronounced decline in cumulative profit. This demonstrates that expanding both PV and BSS capacity does not necessarily lead to better economic performance. Instead, the higher investment costs outweigh the additional savings, resulting in reduced financial viability. Based on these observations, three configurations were identified as the most economically favorable: (5 kW, 14.85 kWh), (14.85 kW, 14.85 kWh), and (19.8 kW, 19.8 kWh). For all configurations, the maximum charging and discharging power of the BSS was assumed to be 15 kW. This simplification was adopted to limit the number of possible system configurations and maintain a clear, tractable analysis, as the primary focus of the study is the economic performance of different combinations of PV system size and BSS capacity. In practice, BSSs are typically available in modular designs with predefined specifications, making continuous adjustment of both capacity and power less realistic. Including charging and discharging power as an additional variable would significantly increase the complexity of the analysis and extend beyond the intended scope of this work. Fig. 4 and Table IV present the payback period as a function of BSS capacity and PV system power.

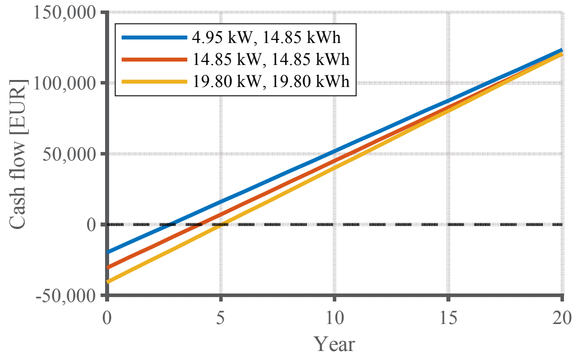


Fig. 4. Payback period as a function of BSS capacity and PV system power.

Table IV. – Payback period as a function of BSS capacity and PV system power.

| Payback period [years] | | **PV system power [kW]** | | | | |
|---|---|---|---|---|---|---|
| | | 4.95 | 14.85 | 19.8 | 30.15 | 37.8 |
| **BSS capacity factor** | 1 | 2,7 | 4,0 | 5,0 | 7,1 | 8,5 |
| | 1.5 | 2,5 | 4,8 | 6,2 | 8,9 | 10,7 |
| | 2 | 2,5 | 5,6 | 7,4 | 10,7 | 13,0 |
| | 2.5 | 2,6 | 6,6 | 8,6 | 12,6 | 15,1 |
| | 3 | 2,7 | 7,5 | 9,9 | 14,4 | 17,3 |

Fig. 4 and Table IV clearly show the cumulative cash flow over the twenty-year operating period for the three selected PV–BSS configurations. It can be observed that the configuration with the lowest initial investment cost reaches the break-even point earliest, thus achieving the shortest payback period. However, the different slopes of the cash flow curves indicate varying long-term profitability. Although the configuration with the lowest investment cost recovers its initial expenditure faster, it does not necessarily achieve the highest cumulative profit after twenty years. The configuration with higher installed capacity exhibits a steeper cash flow slope, resulting in greater long-term financial gains despite a longer payback period. This confirms that minimizing payback time and maximizing long-term profit are not equivalent objectives, and optimal system sizing therefore requires a balanced evaluation of both short-term and long-term economic indicators.

## 4. Conclusion

The aim of this paper was to determine the optimal sizing of PV systems and BSS for self-consumption under contemporary regulatory and market conditions. To this end, a comprehensive techno-economic evaluation of multiple capacity combinations was performed for a case study consumer with a stable annual load profile. The analysis was based on investment cost, payback period, and cumulative profit over a twenty-year operating period. The results demonstrate that economic performance strongly depends on the interaction between PV system size and BSS capacity. For smaller PV installations, increasing storage capacity enhances long-term profitability by improving self-consumption and reducing electrical energy purchases from the grid. In contrast, for larger PV systems, additional BSS capacity yields diminishing economic returns because higher investment costs are not offset by proportional savings. The findings also confirm that minimizing the payback period does not necessarily yield the highest cumulative profit, highlighting the trade-off between short-term cost recovery and long-term financial performance.

Overall, the results indicate that systematic oversizing of PV and BSS does not guarantee improved economic viability. Instead, balanced capacity allocation based on an integrated techno-economic evaluation is essential for achieving sustainable, economically justified self-consumption solutions. Future research should therefore focus on incorporating system degradation, dynamic pricing mechanisms, and uncertainty analysis to further refine optimal sizing strategies under evolving market conditions.

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## References


[1] I. E. A. P. P. S. Programme, *Active Power Management of Photovoltaic Systems - State of the Art and Technical Solutions*, 2024.

[2] A. Pena-Bello, R. Junod, C. Ballif, and N. Wyrsch, “Balancing DSO interests and PV system economics with alternative tariffs,” *Energy Policy*, vol. 183, Dec, 2023.

[3] A. Kesküla, K. Grjaznov, T. Sepp, and A. Allik, “Optimal Sizing of Residential PV and Battery Systems Under Grid Export Constraints: An Estonian Case Study,” *Energies*, vol. 18, no. 16, Aug 19, 2025.

[4] H. K. Ren, M. McCulloch, and D. Wallom, “Optimal sizing of solar photovoltaic and lithium battery storage to reduce grid electricity reliance in buildings,” *Conference of ECEEE 2022 Summer Study on energy efficiency*, 2023.

[5] R. Nematirad, A. Pahwa, B. Natarajan, and H. Wu, “Optimal sizing of photovoltaic-battery system for peak demand reduction using statistical models,” *Frontiers in Energy Research*, vol. 11, Dec 7, 2023.

[6] A. Gonçalves, G. Cavalcanti, M. Feitosa, R. Dias, A. Pereira, E. Jatobá, J. de Melo, M. Marinho, A. Converti, and L. Gómez-Malagón, “Optimal Sizing of a Photovoltaic/Battery Energy Storage System to Supply Electric

Substation Auxiliary Systems under Contingency," *Energies*, vol. 16, no. 13, Jul, 2023.

[7] P. N. D. Premadasa, C. M. M. R. S. Silva, D. P. Chandima, and J. P. Karunadasa, "Optimal Sizing of Solar Photovoltaics and Battery Storage for Domestic Prosumers Using Genetic Algorithm," *Moratuwa Engineering Research Conference (MERCon)*, 2023.

[8] T. Iwayemi, "PV/Battery System Sizing," *International Journal of Scientific Research and Modern Technology*, vol. 3, pp. 101–122, 06/28, 2024.

[9] C. Rus-Casas, C. Gilabert-Torres, and J. Fernández-Carrasco, "Optimizing Energy Management and Sizing of Photovoltaic Batteries for a Household in Granada, Spain: A Novel Approach Considering Time Resolution," *Batteries-Basel*, vol. 10, no. 10, Oct, 2024.

[10] B. Li, M. Li, S. Yan, Y. Zhang, B. Shi, and J. Ye, "An optimal energy storage system sizing determination for improving the utilization and forecasting accuracy of photovoltaic (PV) power stations," *Frontiers in Energy Research*, vol. 10, Jan 18, 2023.

[11] *Act on the Methodology for Charging Network Fees for Electricity Operators (Official Gazette of the Republic of Slovenia, No. 146/2022)*, 2022.

[12] K. Sredensek, J. Pocivalnik, D. Kuhar, E. Simonic, and S. Seme, "Transformation of the Network Tariff Model in Slovenia: Impact on Prosumers and Other Network Users," *Energies*, vol. 19, no. 2, Jan 22, 2026.

[13] M. Aghaei, A. Fairbrother, A. Gok, S. Ahmad, S. Kazim, K. Lobato, G. Oreski, A. Reinders, J. Schmitz, M. Theelen, P. Yilmaz, and J. Kettle, "Review of degradation and failure phenomena in photovoltaic modules," *Renewable & Sustainable Energy Reviews*, vol. 159, May, 2022.

[14] J. Ko, K. Kim, J. Sohn, H. Jang, H. Lee, D. Kim, and Y. Kang, "Review on Separation Processes of End-of-Life Silicon Photovoltaic Modules," *Energies*, vol. 16, no. 11, May 25, 2023.

[15] N. Collath, B. Tepe, S. Englberger, A. Jossen, and H. Hesse, "Aging aware operation of lithium-ion battery energy storage systems: A review," *Journal of Energy Storage*, vol. 55, Nov 25, 2022.

[16] *Climate and Energy (Slovenia), Contribution for Energy Efficiency, Energetika Portal*, 2025.