

11288

C5 Electricity markets and regulation

PS2 Developing reliable price signals and regulation across the value chain

**Market Pricing Analysis for Wind Energy with BESS: A
Stochastic Evaluation of PPA Strategies and Storage Integration**

Antonio PERRELLI*
Affiliation: Axia
Energia, Universidade
Senai Cimatec
Brazil

antonio.perrelli@aln.se
naicimatec.edu.br

Eduardo SODRÉ
Affiliation:
Universidade de
Pernambuco
Brazil

eas@poli.br

Alex SANTOS
Affiliation:
Universidade Senai
Cimatec
Brasil

alex.santos@fieb.org.br

SUMMARY

The purpose of this paper is to extend a previously developed stochastic financial approach for a Hybrid Renewable Energy System (HRES) by incorporating a Battery Energy Storage System (BESS) as a mechanism for temporal energy arbitrage capable of shifting a limited amount of surplus energy from low-to-high price periods. The model is implemented in Python with multiprocessing to evaluate return distributions under uncertain conditions. Economic viability is assessed through discounted cash flow analysis, internal rate of return percentiles, coefficients of variation and the Markowitz risk–return frontier. BESS is found to reduce the median return, reflecting the additional capital expenditure required to enable arbitrage under average pricing assumptions. When surplus energy is shifted at a premium price, the standard deviation of returns decreases modestly, indicating a smoothing effect on revenue distributions. As a result, the coefficient of variation remains largely determined by the technology mix, with solar-heavy portfolios exhibiting lower risk due to their lower generation volatility. When considering the portfolio from a risk-return perspective, the inclusion of BESS changes the local shape of the frontier and shifts the Sharpe-optimal configuration toward a higher wind share, even though overall risk levels remain the same. These findings indicate that, within an arbitrage-only representation, BESS serves more as a stabilizing amplifier than as a mechanism for enhancing peak profitability or contract firmness. Sensitivity analyses incorporating flat ancillary-type revenues show that additional remuneration can materially improve return distributions and alter the relative attractiveness of storage-integrated portfolios. As storage costs continue to decline, the model can provide a basis for determining when and under what circumstances BESS will be economical attractive for hybrid renewable energy portfolios in the long run.

KEYWORDS

Hybrid Renewable Energy System, Battery Energy Storage System, Stochastic Discounted Cash Flow, Risk-Return Analysis, Internal Rate of Return.

1 Introduction

As the penetration of renewable energy sources increases, electricity markets become increasingly susceptible to production intermittency, creating new challenges for system operation and investment planning. Empirical studies indicate that flexibility resources, particularly BESS, have the potential to influence market dynamics and mitigate price volatility in systems with a high share of variable renewable energy generation [1]–[3]. BESS are widely recognized as operational assets capable of enabling energy arbitrage and facilitating participation in short-term electricity markets [2]–[4].

Despite the increasing importance of BESS in market operations, long-term contracting mechanisms remain central to the financing of renewable energy projects. Power Purchase Agreements (PPA) offer price certainty and stabilize revenues over extended periods, consequently reducing exposure to short-term market volatility. The literature generally positions BESS as a complementary asset rather than a substitute for long-term contracts [5]–[7].

This complementarity is economically important because it can reshape revenue profiles, while contractual arrangements continue to anchor capital recovery and risk allocation. Although the operational benefits of BESS are well documented, their economic implications depend on cost structure and technical constraints. Capital expenditure for lithium-ion battery systems typically falls within the range of several hundred USD per kWh, while operation and maintenance costs are relatively low, often expressed as a small percentage of annual capital expenditure [8].

Utility-scale BESS typically operate with storage durations ranging from one to four hours, round-trip efficiencies exceeding 85% and lifetimes spanning several thousand cycles or approximately a decade of operation, depending on the technology and dispatch strategy [9]–[11]. These constraints limit dispatch intensity and arbitrage potential, implying that the economic value of storage cannot be assessed independently of its technical operation.

A central counterargument in the literature addresses the trade-off between short-term revenue maximization and long-term asset degradation. Frequent charging and discharging cycles accelerate battery aging, reducing the effective lifetime and increasing the need for reinvestment. Studies that explicitly model degradation as an economic cost demonstrate that aggressive arbitrage strategies may enhance short-term revenues [12] but can undermine long-term economic performance when the costs of degradation are internalized [13].

Consequently, degradation-aware dispatch strategies, incorporating state-of-charge limits, cycling constraints and health-based control, have been proposed to balance operational flexibility with asset preservation. These findings indicate that the economic contribution of BESS is conditional rather than universal. If the additional capital expenditure and degradation costs are not sufficiently compensated by operational benefits, storage integration may weaken rather than improve project viability.

Evidence from real-world deployments reinforces the importance of conservative operational assumptions. Utility-scale BESS installations are typically designed with limited discharge durations and constrained state-of-charge ranges to ensure reliability and longevity. Case studies from Brazil illustrate that large-scale BESS have been deployed primarily as

infrastructure reinforcement assets, with additional applications, such as renewable energy integration and grid support, being explored to enhance value capture [14].

Economic viability assessments of renewable energy configurations are an essential component of contemporary energy policy and investment decisions. Project revenues become more sensitive to production variability and market price fluctuations as renewable penetration increases, directly affecting the terms of financing, contract design and the pace of capacity expansion. Individual project developers, as well as regulators and policymakers seeking to ensure long-term system adequacy need to understand how different configurations can reshape equilibrium investment prices.

Previous studies utilizing stochastic discounted cash flow models have demonstrated that increased variability necessitates higher equilibrium prices to maintain downside risk metrics, while PPAs significantly reduce the required price markups at low to moderate levels of uncertainty, with their effectiveness diminishing as variability increase [15]. Similarly, analyses of hybrid wind-solar configurations indicate that wind-dominant mixes tend to maximize expected returns, while solar-heavy configurations reduce return volatility [16]. However, these analyses were conducted without considering the integration of BESS, leaving open the question of how storage-induced flexibility may reshape equilibrium pricing and project-level risk-return profiles.

This study builds upon the stochastic economic-financial approach originally developed in Perrelli et al. [15]-[16] to assess changes in the viability and optimal composition of a renewable energy configuration under uncertainty, incorporating a BESS whose economic contribution is modeled exclusively through price arbitrage. Despite the fact that the core model intentionally limits the economic contribution of BESS to price arbitrage, a sensitivity analysis is performed in order to examine how ancillary services might influence long-term investment outcomes, given that such remuneration mechanisms are not yet fully regulated in Brazil. The results suggest that the economic viability of storage is critically dependent on complementary remuneration mechanisms beyond energy arbitrage.

The contribution of the present study helps to clarify when and how storage alters the risk-return balance rather than in claiming generalized economic superiority. In summary, the results can provide useful findings for investment screening and portfolio design, particularly in contexts where storage plays a complementary role to hybrid renewable generation rather than acting as a standalone asset in and of itself.

2 Methodology

The model uses Python for probabilistic economic assessment of HRES combining Monte Carlo simulation with discounted cash-flow analysis and parallel processing to evaluate multiple portfolio combinations and sensitivity scenarios. In this study, price formation is defined as the price needed to ensure economic viability under uncertain market conditions and corresponds to the level at which the internal rate of return (IRR) equals the discount rate, resulting in a net present value (NPV) equal to zero. While spot prices are treated as exogenous inputs, technologies such as BESS are capable of influencing price formation directly by reshaping the distribution of cash flows and risks in a project.

2.1 Plant Configuration, Stochastic Energy Generation and PPA

The hybrid plant used in this study has a fixed installed capacity of $P^{PH} = 100MW$, allocated between wind and solar. Let $\alpha \in [0,1]$ denote the wind share, then the solar share is therefore $1-\alpha$. The analysis evaluates configurations ranging from 100% wind to 100% solar in steps of 5%. Annual generation is modeled stochastically for each technology using independent normal distributions as in (1):

$$G_y^{eol} \sim \mathcal{N}(\mu_{eol}, \mu_{eol}), G_y^{sol} \sim \mathcal{N}(\mu_{sol}, \mu_{sol}) \quad (1)$$

where μ and σ represent the mean capacity factor and standard deviation, respectively. Annual draws are applied uniformly across the months of each year. Monthly average power generation (MW) is given by (2):

$$G_t^{PH} = P^{PH} [\alpha \cdot G_y^{eol} + (1 - \alpha) \cdot G_y^{sol} \cdot D_t] \quad (2)$$

where D_t is the cumulative solar degradation factor. It is assumed in this study that solar output degrades at a given annual rate capped at a maximum degradation of 20%, after which it remains constant. A portion of the plant output is contractually committed under a long-term power purchase agreement (PPA). The firm energy obligation is defined using conservative P90 generation levels as in (3):

$$E^{ACR} = P^{PH} [\alpha \cdot P90_{sol} + (1 - \alpha) \cdot P90_{sol}] \quad (3)$$

This contracted energy is sold at a fixed real price p^{ACR} , indexed to inflation.

2.2 Market Exposure and Energy Balance

The monthly energy balance (in MW) is defined as in (4):

$$S_t = G_t^{PH} - E^{ACR} \quad (4)$$

If $S_t > 0$, the surplus is sold in the free energy market at a given price. If $S_t < 0$, the deficit is implicitly purchased from the market at the same price. Hourly price formation is not explicitly modeled. Instead, a constant average market price p^{ACL} , adjusted for inflation, is assumed. This choice avoids introducing highly speculative assumptions regarding intraday price dynamics while preserving long-term economic consistency. Monthly market revenue (or cost) without BESS is therefore:

$$R_t^{ACL} = p_t^{ACL} \cdot S_t \cdot H_t \quad (5)$$

where H_t is the number of hours in month t .

2.3 Battery Energy Storage System

In this study, the BESS is modeled exclusively as a financial instrument that enables the temporal reallocation of a limited share of surplus energy from lower-price periods to higher-price periods, under the assumption that its storage duration is sufficient to shift energy across consumption windows, justifying an assumed price premium. The storage system is not

assumed to increase contracted energy volumes or to provide delivery guarantees under the PPA. This choice reflects the long-term investment focus of the analysis, which is based on a probabilistic discounted cash-flow that explicitly captures generation uncertainty through wind and solar variability. Within this setting, the objective is to assess whether the expected arbitrage value of storage is sufficient to justify its capital cost, without relying on detailed dispatch or hourly price forecasts. Consequently, the estimated contribution of BESS should be interpreted as a conservative, lower-bound measure of its economic value.

Specifically, the BESS is assumed to have a lifetime of 20 years, after which a replacement lower investment is required, trip efficiency of 90%, rated power of 4 MW and a storage duration of 4 hours, resulting in a total energy capacity of 16 MWh. Investment costs are derived from reference values reported in regulatory and planning documents of the Brazilian Ten-Year Energy Expansion Plan 2035 [17], expressed in terms of capital expenditure per unit of installed power (R\$/kW). Using a reference cost of R\$ 5,500/kW, the total initial investment in storage is calculated proportionally to the BESS power rating, yielding a total BESS CAPEX of R\$ 22 million for a 4 MW system. Let B be the maximum power (MW) that can be shifted per month, η the round-trip efficiency and π the price premium captured through arbitrage. The effective shifted energy is shown in (6):

$$B_t = \min(B, \max(S_t, 0)) \quad (6)$$

Market revenue with BESS becomes (7):

$$R_t^{ACL} = p_t^{ACL}(S_t - B_t) \cdot H_t + (p_t^{ACL} + \mu) \cdot (\eta \cdot B_t) \cdot H_t \quad (7)$$

The premium term μ reflects the assumption of this study that a limited share of surplus energy can be shifted between lower and higher-price periods within the same market day. Energy deficits continue to be settled at the base market price p_t^{ACL} . This formulation abstracts from explicit peak/off-peak window modeling and instead represents the average economic value of temporal arbitrage, which is tested parametrically through sensitivity analysis on π .

2.4 Costs, Investment Structure and Key Modeling Assumptions

Total capital expenditure (CAPEX) is given by (8):

$$CAPEX = CAPEX_{HRES} + CAPEX_{BESS} \quad (8)$$

where hybrid generation CAPEX depends on the wind–solar mix. Operating and maintenance (O&M) costs, sectoral charges and transmission fees are modeled as technology-weighted averages and escalated by inflation. The project is partially debt-financed using a SAC (constant amortization) structure with grace period and fixed interest rate. All cash flows are computed monthly, deflated to real terms and aggregated into Free Cash Flow to Equity (FCFE).

For each configuration, the model performs Monte Carlo simulations to estimate the distribution of returns. The IRR, its standard deviation, coefficient of variation (CV) and risk–return ratios are computed. Portfolio efficiency is evaluated using a Markowitz-type frontier based on expected IRR and risk.

3 Results and Discussion

Figure 1 illustrates the sensitivity of the median internal rate of return (IRR P50) to the wind–solar composition of the hybrid plant, both with and without the inclusion of a battery energy storage system (BESS).

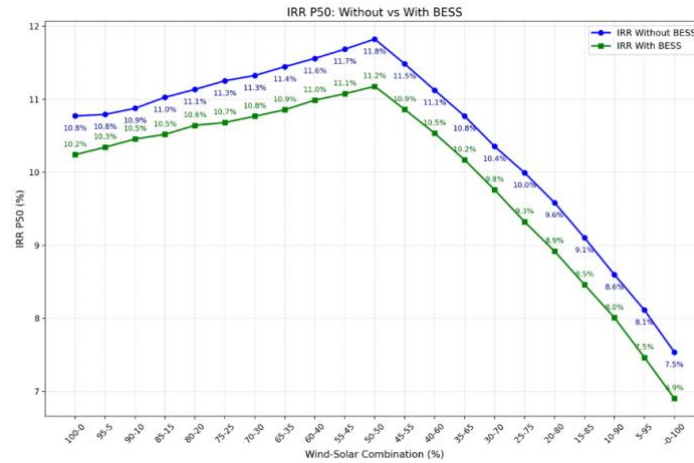


Figure 1 – IRR P50: without and with BESS

From wind-only configurations (100–0) to a roughly balanced mix (around 50–50), the results indicate a systematic increase in IRR with increasing solar penetration, independent of storage availability. Wind–solar hybridization offers diversification benefits through the complementarity between generation profiles, reducing revenue volatility and improving the overall risk–return balance. Beyond this range, however, the profitability of the system declines as the proportion of solar power increases. Due to the lower capacity factor of solar generation and the long-term effects of panel degradation, effective energy output has been reduced while fixed contractual commitments have remained the same.

Observing consistently lower IRRs in configurations including BESS suggests that, under the adopted assumptions, the revenues generated through price arbitrage are insufficient to offset the additional CAPEX associated with storage. These results are directly explained by the way storage is represented in the model. The BESS operates exclusively on positive energy surpluses. Whenever generation exceeds the contracted ACR commitment, up to a fixed amount of surplus energy can be shifted and sold at a higher effective price. If the available surplus is smaller than the storage shifting capacity, only the existing surplus is used. Conversely, when the energy balance becomes negative, the model reverts to its baseline behavior and the project is assumed to purchase the deficit at the ACL price, with no mitigating action from the battery. In this sense, the BESS acts as a catalyst, rather than as a contractual security or firming device.

This mechanism also explains why the economic contribution of storage weakens in solar-dominated configurations. Although the BESS entails an upfront CAPEX (and eventual replacement costs), the probability of having sufficient positive surplus to arbitrage declines as degradation accumulates. Consequently, while storage increases the value of surplus energy whenever it exists, its expected contribution diminishes precisely in scenarios where deficits become more frequent. The net effect is that BESS slightly attenuates the downside of suboptimal mixes but does not offset the structural loss of profitability induced by long-term

degradation. This finding indicates that the economic viability of BESS may depend on revenue streams beyond energy arbitrage such as ancillary services.

Specifically, the analysis assumes that, after reaching the end of its useful life, the battery is replaced for a fraction of its original cost. A more aggressive arbitrage strategy would result in a shorter effective lifetime for the BESS due to a higher replacement fraction and earlier capital reinvestment, thereby reducing project profitability. In an economic sense, such strategies would only be justified if the increased price premium obtained from intensified arbitrage covered the higher costs.

Figure 2 illustrates the IRR sensitivity of a 50–50 wind–solar configuration with BESS to reductions in storage CAPEX. The dashed line represents the benchmark IRR for the same configuration without storage.

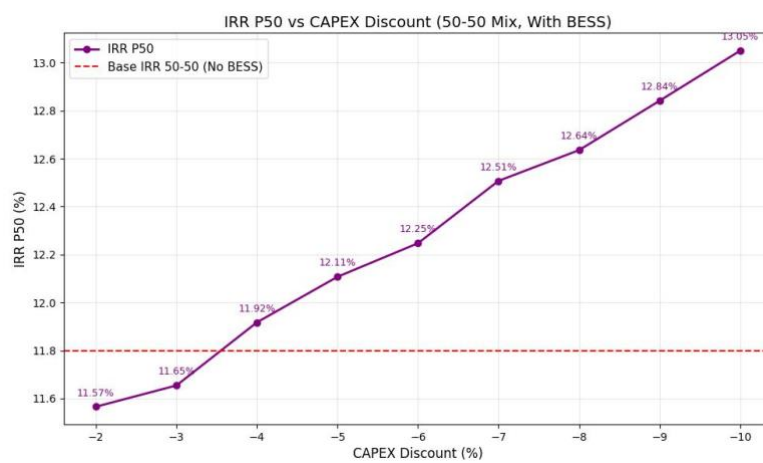


Figure 2 – IRR – CAPEX sensitivity

This behavior indicates that, under the adopted arbitration-only representation, the economic contribution of BESS is highly sensitive to capital costs and price premiums, suggesting that future cost reductions may be sufficient to offset the additional storage investment.

Figure 3 presents the coefficient of variation (CV) of the IRR across wind–solar combinations, with and without BESS.

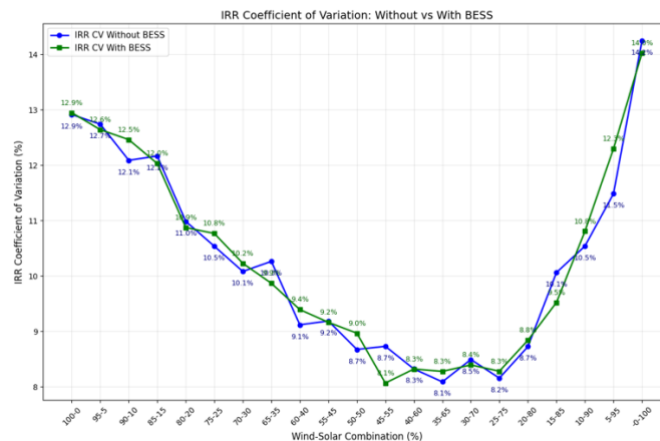


Figure 3 – IRR Coefficient of Variation: Without and with BESS

The minimum CV is consistently observed in solar-dominant configurations. This outcome directly reflects the lower intrinsic variability of solar generation relative to wind, confirming that investors primarily concerned with risk minimization should favor higher solar penetration within hybrid portfolios. The inclusion of BESS produces only marginal changes in the CV profile. This behavior is expected given the role assigned to storage in the model.

Figure 4 illustrates the IRR sensitivity in relation to ancillary service revenues. This analysis examines how alternative remuneration mechanisms may influence long-term investment outcomes in Brazil, where ancillary service markets for BESS are not yet regulated. Flat annual revenues ranging from R\$ 1 million to R\$ 4 million per year are uniformly applied over the project lifetime, representing discrete revenue steps consistent with the order of magnitude observed in the literature [18]-[20]. This sensitivity exercise does not alter the arbitrage-only structure of the core model, but serves to assess how complementary remuneration could affect the economic viability of storage under long-term assumptions.

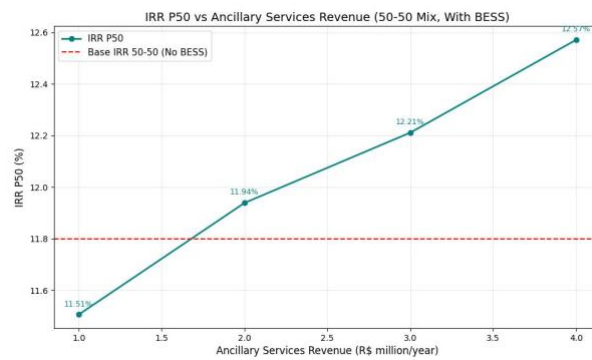


Figure 4 – IRR Coefficient of Variation: Without and with BESS

Under the assumptions adopted, the complementary remuneration can be sufficient to offset the additional CAPEX associated with storage, enabling BESS-equipped configurations to perform better than baseline configurations without storage.

Figures 5 shows the Markowitz risk–return frontiers for the hybrid wind–solar portfolios without and with BESS. In both cases, the efficient frontier is constructed using the median IRR (P50) as the expected return and the standard deviation of IRR as the risk metric. The optimal portfolio is identified as the configuration that maximizes the return-to-risk ratio (red dot), consistent with a Sharpe-based criterion.

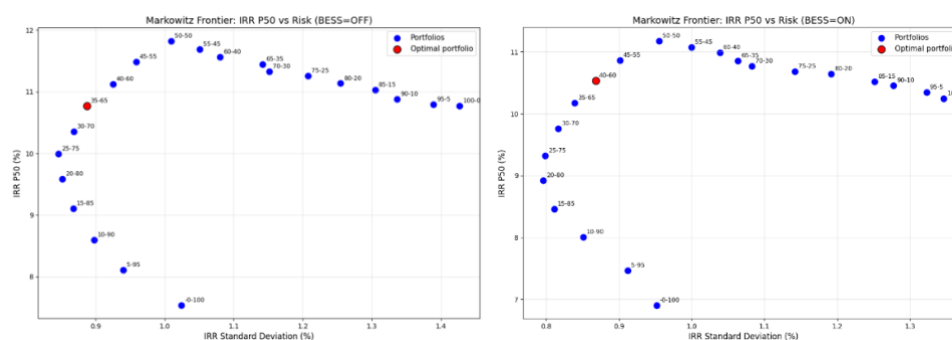


Figure 5 – Markowitz frontier: Without and with BESS

In the absence of BESS, the optimal portfolio is located at a 35% wind and 65% solar mix. This result reflects the dominant role of solar generation in reducing return volatility, while wind contributes higher expected returns at the cost of increased dispersion. Beyond this point, additional wind penetration raises risk faster than it increases expected return, causing the Sharpe ratio to deteriorate.

When BESS is introduced, the optimal portfolio shifts toward a higher wind share. This shift does not arise from a material reduction in overall risk, as the standard deviation of IRR remains largely unchanged across configurations. Instead, the change is driven by a modification in the marginal return–risk trade-off. Since wind-dominant and balanced portfolios tend to generate larger and more frequent surpluses, the expected marginal return of wind-heavy configurations improves relative to solar-heavy ones once BESS is included. Although the fixed CAPEX of storage may slightly reduce absolute median returns, the incremental return associated with higher wind penetration becomes more favorable relative to the associated increase in risk.

A relatively stable and weakly correlated stream of revenue, such as ancillary services, could alter the risk-return frontier. These revenues could increase expected returns while reducing cash flow volatility, thereby shifting the efficient frontier upward and to the left. By acting as a stabilizing component of the portfolio, BESS could also enhance its risk-adjusted performance. However, these effects depend critically on the structure, duration and predictability of ancillary service remuneration, which remains uncertain in the Brazilian regulatory context.

Overall, the Markowitz analysis indicates that BESS affects portfolio optimality by reshaping marginal incentives, rather than by minimizing risk or maximizing returns in absolute terms. Storage therefore functions as a financial enhancer of surplus-prone configurations, altering the location of the Sharpe-optimal mix without fundamentally changing the underlying risk structure of the hybrid system.

4 Conclusion

This study examines the economic impacts of battery storage within hybrid wind-solar projects under uncertainty by explicitly isolating the incremental contribution of storage through price arbitrage. Storage is capable of reshaping marginal incentives, particularly by increasing the relative attractiveness of surplus-prone configurations and shifting the optimal risk-return portfolio in favor of higher wind penetrations. However, when remuneration is limited to energy arbitrage at average prices, storage primarily affects marginal incentives rather than materially increasing expected returns. According to the sensitivity analysis, remuneration schemes such as ancillary services can significantly influence long-term investment outcomes and the relative attractiveness of storage-integrated configurations.

The results suggest that the economic performance of BESS is highly sensitive to assumptions regarding capital costs. As storage CAPEX continues to decline, price arbitrage may be sufficient to justify battery deployment without additional revenue streams. However, the full economic potential of BESS may not be realized if storage is limited solely to energy arbitrage. The absence of transparent and predictable compensation mechanisms may lead to delayed investment and increased costs resulting in higher equilibrium prices, greater pressure on long-

term contracting and an inefficient allocation of investment across generation resources and flexibility resources.

In future studies, it will be important to further examine how ancillary services and other flexibility remuneration mechanisms are structured in international markets, how these arrangements could be more explicitly incorporated into long-term investment models and how they may reshape the risk–return frontier of storage-integrated portfolios. Overall, the proposed approach provides a tool for investment screening and portfolio design in hybrid renewable projects, while offering directions for further research into the evolving economic role of energy storage in power systems with high renewable penetration.

BIBLIOGRAPHY

- [1] Butters, R. A., Dorsey, J., & Gowrisankaran, G. (2025). Soaking up the Sun: Battery Investment, Renewable Energy, and Market Equilibrium. *Econometrica*, 93(3), 891–927. <https://doi.org/10.3982/ecta20411>
- [2] Khan, I. U., & Jamil, M. (2025). Energy Arbitrage Analysis for Market-Selection of a Battery Energy Storage System-Based Venture. *Energies*, 18(16), 4245. <https://doi.org/10.3390/en18164245>
- [3] Andreotti, D., Spiller, M., Scrocca, A., Bovera, F., & Rancilio, G. (2024). Modeling and Analysis of BESS Operations in Electricity Markets: Prediction and Strategies for Day-Ahead and Continuous Intra-Day Markets. *Sustainability*, 16(18), 7940. <https://doi.org/10.3390/su16187940>
- [4] Liu, X., Xue, Y., An, Q., & Liu, J. (2025). Differentiated Pricing-Mechanism Design for Renewable Energy with Analytical Uncertainty Representation. *Energies*, 18(18), 4922. <https://doi.org/10.3390/en18184922>
- [5] Garttan, G., Alahakoon, S., Emami, K., & Jayasinghe, S. G. (2025). Battery Energy Storage Systems: Energy Market Review, Challenges, and Opportunities in Frequency Control Ancillary Services. *Energies*, 18(15), 4174. <https://doi.org/10.3390/en18154174>
- [6] Condé, H., Demition, C. M., & Honra, J. (2025). Storage Is the New Black: A Review of Energy Storage System Applications to Resolve Intermittency in Renewable Energy Systems. *Energies*, 18(2), 354. <https://doi.org/10.3390/en18020354>
- [7] Cui, J., Sakakimoto, T., & Ueda, Y. (2025). Optimal Planning and Operation of BESS Charging/Discharging Under Corporate PPA with BCP Considerations. *IEEE Access*, 1. <https://doi.org/10.1109/access.2025.3608243>
- [8] Areola, R. I., Adebisi, A. A., & Moloi, K. (2025). Integrated Energy Storage Systems for Enhanced Grid Efficiency: A Comprehensive Review of Technologies and Applications. *Energies*. <https://doi.org/10.3390/en18071848>
- [9] Jeon, S., & Bae, S. (2024). Integrated optimization for sizing, placement, and energy management of hybrid energy storage systems in renewable power systems. *Journal of Energy Storage*. <https://doi.org/10.1016/j.est.2024.114793>
- [10] Yang, Y., Wu, Z., Yao, J., Guo, T., Yang, F., Zhang, Z., Ren, J., Jiang, L., & Li, B. (2024). An overview of application-oriented multifunctional large-scale stationary

- battery and hydrogen hybrid energy storage system. *Energy Reviews*. <https://doi.org/10.1016/j.enrev.2024.100068>
- [11] Njema, G. G., Ouma, R. B. O., & Kibet, J. K. (2024). A Review on the Recent Advances in Battery Development and Energy Storage Technologies. *Journal of Renewable Energy*. <https://doi.org/https://doi.org/10.1155/2024/2329261>
 - [12] Eroğlu, H., & Kurtuluş, O. (2025). Strategic design of wind energy and battery storage for efficient and sustainable energy systems. *Scientific Reports*. <https://doi.org/10.1038/s41598-025-18863-5>
 - [13] Wicke, M., & Bocklisch, T. (2024). Hierarchical Energy Management of Hybrid Battery Storage Systems for PV Capacity Firming and Spot Market Trading Considering Degradation Costs. *IEEE Access*. <https://doi.org/10.1109/ACCESS.2024.3387748>
 - [14] Torres, P. F., Manito, A. R. A., Figueiredo, G., Almeida, M. P., Neto, J. C. de S. A., Cavalcante, R. L., Silva, C. C. V. de F. A. da, & Zilles, R. (2025). Energy Storage as a Transmission Asset—Assessing the Multiple Uses of a Utility-Scale Battery Energy Storage System in Brazil. *Energies*. <https://doi.org/10.3390/en18040902>
 - [15] Perrelli, A. C., Sodré, E. A., Silva, A. V., Studzinski, C. D., Silva, V. F., Neto, A. T., & Santos, A. A. (2024). Optimizing price markup: the impact of power purchase agreements and energy production uncertainty on the economic performance of onshore and offshore wind farms. *International Journal of Energy Economics and Policy*, 14(5), 211-219.
 - [16] Perrelli, A., Sodré, E., Silva, V., & Santos, A. (2023). Maximizing Returns and Minimizing Risks in Hybrid Renewable Energy Systems: A Stochastic Discounted Cash Flow Analysis of Wind and Photovoltaic Systems in Brazil. *Energies*. <https://doi.org/10.3390/en16196833>
 - [17] Empresa de Pesquisa Energética - EPE (2025). Ten-Year Energy Expansion Plan 2035 (PDE 2035). Ministério de Minas e Energia. Brasília: MME/EPE.
 - [18] Brogan, P., Best, R., Morrow, J., Duncan, R., & Kubik, M. (2020). Stacking battery energy storage revenues with enhanced service provision. *IET Smart Grid*. <https://doi.org/10.1049/iet-stg.2018.0255>.
 - [19] Hameed, Z., Træholt, C., & Hashemi, S. (2023). Investigating the participation of battery energy storage systems in the Nordic ancillary services markets from a business perspective. *Journal of Energy Storage*. <https://doi.org/10.1016/j.est.2022.106464>.
 - [20] Khalilisenobari, R., & Wu, M. (2020). Optimal Participation of Price-maker Battery Energy Storage Systems in Energy and Ancillary Services Markets Considering Degradation Cost. <https://doi.org/10.1016/j.ijepes.2021.107924>.