EXECUTIVE SUMMARY
ENERGY STORAGE SYSTEMS IN BRAZIL

Brazil's power generation matrix has historically been recognized for its high share of renewables, with hydropower plants once accounting for more than 80% of installed capacity. However, this paradigm has been gradually shifting due to structural changes in the energy mix, bringing new operational challenges: a growing share of non-hydro renewable sources - mainly wind and solar photovoltaics - and increasing operational constraints on hydropower plants.

These changes are significantly impacting the traditional operational dynamics of the Brazilian Interconnected Power System, raising concerns about its ability to provide essential services, such as capacity, flexibility, reserves, and ancillary services, whose demand continues to grow, while the existing supply, mainly from hydro and thermal power plants, faces operational constraints and raises environmental and economic concerns.

ENERGY STORAGE SYSTEMS (ESS) emerge as strategic candidates to ensure system reliability and enable a deeper penetration of renewables without increasing dependence on fossil fuels.

Under this context, the objective of this study was to **evaluate the potential role of ESS in Brazil's electricity sector** and to identify the technical, economic, and regulatory conditions needed to support their deployment. The analysis focuses on five key dimensions:

- **FLEXIBILITY:** growing system needs from wind and solar variability and hydro constraints.
- **TECHNOLOGIES:** most promising storage options (lithium-ion and pumped hydro) due to maturity, cost, and suitability.
- **SYSTEM BENEFITS:** how storage can cut costs and contribute to supply security.
- **ECONOMIC VIABILITY:** market and tax barriers, plus lack of regulation.
- **REGULATION:** current progress and gaps to enable fair competition.

Focusing on system flexibility, this concept refers to the power system's ability to efficiently respond to rapid changes in net load driven by the variability of non-dispatchable renewable generation, especially solar. As solar output fluctuates throughout the day, particularly during steep ramps at sunrise and sunset, the system must be able to quickly increase or decrease other generation sources to maintain reliability and balance supply and demand.

According to PSR projections based on ONS data (February 2025), net demand peaks could reach nearly 70 GW by 2029. Additionally, the Brazilian power system's flexibility needs were analyzed across different months and scenarios in 2029:

1-HOUR RAMP-UPS:
Average requirement of 5 GW annually, reaching up to 16 GW in critical scenarios.

4-HOUR RAMP-UPS:
Average requirement of 19 GW annually, reaching 47 GW in critical scenarios.

7-HOUR RAMP-UPS:
Average requirement of 30 GW annually, reaching 58GW in critical scenarios.

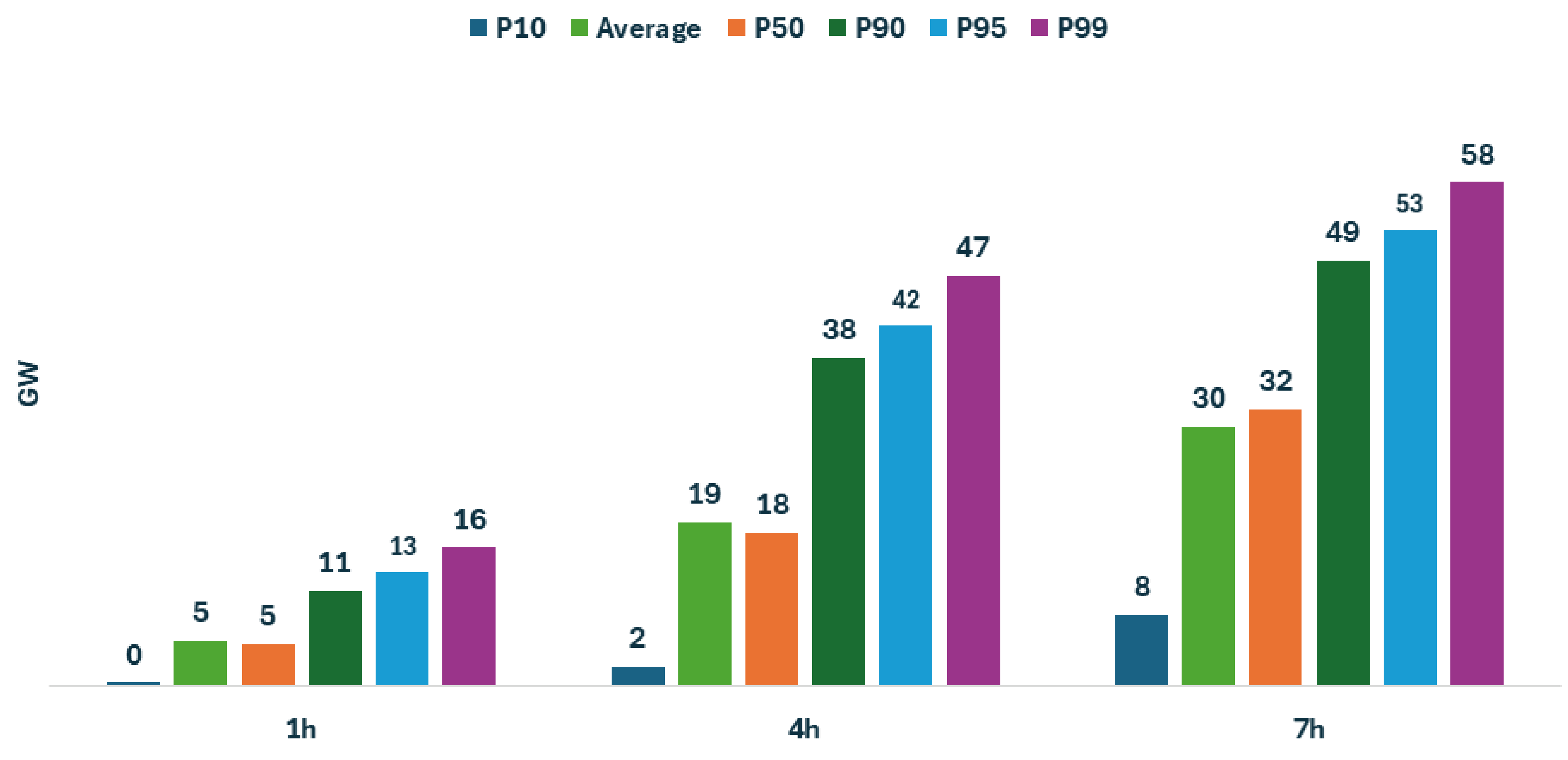

Figure 1 - System's flexibility requirements for different time steps (GW).

Thus, given the results, without the addition of fast-response resources, grid reliability might be at risk, particularly during the dry season and at sunset, when solar generation drops sharply, forcing the system to rely on more expensive and carbon-intensive alternatives. **In this context, ESS can play a key role in supporting system flexibility.**

Among the range of available storage technologies, two stand out for near- and medium-term implementation in Brazil, based on its technological maturity, deployment experience, and cost competitiveness: **lithium-ion batteries and pumped-storage hydropower (PSH):**

Lithium-ion batteries are ideal for short-duration applications of up to four hours, offering fast response, modular deployment, and falling costs.

PSH, in contrast, is best suited for long-duration and large-scale storage, leveraging Brazil's geographic potential and extensive experience in hydropower development.

From a system planning perspective, both lithium-ion and PSH are aligned with Brazil's evolving operational needs, particularly for managing ramping events, but not only this: these technologies are also interesting, since they can help reducing curtailment of renewable energy (a matter that is at the core of several regulatory and market discussions nowadays), and providing ancillary services.

Additionally, from a **system economic perspective**, a numerical simulation was developed considering four distinct scenarios, assessing the provision of additional flexibility required from different sources:

REFERENCE SCENARIO:	SCENARIO B	SCENARIO C	SCENARIO D
Current generation resources	32 GW of expansion with flexible gas-fired thermal power plants.	32 GW of expansion with short-duration batteries (4-hour batteries).	32 GW of expansion with long-duration pumped-storage hydro (100-hours PSH).

The figure below presents the results of demand service costs for the different scenarios:

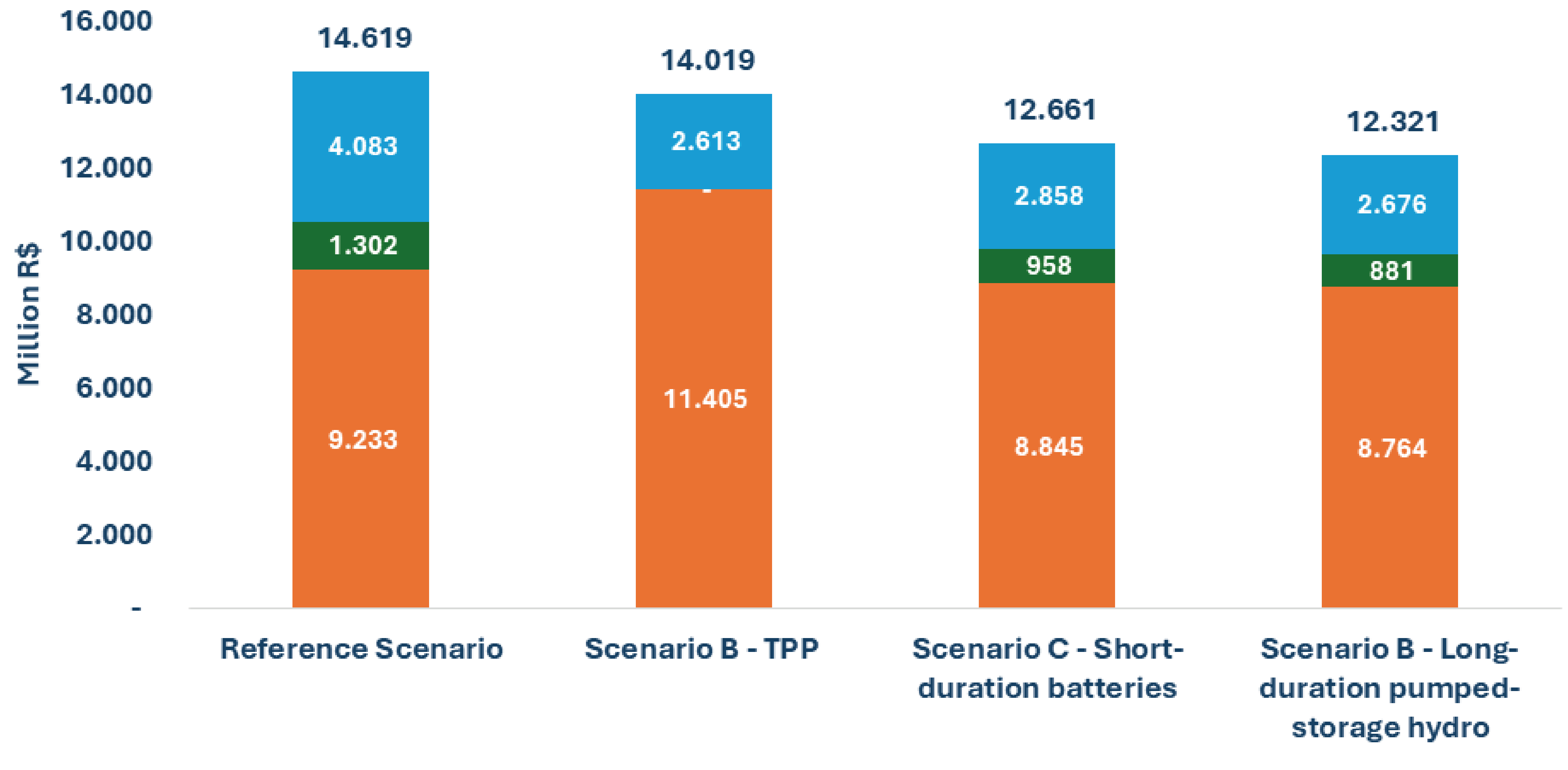

Figure 2 – Results of demand service costs for the different scenarios.
Others, represent the costs of the violations of some operative restrictions, mainly use of water restrictions

KEY RESULTS:

REFERENCE SCENARIO: even with seemingly stable monthly averages, hourly analyses reveal deficits, especially at the end of the dry season.

SCENARIO B: no significant difference in total system costs compared to the Reference Scenario, although thermal dispatch costs increase while the cost of deficits goes to zero.

SCENARIOS C AND D: included to assess the energy benefits of ESS compared to expansion via thermal plants.

- The introduction of 4-hour batteries reduced system costs in 2029 by 13%, while 100-hour pumped-storage hydro reduced costs by 16%.
- Both scenarios still show positive deficit costs, as storage systems cannot generate energy continuously like flexible TPPs.

Based on the analysis, short- and long-duration storage solutions, emerge as strategic alternatives to address flexibility and capacity deficits, ensuring reliability and balance between supply and demand. ESS should be considered a candidate technology for system expansion, as they can, in combination with firm energy generation, help meet demand at lower costs.

Despite the favorable system-level results for batteries, a complementary analysis was made in order to consider investment costs, regulatory feasibility, and potential implementation barriers.

Currently, there are few examples of storage technology applications (and potential viable applications) in Brazil, which can be explained by two factors:

- Market conditions and taxation still do not make storage systems economically viable in the country;
- lack of adequate regulatory frameworks creates barriers to their integration into the system.

Price arbitrage is a key application of energy storage systems in the power sector, allowing energy to be stored when prices are low and dispatched when prices are high. However, under current market conditions, arbitrage revenues are insufficient. **For batteries to be financially viable, they would require an average daily price difference of US$ 72–152/MWh sustained for four hours per day, considering a lifespan of 15 years.** Similarly, **PSH would require a price difference of US$ 65–161/MWh over eight hours per day, assuming a 40-year lifespan.** Nevertheless, the hourly price formation model in Brazil shows low daily variation - averaging around US$ 29/MWh - which is insufficient to make arbitrage economically viable.

Therefore, it is crucial to explore other potential revenue sources to make these technologies economically viable (revenue stacking). In this regard, capacity remuneration and ancillary services are mentioned as potential revenue streams for these technologies in Brazil.

The following figure shows, for an example of illustrative nature, the importance of revenue stacking. It is only through the sum of revenues arising from the provision of different services that the ESS in the example is able to cover its costs (capital costs, operation and maintenance, and taxes).

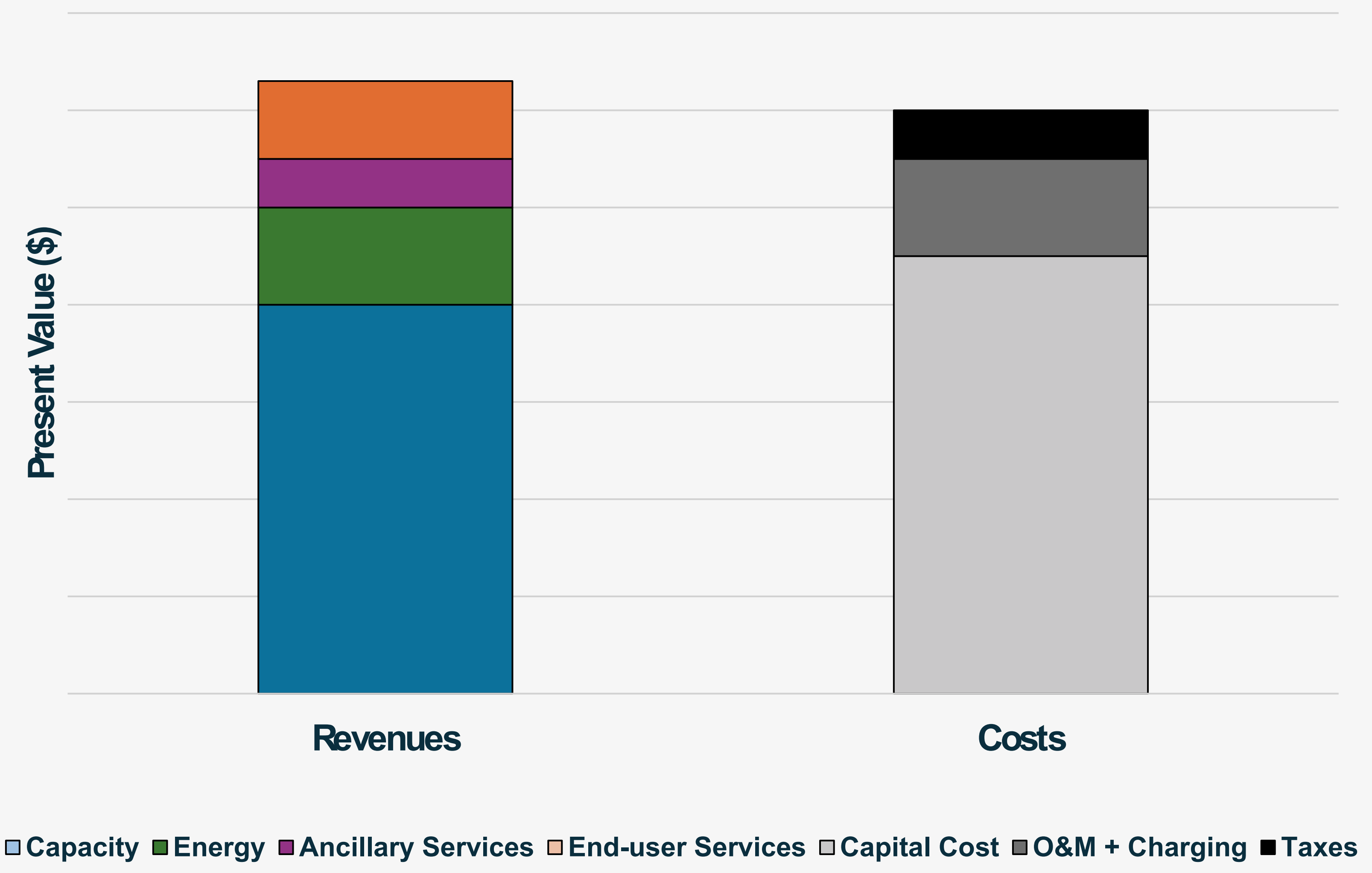

Figure 3: Comparison between revenue streams related to the range of services an ESS can deliver and its costs

Beyond revenue stacking, another key challenge for the economic viability of storage technologies is taxation. Batteries face a higher tax burden compared to traditional generation, which may discourage investment in storage in Brazil. **On average, costs are estimated to increase by 76% once taxes are applied.**

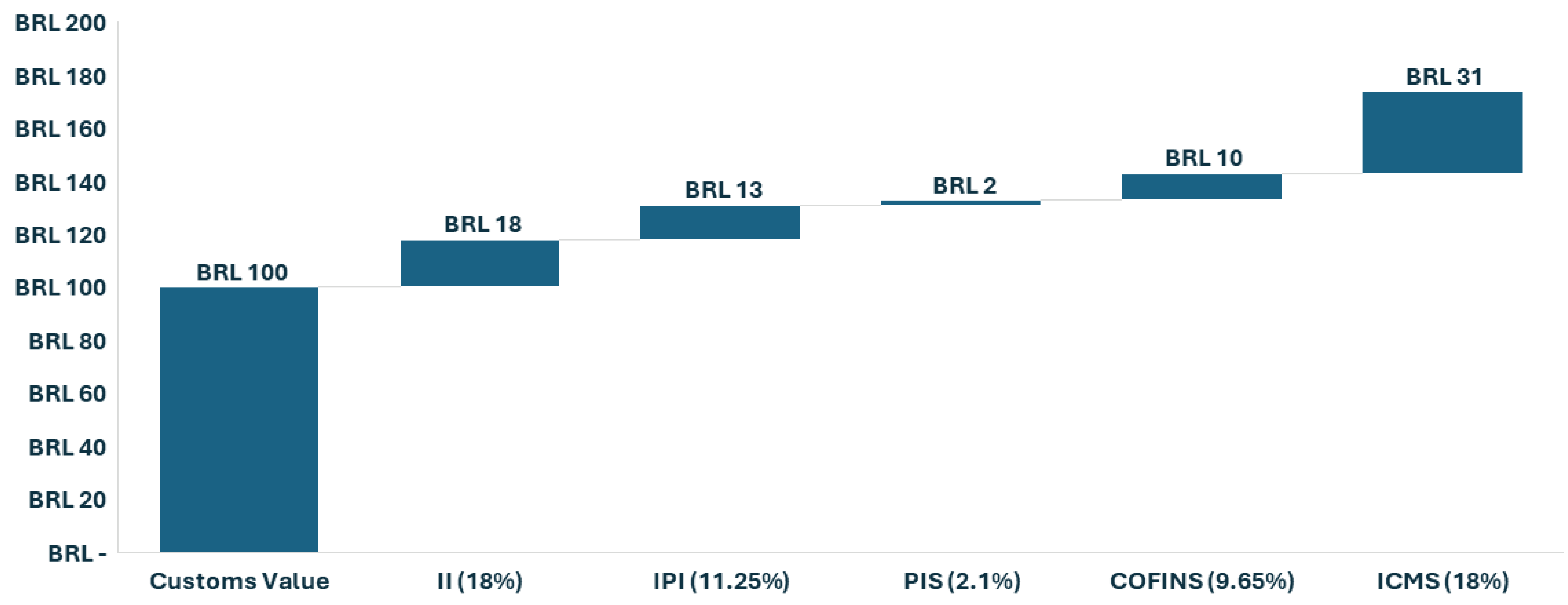

Figure 4 – Impact of taxes in the cost of batteries.

Finally, it is important to highlight that the regulatory framework for ESS in Brazil is still at an early stage. Since 2023, the Brazilian regulator (ANEEL) has been developing a regulatory roadmap, to be completed by 2027.

While progress has been made, significant gaps remain, especially regarding revenue stacking, capacity auctions, environmental license and clearer rules for integrating storage technologies broadly into the market. Without these developments, investments in ESS will remain limited despite their technical potential.

In face of these challenges, this study provides a clear roadmap for 2025–2028, with short-term actions focused on completing the first phase of the regulatory roadmap, defining auction guidelines for storage participation, and advancing environmental regulations for PSH. Medium-term priorities include creating tax incentives, holding Brazil's first dedicated capacity auction for storage, and improving ancillary service rules. In the long term, adjustments to spot pricing and mechanisms to reduce renewable energy curtailment should be implemented.