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THE ROLE OF ENERGY STORAGE TECHNOLOGIES IN DECARBONIZING ENERGY SECTOR

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Abstract:
The requirement to increase the storage capacity of wind and solar energy technologies leads to a higher demand for energy storage, which is reflected in scaling up a diverse blend of hardware and software technology solutions. The literature on energy storage supports an integrated approach, incorporating different factors to explain and handle energy decarbonization. The present research builds on this inquiry and investigates the general attitude toward energy storage adoption and use, covering issues such as economic constraints, industry acceptance, contemporary technology, and regulatory barriers. The researcher used a focus group methodology, bringing together seven participants to generate data. This approach capitalized on communication and interaction between research participants. They were asked about their opinions on the investigated model and were guided through the research questions via a facilitated discussion. Research has shown that energy produced from wind and solar energy requires additional storage capacity. While decreasing battery prices contribute to the growth of energy storage, grid-scale battery additions still need to increase. For this reason, the role of international financial institutions in unlocking capital and knowledge, particularly in the context of developing countries, becomes even more prominent.

Keywords:
renewables, wind energy, solar energy, lithium-ion, energy finance.

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INTRODUCTION

Due to the increasing use of wind and solar energy, there's a growing need for energy storage to compensate for periods with less wind and sun. Such demand drives an unparalleled increase in the energy storage sector, with countries across the globe being determined to take part in the global storage supply chains. As clean energy promptly gains impetus, an intensified mandate for energy storage infrastructure handling intermittency matters will likely become more apparent. However, as far as energy storage is concerned, there is no one-size-fits-all approach (Khan *et al.*, 2024). In this regard, scaling up a different blend of hardware and software technology solutions is likely to become indispensable.

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Energy storage is a power system buffer because it absorbs excess energy when renewables generate more than necessary. Furthermore, when supply is limited, the stored energy is dispatched back to the grid. Likewise, such an approach becomes essential during grid emergencies because it can provide sufficient power and prevent grid failures (Szott *et al.*, 2021). Crucial to the recent growth in energy storage are Battery Energy Storage Systems (BESS), namely those based on lithium-ion (Carpinelli *et al.*, 2024). BESS is substantially linked to the electric vehicles market, which makes up about 80% of BESS demand. In 2024, the global energy storage market was projected to be approximately 360 GWh and is predominantly comprised of mature compressed air and pumped hydro storage (Ahmadi, 2024). Simultaneously, what drives the growth is that about 90% of all new energy storage deployments between 2015 and 2024 occurred in BESS (Vasilev, 2024). Furthermore, by 2030, the global energy storage market is estimated to increase by an average of 21% per year to more than 2 TWh (Fletcher & Smith, 2024). China is projected to attain 43% of this future market, allowing it to remain the leader in energy storage, followed by the United States (US) with a 14% market share, and Europe and India, occupying the third and fourth positions, respectively.

Over the last decade, the cost of lithium-ion batteries has decreased by more than 90% (Schmidt & Staffell, 2023). Only in 2024, costs have dropped by about 40%. Likewise, battery cell prices are estimated to continue this downward trend, adding to the attractiveness of energy storage. Accordingly, increasing scale and continuous innovation help drive down costs, with the most recent price drops linked to a global oversupply of batteries. As of 2024, China alone is projected to produce enough batteries to meet global demand (Michaelides, 2025). On the other hand, the US and Europe are estimated to make batteries at a cost premium of 20% more compared to batteries manufactured in China.

Despite challenges with overcapacity, major countries are prioritizing the lithium-ion battery supply chain. Their goal is to build local manufacturing, secure a competitive international advantage, attract investment, and create jobs (Wali *et al.*, 2023). Another crucial concern is linked to supplies of raw materials required in battery production, such as lithium, graphite, manganese, nickel, and cobalt. China currently dominates the sector with more than 90% of the processing capacity of minerals and raw metals and more than 60% of the global manufacturing capability of lithium-ion batteries (Emenike & Falcone, 2020). On the other hand, by promoting domestic manufacturing through grants, subsidies, tax incentives, and production-linked incentives, many countries, such as the United States (US), Japan, and Australia, try to catch up and compete with duties and taxes on imports from China.

Due to its technological maturity and an established supply chain, lithium-ion remains the prevailing chemistry option for energy storage and is likely to dominate the market throughout this decade (Rahimi, 2021). However, at the moment, the global storage requirement is between two and four hours. The lack of solutions for long-duration energy storage remains one of the most fundamental bottlenecks in energy decarbonization. Despite shaping the past decade, lithium-ion batteries and pumped hydro cannot handle the full extent of the challenges the grid currently faces. Nevertheless, other emerging technologies go beyond the current four-hour duration, such as liquid CO2 storage, flow batteries, sodium-ion, and a combination of clean hydrogen and lithium-ion (Márquez *et al.*, 2023). These technologies are particularly appealing to many governments because they are less reliant on critical minerals, which enables the creation of more resilient and diverse supply chains.

Notably, the literature on storing energy supports an integrated approach to energy solutions, embracing carbon removal, hydrogen, clean fuels, and advanced nuclear, recognizing that no single technology can handle the energy transition alone (Kaushik *et al.*, 2021; Wagner, 2020). Instead, a blend of approaches is required, manifested through strategies of different companies, industries, and

regions and their cooperation. Accordingly, the present research investigates the general attitude toward energy storage adoption and widespread use, covering issues such as economic constraints, industry acceptance, contemporary technology, and regulatory barriers.

METHODOLOGY

The researcher used a focus group methodology as a form of group interview to generate data. This method was specifically chosen to foster and capitalize on the communication and interaction between research participants (Aityan, 2022). Instead of asking each participant to respond to a question, the researcher stimulated discussion among the participants, motivating them to comment on each other's perspectives and proficiencies, exchange anecdotes, and ask questions. The researcher acknowledges that the method is specifically convenient for exploring people's experiences and knowledge, examining their opinions.

Participants were asked about their attitudes toward a concept. The discussion was facilitated to explore their perspectives on the following guiding hypotheses:

H1: Additional capacity is required to store the energy produced from wind and solar power for periods of less wind power and sunlight.

H2: Battery prices are decreasing substantially, adding to the recent growth in energy storage.

H3: Despite lithium-ion batteries dominating the market, other emerging energy storage technologies are becoming increasingly appealing.

H4: Annual additions of grid-scale battery energy storage must increase to meet the Net Zero ambitions of 2050.

H5: Policies and regulations in developing countries do not incentivize adopting battery energy storages, making the role of international financial institutions in unlocking capital and knowledge even more critical.

The researcher's primary goal was not to test the hypotheses but to use them as a framework for structuring the discussion. Seven participants were selected based of their professional backgrounds in the banking sector. All participants were required to have experience as project team members on BESS transactions. This type of expertise provided insight into the structuring, risk assessment, and financial modeling of BESS projects. The participants' affiliations are listed in Appendix 1; the specific questions they were asked are listed in Appendix 2.

The focus group was conducted online, via the Zoom platform, on February 7th, from 15:30 to 17:00, and on February 8th, from 10 am to 11 am. During the first focus group meeting, the hypotheses were used to facilitate the discussion and refine the research questions. During the second meeting, the researcher used these modified questions for the discussion among the participants.

RESULTS AND DISCUSSION

Bess powering to net zero

Power systems across the globe are experiencing unprecedented change. Along with spreading low-cost renewable electricity, there is an increasing requirement to enhance digitalization and boost power system resilience (Migała-Warchoł *et al.*, 2025). Such a venture necessitates massively stockpiling renewables, especially in developing countries, making energy storage essential. In 2022, around 75GW of wind and 192GW of solar were installed across the globe. However, in the same year, only 16GW/35GWh of new storage systems were installed (Michaelides, 2025). A recent study illustrated a substantial increase in BESS (Kumar *et al.*, 2024). However, it also confirmed that grid-scale storage capacity still requires scaling up to attain Net Zero Emissions by 2050. Most certainly, BESS cannot unravel the numerous challenges facing power systems of the 21st century, but it can considerably add to stronger and cleaner power networks. Notably, BESS is principally compatible with the requirements of developing countries with relatively weak power grids.

Challenges for developing countries include a lack of skilled human resources and adequate monitoring and control equipment, underdeveloped or non-existent grid infrastructure, insufficient generation capacity, and poor supply security (Rahman *et al.*, 2022). In this regard, energy storage can boost reliability, which is vital when shifting from thermal to hybrid projects (Asif, 2021). It enables excess electricity produced by variable renewables, such as wind and solar, to be used when the demand is high and sunlight is low, adding considerably to both availability and reliability. A hybrid venture, which combines variable renewables and a BESS, reduces reliance on fossil fuels and creates a more sustainable energy system. However, current policies and regulations in developing countries do not incentivize the adoption of BESS, which is why hybrid ventures can hardly compete with more traditional energy sources. In addition, revenue flows in these markets are typically limited, making validating their high upfront costs tough. Still, some business models stand for monetizing hybrid projects and, accordingly, integrate BESS.

Participants noted that the World Bank actively mobilizes concessional funding for BESS in developing countries. Through its Energy Sector Management Assistance Program (ESMAP) and from several climate funds, the World Bank has mobilized around $850 million in concessional financing (Raikar & Adamson, 2024). It has a commitment of 5.5 GWh to BESS capacity in active projects. ESMAP supports developing countries installing energy storage by ensuring access to technical assistance and concessional finance, including utilizing the Energy Storage Partnership (ESP) to cope with knowledge gaps. With the partners' help, the ESP is considering all energy storage forms. It is developing a profound knowledge base in energy storage approaches that are adjusted to the requirements of developing countries.

Despite the growing global interest in hybrid projects, there is a gap in the market for a comprehensive guide and framework for their Power Purchase Agreements (PPAs). A PPA, encompassing a long-term contract between a client and an electricity producer – usually a company, government entity, or utility – allows the buyer of electricity to acquire energy at a predetermined price. The absence of a standardized PPA mechanism makes it challenging for organizations to make informed decisions about the optimal business model for their needs. This, in turn, complicates accurate financial calculations and risk assessment for these projects.

Participants stated that the ESP has developed a hybrid PPA that monetizes the benefits of energy storage to ensure a sustainable payment mechanism. This approach aids in incorporating BESS into renewables auctions. It attempts to help countries implement hybrid renewable projects comprised of solar and BESS. The objective is to reduce dependence on public finances and unlock private capital, allowing developers to make knowledgeable decisions within their business models that fulfill their requirements. Considering other emerging business models and their variations, the suggested approach can be developed further and promptly enhanced using best practices and in-depth knowledge adjusted from various models worldwide.

Enabling energy storage systems to become more conventional in the developing world will be essential (Rahman *et al*., 2022). The aim of using storage systems is to ensure much greater use of renewables while providing more comprehensive access to electricity, eventually allowing fulfillment of Net Zero decarbonization targets. Development institutions and international organizations are crucial in leading the global push for decarbonization, and their cooperation is crucial. For instance, the World Bank has partnered with the Global Energy Alliance for People and Planet (GEAPP) and the Long Duration Energy Storage (LDES) Council to take a step towards energy decarbonization and ensure further finance of BESS in developing countries (Zioło *et al*., 2024). One of the participants suggests the possibility that deploying energy storage systems in developing parts of the world is likely to revolutionize the energy landscape. Still, as mentioned earlier, the collective efforts of different institutions remain pivotal in driving this critical modification.

Financing bess and ensuring constant clean energy

Clean energy sources, such as wind, solar, and hydro are essential for combating global warming and creating a sustainable energy system. However, most clean energy technologies have fluctuating features and are inherently intermittent. Accordingly, while fluctuation of clean energy destabilizes the grid, intermittence does not allow a constant flow of energy. Such occurrences are not ideal for the contemporary energy system. The participants acknowledge that BESS is one of the most effective means to respond to these challenges, through wholesale arbitrage, frequency regulation, and congestion relief. Simultaneously, BESS can produce and dispatch stored clean energy when the sun is not shining and the wind is not blowing, which further addresses challenges related to power adequacy. BESS can ensure additional benefits such as creating fixed/variable charge reduction, network upgrade deferral opportunities, and contingency reserves.

The adoption of BESS is currently low, with the progress in installation being less than anticipated. In 2023, the capacity of BESS was 85 GW (Raikar & Adamson, 2024). To ensure smooth grid integration of renewables, backed by a net-zero 2050 emissions scenario as an objective, the capacity of BESS needs to reach 1200 GW by 2030. However, according to the estimates of the Stated Policies Scenario (STEPS), the capacity of BESS will be around 760 GW, which is considerably less than needed. Financial risk, lacking a secured financial model backed by introducing novel technology, is likely the most prominent risk associated with adopting BESS (Mamun *et al*., 2022). On the other hand, technological risk encompasses moderately consolidated supply chains and supporting infrastructure, followed by unproven track records of warranty providers, many of whom are newly founded (Zhang *et al*., 2022). Likewise, BESS requires materials such as nickel, cobalt, and lithium, which are mined in a way that negatively affects local communities and ecosystems. Extracting these resources contributes to land degradation and generates greenhouse gas (GHG) emissions, substantially adding to the environmental risk.

Furthermore, the capital obtainable with such types of investors is relatively limited. The participants expressed concerns that adopting BESS on a larger scale requires more active participation of low-cost/low-risk capital providers and established institutional investors such as insurance companies, pension funds, and banks, subject to adopting more comprehensive investment risk mitigation strategies.

Because the cost of capital for clean energy projects is still relatively high in emerging economies, capital flows for BESS are concentrated in the developed world and China. Development Financial Institutions (DFIs) and multilateral development banks (MDBs) can, by better credit ratings compared to companies in developing countries and by their climate and development mandate, can generate a "pull factor" to increase the funding scale, followed by allocation of capital across geographic areas and clean energy value chain (Bahl & Bird, 2018). Accordingly, in middle- and low-income economies, DFIs and MDBs can ensure conventional soft loans to public finance institutions at a national level to deploy BESS capabilities and mission-mode development. These measures can enhance the creditworthiness of their BESS projects, which in turn reduces capital costs. The involvement of Development Finance Institutions (DFIs) can also attract private capital and serve as a risk-mitigation tool. Furthermore, to a certain extent, the DFI funding stream can be committed to creating a robust talent pipeline for BESS ecosystems. To optimize their limited capital, DFIs may also choose to underwrite the interest component of debt taken on by BESS technology and project developers, ensuring its efficient and judicious allocation. The MDB/DFI financial resources in such designed transactions are usually much smaller than the quantum intended for conventional soft loans. In addition, such structured transactions can accomplish the dual objective of releasing valuable MDB/DFI capital while increasing the creditworthiness of BESS projects. This enables broader geographical coverage and reaches the most underserved communities.

Blended financing can be a useful financial model for BESS projects, as it uses public capital – such as a guarantee or first-loss capital – to attract private investors. The participants stated that this approach provides private financiers with greater comfort and encourages them to offer capital at a more competitive rate. BESS supporting only renewables projects can be grouped and issued as green bonds (Mohamadi, 2021). Public capital providers can ensure partial credit guarantee (PCG), hence improving the credit ratings of green bonds, which are required to gather private investors seeking low-returns and low risk.

Likewise, debt financing may be regulated to use BESS more optimally. For instance, the outcome can be the ability to recycle after-life BESS systems, the cost of supplying electricity, the ability to respond to supply/demand with very low breakdown times, and the number of charge/discharge cycles. These features can incentivize developers to create the required mixture of execution models, business, and BESS technology. This, in turn, signals to manufacturers that they should produce environmentally friendly, superior-quality BESS equipment.

Battery-as-a-service (BaaS) and other new-age business models allow users to avoid technology performance risks. BaaS, for instance, incorporates Customized Leasing Models (CLM) in which the lessor accepts the upfront capital costs. While promoting behind-the-meter deployment, the participants suggested that it can accommodate evolving requirements (self-consumption optimization, distributed energy, and backup power) of industrial (C&I), commercial, and residential consumers. Consumers can sell surplus electricity from rooftop solar systems while procuring electricity from distribution grids. Comparable business models can be explored for electricity generation and transmission companies, including other front-of-the-meter players. BaaS can optimize investments in grid upgrades and spare them from incurring high upfront capital for BESS. In conjunction with relevant private capital providers, DFIs, MDBs, and governments can accelerate the adoption of this business model.

Finally, trading green credits by facilitating clean energy is another evolving model that can generate additional revenue for BESS adopters. As participants have noted, this approach is becoming increasingly relevant as more countries establish regulated and structured carbon markets. Notably, carbon credits obtained from BESS projects can be traded in the market at a favorable price. Being regarded as a "sunshine industry," BESS is fundamental for policy, business, and technology stakeholders to build appealing ventures, thus helping the economies leapfrog into a net-zero future.

Guiding investment in battery storage

The energy system transforms much faster than anticipated. Renewables are now projected to dominate global electricity generation by 2038, followed by multiple conversions remodeling the energy landscape across the globe. Backed by the growth trajectories, market environment, and existing policies, wind and solar generate more than 15% of global power, with projections of further increase by 2.5x by 2030. Electrifying households, transport, and industry, combined with the build-out of data centers, is likely to raise electricity demand 1.7x by 2050. It aims to create energy systems that are increasingly localized and likely more affordable, equitable, maintainable, and resilient. One participant noted that such an endeavor depends on the electricity infrastructure and network, followed by the capability to maximize the power produced. The proliferation of electrification and renewables illustrates a substantial challenge to price volatility, grid management, and system adequacy (Hafner & Tagliapietra, 2020). It requires upgrading and expanding the grid to build out flexibility at scale and connect more distributed energy resources to ensure a reliable power supply and demand. The participants stated that, without these improvements, more grid curtailments, higher bills for consumers, and power outages are at risk. For instance, with the share of renewables in the system increasing twofold, curtailment rates have also increased from about 2% in 2015 to around 8% in 2022 in the US, the UK, Germany, and Ireland. Likewise, load-shedding events are becoming more consistent. Accordingly, given the evolving nature of the energy system, energy storage becomes essential. Different energy storage technologies are projected to be deployed differently globally. However, at the grid level, participants agree that BESS will likely become the prevailing adopted technology due to its superior energy response times, modularity, efficiency, and density. Compared to many other energy projects, BESS can be constructed quickly and with less capital. Its capacity to fulfill multiple roles within a changing energy system implies that it can handle multiple challenges across various power requirements and timeframes.

Investment in BESS is projected to grow along with the demand for energy storage. According to a 2020 study by Hafner and Tagliapietra, global BESS capacity is expected to reach 572 GW/1,848 GWh by 2030, with a substantial portion of this capacity being installed at the grid level. However, the capability to attain required returns entails grasping a complex, rapidly changing, and regionalized market. As the participants have noted, evaluating the attractiveness of a given BESS market goes beyond simple investment figures; it require further evaluation within the context of financing options, technical considerations, market maturity and design, and cultural fit. Appealing markets have several standard features in common. In the competition for providing power, markets with a digitized and modern grid create a level playing field, allowing batteries to compete effectively with other energy technologies. Compared to most competing technologies, such as gas, BESS can respond far more quickly (Yoo & Ha, 2023). However, optimizers must employ modern technology, including artificial intelligence (AI), enabling it to affiliate with system operators. Furthermore, greater volatility, typically in locations with lower degrees of interconnection and high penetration of wind and solar generation, adds energy

arbitrage opportunities for BESS, i.e., storing power when it is cheap and free and selling it back to the grid when prices increase (Ahmadi *et al*., 2024). Also, battery operators usually must "stack" revenues to make the investment worthy, unlike other renewable assets (Paredes & Aguado, 2024). The participants stated that regions allowing BESS to take part within multiple markets, i.e., ancillary services, energy arbitrage, and capacity illustrate the most prominent possible manner to attain it.

Ancillary services remunerate battery operators for their support to grid stability and are among the key BESS markets. They include backup support, peak shaving, voltage control, and frequency response. Energy arbitrage enables battery operators to acquire revenues by aiding in balancing the grid, obtaining and storing energy when the demand is low, and releasing it when it is most needed, which is typically during morning and afternoon peaks. Revenues are acquired by taking part in wholesale trading via options, including forward, intraday, and day-ahead. Finally, capacity markets enable battery operators to obtain contracts to ensure future capacity, hence offering steady and secure returns, yet these do not exist in all markets.

How to undertake a more resilient perspective on batteries?

The evolving energy mix and uncertainty about the future scale of energy storage mean that market conditions are changing rapidly.

Batteries generate revenues by participating in different markets of ancillary services, energy arbitrage, and capacity, and which are operational across various timescale practices. Changing policies and conditions influence these models differently (Seward *et al*., 2022). With markets becoming more saturated in the short- to mid-term, the revenue stack is projected to move from ancillary services via energy arbitrage to capacity markets. For instance, ancillary services in the UK market generally comprised most of BESS's revenues. In 2022, frequency response services comprised about 84% of the BESS revenue stack. However, with BESS increasingly dominating these markets, saturation set in, deflating the prices. By 2023, average revenues had dropped sevenfold, with frequency response revenues making up only about 20% of the stack in 2024. Likewise, in 2023, across European markets, ancillary services ensured around 40% of the revenues, which, in 2024, decreased to 33%. A similar decline was seen in the US, where BESS ancillary revenues decreased by 48% between 2021 and 2023.

The UK National Grid ESO's Open Balancing Platform, which in real-time supports the bulk dispatch of battery storage, illustrates the aforementioned value of BESS (Guerra *et al*., 2024). From 2022, wholesale trading revenues increased from about 7% of the revenue stack to 30% in 2024. At the same time, balancing revenues have increased from 7% to 17%. Similarly, BESS revenues from arbitrage are projected to rise 47% by 2030 in the US. However, despite the growing importance of energy arbitrage for a diverse revenue stream, some markets, such as Spain, have been hesitant to fully embrace it as a standalone strategy. The investment approach for battery storage would gather the needed pace with additional revenues stacked from the capacity market and ancillary services. Spain's battery storage market leans toward growth, with the sector anticipating government approval of a capacity market in the upcoming months.

An adequate bidding strategy supported by optimization is expected to become crucial to allowing maximum returns for storage assets. With the proliferation of renewables and increasing volatility, future value opportunities will become more localized (Talus, 2024). Already on the rise are zero- or negative-price events, which are expected to become more frequent, adding opportunities for energy storage. Participants agree that an exciting summer in continental Europe is ahead, with countries

such as Germany and the Netherlands doubling on solar, creating massive excess generation periods in which energy storage can efficiently shift time. Hence, in markets with such volatility levels, colocation storage is becoming fundamental to the commercial approach to solar PV ventures. Besides location, the timing of a Battery Energy Storage System (BESS) project is critical, especially given their rapid deployment and short development cycles. Securing a first-mover advantage is essential for profitability and investment resilience. This is particularly true as ancillary markets become saturated and longer-duration storage technologies evolve.

More than 50% of BESS revenues are projected to derive from wholesale markets within three to five years, with around 30% from balancing, which ultimately depends on the location. In this regard, island states are expected to experience higher volatility (Talus, 2024). For instance, over the past five years, price spreads in Australia have risen more than six times. Over that time, prices across Europe have also doubled on average, illustrating that even markets with the electricity interconnector's inherent resilience are experiencing more fluctuations. With grid operators acknowledging the requirement of securing future capacity, regulators are reforming or introducing capacity market mechanisms, enabling participation of BESS. For instance, the UK holds auctions for one- or four-year-ahead capacity contracts, with the 2024 round of auctions increasing BESS capacity by about 80%. Italy is modifying its current approach to incorporate a more regulated model, with 15-year capacity auctions suggesting long-term certainty.

How to maintain the competitiveness of batteries?

Digital capabilities are essential to performance optimization.

An agile mindset is needed to continue capturing value in a fast-changing market. In terms of energy storage, a participant describes batteries in the context of the Swiss Army Knife, prescribing that the best chances of success lie within the flexible approach. The same participant suggests that, for instance, no one knows what the battery will be used for in two years. Adding to the flexibility concerning the batteries' assets requires building flexibility. Notably, the digital footprint needs to be adjustable to bring in new interfaces with diverse market entities and new concepts. Digital tools, including AI, will be critical to adapt (Jaheer *et al.*, 2024). Leveraging and understanding AI and other digital tools for optimization of storage trading approaches can assist firms in promptly steering regulatory changes, de-risk investments, and better monetizing opportunities laid down by market volatility and new market structures.

For instance, moving to dynamic pricing and real-time trading in the US, namely Texas and California, followed by the UK, the Netherlands, and Australia, adds more opportunities to participate in BESS. However, it also depends on real-time monitoring, intelligent grid orchestration, and qualified proficiency to price the bid competitively or offer and adequately handle the state of charge utilizing the wholesale power market. There are various trading products within wholesale trading, including, as mentioned, forward, intraday, and day-ahead, as well as different trading strategies that will require tailoring to the following factors: market conditions, warranty, and type of battery. One participant argues that intraday trading offers more revenue potential, but obtaining it entails the approach of an asset-backed trader, in which an owner is entitled to dispatch an asset.

Another important matter is mastering the data generated by BESS. One participant stated that the asset generates vast amounts of data. The real power resides in relating the data to those of market data and acknowledging the market's present, future, and past. According to the same participant, what matters is reconciliation and optimization. With evolving battery duration, it will become even more

important. Shrinking revenues from regulatory support, frequency markets, and declining costs imply that longer-duration batteries will likely become certain, theoretically making shorter-duration products unfavorable from a commercial perspective. According to another participant, the business case for batteries will increase to eight- to twelve-hour duration. Eight-hour batteries are already deployed in several markets, including the US and Israel. However, an essential requirement for batteries with longer duration is to entail higher capex, both to maintain and to build, which, according to participants, requires relatively complex calculations. Accordingly, the battery is less arduously used if it is more significant, effectively extending its life (H. Zhang *et al.*, 2022). Benefits related to reliability, such as a half-hour battery, are cycling substantially. Furthermore, investors must reflect on alternative storage systems and how they may erode future business cases. For instance, as early as 2027, hydrogen storage may appear as a cost-competitive alternative, subsequent to the decreasing cost of electrolyzers. In the near term, as the adoption of electric vehicles (EVs) increases, the scaling of vehicle-to-grid (V2G) technology may impact BESS in some instances, likely consolidating the case for larger-scale projects. However, as the participant suggests, battery storage can reduce the need for longer-duration storage by enabling demand response, particularly as transportation and heating systems become increasingly electrified.

What are the optimal financing structures or business models for BESS?

BESS projects will require financing as they are capital-intensive. However, it does not mean they are "set and forget" investments.

BESS are active assets that require ongoing management throughout their lifespan. They refer to the capacity to tie up capital with optimization, operation, construction, and development, which are crucial to practical BESS projects (Raikar & Adamson, 2024). Major energy players such as EDF, NextEra Energy, and Shell increased their investment in batteries, acquiring both platforms and assets as part of hedging and trading strategies. Infrastructure funds and private equity firms have also made numerous investments in Battery Energy Storage System (BESS) platforms.

Investors are required to align their offtake and financing strategies. For instance, they should consider whether they are eager to assume merchant risk for a higher return or if their objective is long-term contracted revenues. In evolving markets like the UK, a variety of offtake structures, including floor – price structures/constraints, can provide a reliable stream of fixed income. An inclination to assume a longer-term perspective and accept volatility associated with various cycles remains essential (Mohamadi, 2021). BESS development lifecycles are short, and though market dynamics differ, supply and demand can be corrected relatively quickly. For instance, within just a few years, there were numerous cycles of boom and bust in the UK. To finance battery storage projects, lenders usually want a level of long-term contracted revenues, while only some of them consider taking on an element of merchant revenues following the revenue stack forecasts. Also essential to the debt market is the operation of a BESS asset and the quality of the sponsor. According to a participant with a background in banking, it is important to speak to the developers and ask them about their choice of asset location and optimizer, among others.

Investors with strong management teams and local market capabilities, including differentiated capabilities across the value chain, execute projects successfully. Understanding offtake markets and local planning regimes and regulations, can smooth the development process, as can relationships with landowners. From a broader perspective, considering behind-the-meter projects or colocation can optimize earnings potential over the longer term. An example is Warrington Renewables, the UK's largest

solar and battery facility, which has completed a hybrid power optimization and purchase contract with Norway's Statkraft. There are also other major offtake agreements with colocated projects in the US, namely Texas, California, and Australia. Deals with corporations that wish to consolidate green credentials could also illustrate another opportunity for BESS. One participant revealed that in the UK, these deals are on the rise, mentioning a lot of renewable PPAs with above-market prices. Accordingly, a firm with a solar project wanting to be green can use the power from that solar project as they require time shifting, they will also require batteries.

How to navigate geopolitical risks and supply chain complexity?

Essential to the scaling up of BESS investment will be the ability to reduce capex.

With battery cell supply chains feeling the effect of a recent slowdown in EV adoption, supported by technology advances and an increase in government subsidies, participants expect costs of grid-scale BESS to decrease by around 20% to 30% across key markets by 2030. Supply chain bottlenecks and volatile commodity prices may offset these reductions (Scholten, 2023). For instance, slow lead times around building electricity transformers can delay connecting new BESS projects to the grid. Increasing resource protectionism and nationalism in many markets, including China's Mainland's battery supply chain dominance, could influence future projects' viability. Some markets aim to establish domestic battery industries and reduce dependence on others, yet such an attempt may be overly complex and expensive. According to estimations, localization of the supply chain across the US and the EU would entail around US$170b of investment by 2030. In this regard, investors must also pay attention to how the evolution of technological innovation may reshape the supply chain and change the demand for commodities. For instance, sodium-ion and vanadium may challenge the domination of lithium post-2030.

Furthermore, battery recycling can assist in supply chain risk mitigation. With BESS companies expanding their services through the value chain, greater investment in recycling, predominantly within broader vertical integration, can be observed. For instance, companies in Spain and Portugal, such as FCC Ámbito, Glencore, and Iberdrola, focusing on second-life applications and recycling, cooperate to develop lithium-ion battery circularity solutions. Nearly half the people across the globe headed for an election in 2024, marking a potential for shifting political landscape during the next few years. Hence, broader geopolitical factors will likely play a substantial part in the BESS business case's evolution, mainly if broader factors influence global oil and gas prices or new governments backtracking on clean energy commitments (Montana *et al*., 2024). One participant noted that battery storage prospers on market volatility, yet investors should consider different geopolitical scenarios to create a resilient and agile business model.

CONCLUSION

To a substantial extent, grid-level energy storage influences the future of clean energy. Global attempts to decarbonize the energy systems could lead to a more expensive, insecure, and unreliable power supply if the volatility of intermittent and distributed energy sources is not addressed. While various aspects of BESS make it a favorable alternative to incorporate stability and flexibility across the grid, investing in these assets on a larger scale is still required to fulfill the demand. Investors who explore how highly regionalized markets may evolve and act accordingly to comprehend where current opportunities lie can help build a more sustainable energy system while attaining lucrative rewards.

The research has illustrated that additional capacity is required to store the energy produced from wind and solar power for periods with less wind and sun (H1). In this regard, battery prices are decreasing substantially, which is why they are at the core of the recent growth in energy storage (H2). In addition, despite lithium-ion batteries dominating the market, other emerging energy storage technologies are becoming increasingly appealing (H3). However, annual grid-scale battery energy storage additions must increase to meet the Net Zero ambitions of 2050 (H4). Most notably, policies and regulations in developing countries do not incentivize the adoption of battery energy storage, making the role of international financial institutions in unlocking capital and knowledge even more considerable (H5).

Likewise, the research has shown that uncertainty over the scaling of storage and an evolving energy mix may indicate that conditions are changing rapidly. Also, digital capabilities, such as AI, are essential to performance optimization. Furthermore, BESS projects will require financing, as they are capital-intensive, hence tying up capital with optimization, operation, construction, and development. Essential to scaling up BESS investment is the ability to reduce the capex, reflected through the decrease in grid-scale costs as well as battery recycling.

REFERENCES

Ahmadi, A., Mna, A., & Slimani, A. (2024). *Renewable energy and the economic welfare of society*. IGI Global.

Aityan, S. K. (2022). *Business Research Methodology: Research Process and Methods*. Springer Nature.

Asif, M. (2021). *Energy and environmental security in developing countries*. Springer Nature.

Bahl, R., & Bird, R. M. (2018). *Fiscal decentralization and local finance in developing countries*. Edward Elgar Publishing.

Carpinelli, G., Noce, C., Russo, A., Varilone, P., & Verde, P. (2024). Optimal siting and sizing of battery energy storage systems in unbalanced distribution systems: A multi-objective problem under uncertainty. *International Journal of Electrical Power & Energy Systems, 162*, 110316. https://doi.org/10.1016/j.ijepes.2024.110316

Emenike, S. N., & Falcone, G. (2020). A review on energy supply chain resilience through optimization. *Renewable and Sustainable Energy Reviews, 134*, 110088. https://doi.org/10.1016/j.rser.2020.110088

Fletcher, W. D., & Smith, C. B. (2024). *The global climate crisis: What To Do About It*. Elsevier.

Guerra, K., Welfle, A., Gutiérrez-Alvarez, R., Freer, M., Ma, L., & Haro, P. (2024). The role of energy storage in Great Britain's future power system: focus on hydrogen and biomass. *Applied Energy, 357*, 122447. https://doi.org/10.1016/j.apenergy.2023.122447

Hafner, M., & Tagliapietra, S. (2020). *The geopolitics of the global energy transition*. Springer Nature.

Jaheer, M. K. P., Jain, V., Tsai, S. B., & Wu, C. H. (2024). *Digital innovations for renewable energy and conservation*. IGI Global.

Kaushik, A., Kaushik, C. P., & Attri, S. D. (2021). *Climate resilience and environmental sustainability approaches: Global Lessons and Local Challenges*. Springer Nature.

Khan, M. K., Raza, M., Shahbaz, M., Farooq, U., & Akram, M. U. (2024). Recent advancements in energy storage technologies and their applications. *Journal of Energy Storage, 92*, 112112. https://doi.org/10.1016/j.est.2024.112112

Kumar, R., Lee, D., Ağbulut, Ü., Kumar, S., Thapa, S., Thakur, A., Jilte, R. D., Saleel, C. A., & Shaik, S. (2024). Different energy storage techniques: recent advancements, applications, limitations, and efficient utilization of sustainable energy. *Journal of Thermal Analysis and Calorimetry, 149*(5), 1895–1933. https://doi.org/10.1007/s10973-023-12831-9

Mamun, M. A., Boubaker, S., & Nguyen, D. K. (2022). Green finance and decarbonization: Evidence from around the world. *Finance Research Letters, 46*, 102807. https://doi.org/10.1016/j.frl.2022.102807

Márquez, J. M. A., Manzano, F. S., & Luengo, J. R. (2023). *Energy Storage Systems: Fundamentals, Classification and a Technical Comparative*. Springer Nature.

Michaelides, E. E. (2025). Energy storage: Driving the Renewable Energy Transition. CRC Press.

Migała-Warchoł, A., Ziółkowski, B., Lew, A., Stec-Rusiecka, J., & Warmińska, A. (2025). Factors enabling access to affordable, reliable, sustainable and modern energy in the European Union. *Energies, 18*(3), 722. https://doi.org/10.3390/en18030722

Mohamadi, F. (2021). *Introduction to project finance in renewable energy infrastructure: Including Public-Private Investments and Non-Mature Markets*. Springer Nature.

Montana, F., Cellura, M., Di Silvestre, M. L., Longo, S., Luu, L. Q., Sanseverino, E. R., & Sciumè, G. (2024). Assessing Critical Raw Materials and their Supply Risk in Energy Technologies—A Literature Review. *Energies, 18*(1), 86. https://doi.org/10.3390/en18010086

Paredes, Á., & Aguado, J. A. (2024). Revenue stacking of BESSs in wholesale and aFRR markets with delivery guarantees. *Electric Power Systems Research, 234*, 110633. https://doi.org/10.1016/j.epsr.2024.110633

Rahimi, M. (2021). *Lithium-Ion Batteries: Latest Advances and Prospects*. MDPI.

Rahman, M. M., Khan, I., & Alameh, K. (2022). The role of energy storage technologies for sustainability in developing countries. In *Elsevier eBooks* (pp. 347–376). https://doi.org/10.1016/b978-0-323-88668-0.00004-8

Raikar, S., & Adamson, S. (2024). *Renewable Energy Finance: Theory and Practice*. Elsevier.

Schmidt, O., & Staffell, I. (2023). *Monetizing energy storage: A Toolkit to Assess Future Cost and Value*. Oxford University Press.

Scholten, D. (2023). *Handbook on the Geopolitics of the Energy Transition*. Edward Elgar Publishing.

Seward, W., Qadrdan, M., & Jenkins, N. (2022). Revenue stacking for behind-the-meter battery storage in energy and ancillary services markets. *Electric Power Systems Research, 211*, 108292. https://doi.org/10.1016/j.epsr.2022.108292

Szott, M., Wermiński, S., Jarnut, M., Kaniewski, J., & Benysek, G. (2021). Battery energy storage system for emergency supply and improved reliability of power networks. *Energies, 14*(3), 720. https://doi.org/10.3390/en14030720

Talus, K. (2024). *A research agenda for international energy law*. Edward Elgar Publishing.

Vasilev, V. (2024). *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*. Springer Nature.

Wagner, S. M. (2020). *Business and environmental sustainability: Foundations, Challenges and Corporate Functions*. Routledge.

Wali, S., Hannan, M., Ker, P. J., Rahman, S., Le, K. N., Begum, R., Tiong, S., & Mahlia, T. I. (2023). Grid-connected lithium-ion battery energy storage system towards sustainable energy: A patent landscape analysis and technology updates. *Journal of Energy Storage, 77*, 109986. https://doi.org/10.1016/j.est.2023.109986

Yoo, Y., & Ha, Y. (2023). Market attractiveness analysis of battery energy storage systems in Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. *Renewable and Sustainable Energy Reviews, 191*, 114095. https://doi.org/10.1016/j.rser.2023.114095

Zhang, A., Alvi, M. F., Gong, Y., & Wang, J. X. (2022). Overcoming barriers to supply chain decarbonization: Case studies of first movers. *Resources Conservation and Recycling, 186*, 106536. https://doi.org/10.1016/j.resconrec.2022.106536

Zhang, H., Gao, S., & Zhou, P. (2022). Role of digitalization in energy storage technological innovation: Evidence from China. *Renewable and Sustainable Energy Reviews, 171*, 113014. https://doi.org/10.1016/j.rser.2022.113014

Zioło, M., Bąk, I., & Spoz, A. (2024). The role of financial markets in energy transitions. *Energies, 17*(24), 6315. https://doi.org/10.3390/en17246315

APPENDIX 1

The participants are members of the following organizations:

Nordic Business Alliance (NBA) is a non-profit business association founded in 2009 to promote unique Nordic values and business practices. Its focus is on innovation, sustainability, transparency, the environment, social responsibility, and equality. It also aims to promote and strengthen the network and cooperation between Nordic companies in Serbia, encouraging domestic companies to embrace Nordic business models.

The Association for Sustainable Development (ASOR) is a Non-Governmental Organization established by experienced professionals in energy, energy policy, and ecology. It is dedicated to promoting environmental awareness and global issues of sustainable development. ASOR aims to unite economic entities and scientific research institutions in implementing projects that contribute to a better understanding of the need to preserve resources and the rational use of energy.

The Faculty of Economics and Business in Belgrade belongs to the group of faculties within the University of Belgrade, which is ranked among the best in Central and Eastern Europe. From its foundation in 1937, the Faculty of Economics and Business has successfully connected and harmonized higher education in economics, business management, and statistics with the modern requirements of the economy and society, keeping pace with all important achievements in economics.

APPENDIX 2

The participants were asked the following questions:

Part 1

1. What is the potential solution for storing the energy produced from wind and solar power for periods with less wind and sun?
2. Can the recent growth in energy storage be explained by a substantial decrease in the prices of batteries?
3. Lithium-ion batteries are widely acknowledged as the market leader, yet are there any other emerging energy storage technologies that are becoming increasingly appealing?
4. How significant are increases in annual additions of grid-scale battery energy storage to meet the Net Zero ambitions of 2050?
5. If policies and regulations in developing countries do not incentivize the adoption of battery energy storage, does this make the role of international financial institutions in unlocking capital and knowledge even more considerable?

Part 2

1. How can we undertake a more resilient perspective on batteries?
2. How do we maintain the competitiveness of batteries?
3. What are the optimal financing structures or business models for BESS?
4. How can we navigate geopolitical risks and supply chain complexity?

ULOGA TEHNOLOGIJA ZA SKLADIŠTENJE ENERGIJE U DEKARBONIZACIJI ENERGETSKOG SEKTORA

Rezime:

Zahtev za povećanjem kapaciteta skladištenja energije tehnologija vetra i sunca izaziva veću potražnju za skladištenjem energije, što se odražava u primeni širokog spektra hardverskih i softverskih tehnoloških rešenja. Stručna literatura o skladištenju energije podržava integrisani pristup, što uključuje različite faktore za objašnjenje i rukovođenje dekarbonizacijom energije. Ovo istraživanje se zasniva na trenutnom pristupu i analizira opšti stav o usvajanju i upotrebi skladištenja energije, dajući odgovore na pitanja koja se tiču ekonomskih ograničenja, prihvatanja industrije, savremenih tehnologija i regulatorne prepreke. U ovom radu primenjena je metodologija fokusne grupe, u kojoj je učestvovalo sedam učesnika s ciljem da se generišu podaci, prikupljeni u komunikaciji i interakciji između učesnika istraživanja. Od učesnika je traženo da iznesu svoja mišljenja o istraživačkom modelu, a kroz istraživačka pitan ja ih je vodio istraživač. Istraživanja su pokazala da energija proizvedena iz energije vetra i sunca zahteva dodatni kapacitet za skladištenje. Cene baterija se smanjuju, što doprinosi rastu potražnje za skladištenjem energije. Međutim, kapaciteti za skladištenje energije baterija u mreži moraju se povećati. Iz tog razloga, uloga međunarodnih finansijskih institucija u omogućavanju kapitala i znanja, posebno u kontekstu zemalja u razvoju, postaje još istaknutija.

Ključne reči:

obnovljivi izvori energije,
energija vetra,
solarna energija,
litijum-jonski,
finansiranje energije.

JEL klasifikacija:
O32, Q42