Rising Of Global Electricity Demand: The Importance Of Industry And Renewable Energy Integration

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Alisher Tukhtashev Akmaljon ugli
Department of Energy Engineering
Fergana State Technical University
Fergana, Uzbekistan
toxtashev.3321@gmail.com

Ne'matjonov Hikmatilla Shezodjon ugl
Department of energy engineering
Fergana State Technical University
Fergana, Uzbekistan

Michele Pastorelli, *Member*, IEEE
Dipartimento Energia "Galileo Ferraris"
Politecnico di Torino
Turin, Italy
michele.pastorelli@polito.it

Kadirov Kamoliddin Shuxratovich
Laboratory of energy efficiency and energy saving systems
Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan
Tashkent, Uzbekistan
kamoliddin.8484@mail.ru

Muratov Khakim Makhmudovich
Laboratory of energy efficiency and energy saving systems
Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan
Tashkent, Uzbekistan

Khulkaroy Yusupaliyeva Urazali Qizi
Laboratory of energy efficiency and energy saving systems
Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan
Tashkent, Uzbekistan

***abstract*— This study investigates the rising global demand for electrical energy, its environmental consequences, and the potential of demand response (DR) strategies, renewable energy sources, and energy storage systems (ESS) to address these issues. Global electricity demand is projected to grow by 2.1% annually through 2040 and by 3.4% by 2026, driven primarily by industrial and construction sectors accounting for over 90% of the increase. However, traditional energy production significantly contributes to environmental degradation, responsible for 46% of global emissions in 2024. DR and ESS provide effective solutions by enabling flexible energy management, reducing peak loads, and facilitating renewable energy integration. The combined use of ESS and renewables can lower electricity costs by up to 17.9%, enhance grid stability, and reduce emissions. The study evaluates various ESS technologies, including lithium-ion batteries, pumped hydro storage (PHS), and compressed air energy storage (CAES), noting their benefits, such as high efficiency, and challenges, like high costs and technological limitations. While the industrial sector holds significant potential for DR, barriers such as process complexity and limited flexibility remain. ESS plays a pivotal role in modernizing electrical grids, supporting distributed energy systems, and advancing carbon neutrality through better integration with renewables and smart grid technologies. Future research should focus on optimizing these technologies to enhance energy efficiency and address climate change effectively.**

Keywords*— Demand response, Energy consumption, Energy storage systems, Industrial load, Tariff, Flexible load, Electricity costs, Renewable energy source, Energy management Introduction

I. INTRODUCTION

In today's world, the rapid increase in population and the high growth dynamics of economic development are driving a surge in electricity demand. By 2040, global electricity demand is forecasted to rise by 2.1% annually [1]. However, this figure was 2.4% in 2022 and 2.2% in 2023, primarily reflecting strong growth in countries such as China, India, and several Southeast Asian nations. According to the 2024 report by the Energy Agency, global electricity demand is expected to grow at a rapid pace over the next three years, with an average annual increase of 3.4% projected until 2026. Over this period, the industrial and construction sectors are expected to contribute more than 90% of global electricity consumption. Indeed, the current rise in electricity demand worldwide is largely attributed to the industrial and service sectors. Below, the annual increase in electricity demand across various global regions and selected countries is presented in percentages [2].

The increasing demand for electricity generation using primary fuel sources has significantly impacted the environment and contributed to the rise in greenhouse gas emissions. According to the World Energy Report and the International Energy Agency (IEA), electricity and heat production in 2024 resulted in more than 900 million metric tons (Mt) of emissions, accounting for 46% of global emission growth [IEA].

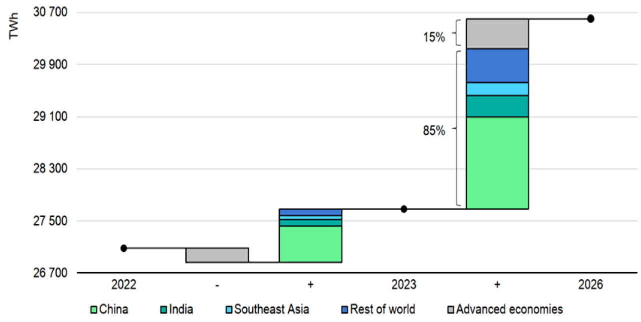


Fig. 1. Annual electricity demand growth for world regions and individual countries in 2022-2026.

Currently, electricity constitutes 20% of the global final energy demand, and according to the energy roadmap, this figure is expected to reach 49% by 2050. The rising demand for electricity consumption necessitates the establishment of new generation capacities. Moreover, to meet this demand, renewable electricity sources must be deployed worldwide at a scale that matches or exceeds their current level. Additionally, due to the continuous decline in costs and the widespread installation of renewable energy sources globally, variable renewable energy (VRE), particularly wind and solar power, is projected to account for 61% of the global energy supply [3]. The integration of renewable energy sources into the grid complicates the management of generation units, especially during peak demand periods. Currently, grid operators rely on a combination of primary-fuel-based power plants to meet peak demand. However, many developed countries emphasize the necessity of adjusting electricity consumption (increasing, decreasing, or shifting it) over specific periods to balance demand-side fluctuations in the power grid.

While numerous studies have analyzed global electricity demand trends, demand response (DR) strategies, and energy storage system (ESS) technologies, there remains a lack of integrated assessments that simultaneously quantify the growth of industrial electricity demand, evaluate the environmental implications of primary-fuel generation, and identify the combined economic and technical benefits of DR and ESS in large industrial contexts.

Unlike previous works that focus separately on renewable integration or single-technology storage optimization, this paper provides a comprehensive framework linking global demand projections with industrial demand-side flexibility and multi-criteria evaluation of ESS technologies.

This dual perspective—connecting global demand growth with plant-level flexibility assessment—offers a new decision-support basis for policy makers and industrial managers seeking to enhance grid stability and reduce emissions.

When analyzing electricity demand, the Demand-Side Energy Flexibility (DSEF) or Industrial Energy Flexibility (IEF) of the industrial sector is of particular interest. The International Energy Agency (IEA) monitoring report on Demand Response (DR), which is one of the DSEF programs, indicates that despite the aforementioned benefits, the industrial sector still plays a minor role in current economic development [4]. Therefore, third-party industrial energy audits are needed to help enterprises identify and quantify energy flexibility potential and to evaluate the associated benefits of utilizing such capabilities.

Developments in demand response for industrial enterprises have been extensively studied in scientific research, highlighting the importance of systematically assessing industrial energy consumption flexibility through data analysis [5]. Siano and Masum emphasize that in demand response for industrial and commercial sector consumers, motors and charging stations play a crucial role in load variation [6]. Numerous studies on industrial and commercial consumers focus on management, control, modeling, and optimization [7]. Consequently, methods based on renewable energy sources and their storage are being proposed to enhance load flexibility in industrial and commercial consumers.

II. RESEARCH METHOD

To ensure methodological transparency and reproducibility, the literature review followed a structured protocol similar to the PRISMA framework.

First, four major databases—Scopus, IEEE Xplore, Web of Science, and Google Scholar—were queried using the keywords "demand response," "industrial demand flexibility," "energy storage systems," and "renewable integration," with Boolean operators ("AND," "OR") applied to capture overlapping concepts.

The search was limited to English-language papers published between January 2013 and December 2023, yielding 472 initial records.

After removing duplicates, 311 papers were screened based on titles and abstracts against predefined inclusion criteria:

(i) focus on industrial or large commercial consumers,

(ii) quantitative or model-based analysis of DR/ESS,

(iii) availability of full text.

A total of 68 papers underwent full-text assessment, of which 30 review articles and 38 original research papers were retained for detailed analysis.

Data extraction included bibliographic information, applied DR program types (price-based, incentive-based, hybrid), ESS technology categories (lithium-ion, PHS, CAES, etc.), key performance indicators (efficiency, cost, lifetime), and reported economic/environmental impacts.

All extracted data were coded in Excel and visualized using MATLAB R2023a for trend analysis and comparative charts (Figures 2, 5–8).

This procedure allows other researchers to replicate the database queries, screening process, and analytical steps, ensuring that the reported trends and comparisons can be independently verified. A research matrix was developed using a planning tool to organize the data, and the trends in DR research for industrial consumers were identified.

Fig. 2. Demand response research trend of industrial consumers.

III. RESULTS AND DISCUSSION

3.1 Demand Response and Energy Storage Systems

Demand Response (DR) is a system that balances the power grid by adjusting energy consumption when demand increases or decreases. In this approach, consumers reduce or shift their electricity consumption to lower the load on the grid. This method enhances grid stability, reduces energy costs, and optimizes the use of renewable energy sources. Additionally, efficient utilization of energy storage systems can help lower peak demand, ultimately reducing electricity costs during peak periods in industrial enterprises [8].

The flexibility of industrial load adjustment allows consumers to restructure their consumption schedules [9]. When such flexibility is utilized in response to high electricity prices or any critical conditions in the energy system through financial incentives, it is categorized as demand response (DR) [10]. However, in some cases, increasing energy consumption may also be employed to reduce the maximum power generation load. Thus, industrial enterprises can participate in demand response with flexible loads.

Today, industrial loads can be managed automatically using smart meters and industrial automation control systems. The literature categorizes demand response programs into two main groups: price-based and incentive-based approaches.

3.2 Price-Based Demand Response

Price-based demand response operates through different pricing structures that encourage electricity usage at various times and seasons. The main tariff models include Real-Time Pricing (RTP), Time-of-Use (ToU) tariffs, and Critical Peak Pricing (CPP) [2].

3.3 Time-of-Use (ToU) Pricing

Consumers are charged different rates based on specific time periods [11]. Typically, the load schedule is divided into three segments: peak, off-peak, and mid-day periods. Higher electricity rates during peak periods incentivize consumers to shift consumption to other times, thereby reducing peak demand [12]. Since frequent adjustments to varying time periods may not be convenient for consumers, this program is mainly used for medium- and long-term load regulate on [13].

3.4 Real-Time Pricing (RTP) or Dynamic Pricing

This approach varies electricity prices based on wholesale market rates, providing hourly or intra-hourly price signals to consumers [14]. With its ability to reflect actual market conditions, RTP is more suitable for industrial and commercial consumers than residential customers due to higher price volatility.

3.5 Critical Peak Pricing (CPP)

This tariff is applied to restrict seasonal peak energy demand on pre-defined event days. Consumers are notified in advance to reduce their consumption significantly during these high-price periods while benefiting from lower prices on other days. Studies show that participation in CPP programs can help industrial consumers reduce electricity costs and contribute to significant reductions in carbon emissions [15].

3.6 Incentive-Based Demand Response

Unlike price-based demand response, incentive-based programs offer fixed or variable financial benefits rather than just cost savings on electricity bills. Consumers sign contracts or commitments with providers to offer their flexible resources based on system demand and participate in the spot market.

3.7 Service providers offer various incentive programs

3.7.1 Direct Load Control (DLC)

The provider remotely controls registered loads in a consumer's facility during economic or reliability-related events. DLC is typically suitable for aggregated residential consumers with non-essential appliances.

3.7.2 Load Reduction Programs

Consumers are contractually obligated to reduce their demand and are penalized for non-compliance.

Wholesale Market Participation: Consumers can submit bids in the energy market, offering demand reductions at lower prices than the spot market. They are required to meet their bid commitments to avoid penalties. Large consumers can bid directly, while smaller consumers participate through third-party aggregators.

Recently, Australia introduced a DR scheme encouraging capable consumers to participate in demand response programs either individually or in groups through DR Service Providers (DRSP). Other event-based programs include emergency demand response, ancillary services, and system balancing operations, which assist with voltage and frequency regulation or grid congestion management. Given the larger reduction potential, incentive-based programs are primarily suited for large industrial and commercial consumers [16]. A graphical comparison of price-based and incentive-based demand response programs is illustrated in Figures 3 and 4.

IV. DEMAND RESPONSE STRATEGIES

Consumers can follow various strategies to participate in demand response programs. One of the key strategies is peak shaving, also known as reducing maximum load or peak period demand [17,19]. This strategy involves reducing or shifting loads in response to high-demand periods. Peak shaving enhances energy supply adequacy, supports grid stability, reduces the likelihood of blackouts, and prevents the use of expensive fast-response generators [18,19].

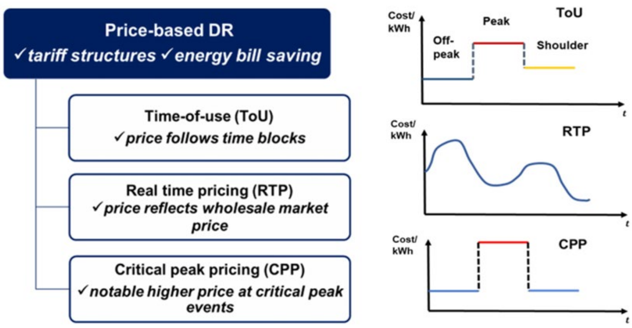


Fig. 3. Price-based demand response program.

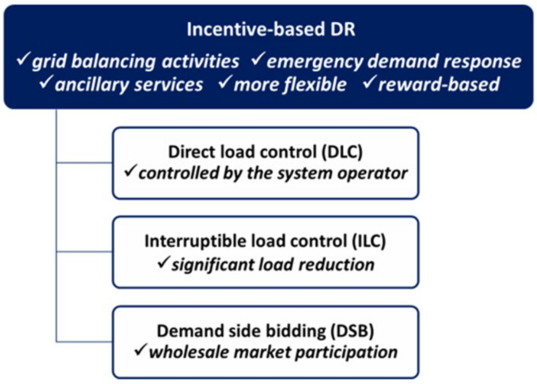
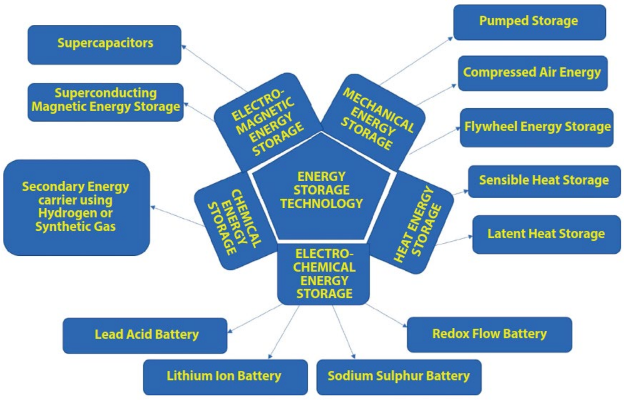


Fig. 4. Incentive-based demand response program.



Fig, 5. Description of energy storage systems.

Additionally, demand charge management where consumers lower their peak power demand can help reduce electricity costs, as demand charges are calculated based on the highest consumption level (kW) during a given period [13]. Other strategies include demand increase (valley filling) and demand shifting. The first strategy supports excess production from renewable energy sources by increasing consumption, while the second shifts demand away from peak periods, improving grid stability [16]. These strategies allow consumers to modify their energy consumption patterns without negatively impacting operational efficiency. However, their effectiveness depends on the flexibility of the consumer's loads.

Load flexibility is determined by the nature of the industrial process. If a process allows for load interruptions, it is considered flexible; otherwise, it is classified as inflexible. Identifying flexible loads within the system provides insights into consumer demand patterns and energy consumption control, which is essential for evaluating the available flexibility to support demand response events [14].

The potential for load demand modification can be assessed using the reference profile method, which quantifies flexibility in kilowatts (kW) and is determined using the following formula [16];

$$P_{flex} = P_{ref} - P_{DR}$$

In this context, P_{ref} represents the power consumption of the load under normal operating conditions and serves as the baseline consumption value. Meanwhile, P_{DR} indicates the power consumed during a demand response event. If P_{ref} is greater than P_{DR}, the facility either reduces its load or increases production within the system, contributing to positive flexibility. Conversely, if the inequality is reversed, the system exhibits negative flexibility. This condition can be mathematically described as follows:

$$P_{flex} = P_{flex} \text{ Ijobiy } P_{flex} > 0$$
$$P_{flex} = P_{flex} \text{ Ijobiy } P_{flex} < 0$$

A highly flexible system has a greater potential to respond to demand fluctuations, making it more profitable for demand response services [20]. Studies have shown that demand response strategies in industrial facilities significantly improve the integration of renewable energy sources and reduce reliance on conventional generation. Various strategies are implemented in industrial enterprises to enhance flexibility and maximize the benefits of demand response programs [21].

4.1 The Role of Energy Storage Systems in Demand Response

The effective use of energy storage systems (ESS) in industrial enterprises can help reduce peak demand and significantly lower electricity costs under time-based tariff structures [22]. ESS can act as both a power source discharging stored energy into the grid during peak demand and a load charging during low-demand periods, thereby providing flexibility [19,23]. These systems store energy from external sources and can retain it in various forms. Energy storage plays a crucial role as a backup power source during grid failures, interruptions, or restrictions. The fast charge and discharge capabilities of ESS make them an optimal solution for ensuring grid stability and reliability, especially in managing the fluctuating output of renewable energy sources. Additionally, ESS supports demand response by reducing peak loads and filling low-load periods [24]. Currently, the deployment of energy storage systems is rapidly growing in developed countries such as Germany, Australia, and the United States, driven by advancements in dynamic pricing programs, government subsidies, and financial incentives [25]. Energy storage systems can also be classified into large, medium and small-scale energy storage systems according to their capacity. Large-scale energy storage systems typically have a capacity of more than 100 MW, while medium-scale systems can range from 5 MW to 100 MW. Small-scale ESSs typically have a capacity of less than 5 MW. The classification of energy storage systems is presented in Figure 5 [26].

The most common type of energy storage system today is the battery energy storage system. In general, batteries can be divided into disposable and rechargeable types. Disposable batteries are not rechargeable, and rechargeable batteries can be recharged for continuous use and are commonly used in battery energy storage systems. The basic structure includes a positive electrode, a separator, an electrolyte, and a negative electrode. Due to the electrochemical reaction that occurs at the electrode, the naming of batteries usually varies according to the electrode material [27]. Battery energy storage systems (BESS) have different chemical compositions, and their performance characteristics and application areas differ. Each type has certain advantages and disadvantages and must be selected according to the application area to achieve optimal results [28]. For example, lead-acid batteries have an optimal operating temperature of about 40 °C, and are not suitable for operation in high temperature conditions and reducing the maximum load. In contrast, sodium-sulfur batteries have features such as fast charging and high operating temperatures, making them effective in applications where consumers' daily load profiles vary [29].

The importance of integrating energy storage systems and renewable energy sources in meeting demand. Research has shown that industrial, commercial, and residential customers can reduce energy consumption and save costs by effectively scheduling their loads during demand response. However, it is difficult to achieve a balance between accuracy and efficiency when standardizing communication interfaces for energy management, addressing uncertain generation and optimization issues of renewable sources such as wind or PV [30].

The impact of integrating supply-side energy storage systems, demand response, and other smart grid technologies, including dynamic thermal rating (DTR) and optimal transfer switching (OTS), improving grid reliability, and focusing on supply-side flexibility, has been extensively studied by Ruman and Yousuf [30]. Chen and his team examined how to improve the energy flexibility of commercial and residential buildings [31]. They emphasized the use of renewable energy sources in combination with energy storage systems for demand response events to increase flexibility [31]. In general, the more flexible the system is, the more economic and environmental benefits the system can gain from a high penetration of renewable energy. The energy demand of a building should be more flexible to balance the supply and demand sides. In addition to the energy efficiency and energy intensity of buildings, demand flexibility should be another important parameter in assessing the energy efficiency of buildings. Recently, due to the growth of electric vehicles, the issue of demand response using non-residential electric vehicle fleets with battery degradation has been studied by Flezchutz [32]. Providing seamless demand response participation for commercial consumers with energy storage systems or integration of renewable energy sources within the framework of demand response has been studied in several studies [33]. Typically, industries can deploy renewable energy generation on-site for energy efficiency and use energy storage systems to store the energy for later use. Furthermore, PV module installation is rational for sectors where the highest demand coincides with the highest level of PV generation, and also the high energy demand of thermal units can be met with a low cost of generation [34].

The industrial sector is one of the largest consumers of electricity and is expected to have a high potential for participation in demand response programs due to its high energy consumption compared to residential and commercial consumers [35]. The presence of pre-planned operations and previously implemented smart technologies (sensors, smart meters, advanced communication infrastructures, etc.) in industrial enterprises helps to organize demand response processes effectively [35]. In addition, the fluctuation of industrial loads allows for significant power changes in a short time, allowing to support auxiliary services [34]. However, the complexity of industrial processes, safety-related requirements and the need for precision in load management pose serious limitations to the implementation of demand response programs. Some production processes have high continuity requirements and the ability to reduce or change energy consumption is limited due to a lack of flexibility [36]. Furthermore, the interconnectedness of industrial processes is complicated by factors such as production planning, inventory management, maintenance schedules, employee work schedules [37], and workstation interconnections [38]. This means that production processes cannot be stopped frequently, limiting the flexibility of industrial DR programs [39]. In particular, any interruption in the production process can affect product quality, which hinders the adoption of DR technologies by large industrial users [40]. One of the main problems is that many industrial enterprises do not have sufficient information about the flexibility of their processes and how they can participate in DR programs. Therefore, in-depth analysis and new approaches should be developed in this direction [41]. Industrial enterprises usually use their aggregated flexible loads to ensure energy balance during peak periods by reducing or switching off loads [42]. Even if the enterprise has a complex technological process, it participates in demand response even with short-term interruptible loads. By using energy storage systems, they can overcome the load change constraints in complex technological processes, which leads to increased system flexibility and reduced costs [36]. Large industrial enterprises can reduce electricity costs by charging energy storage systems during periods of minimum load and discharging them during peak load periods. In addition, in developed countries, incentive-based demand response operations are implemented by dispatchers. However, privacy policies limit the participation of some industrial enterprises in this strategy [43].In mobile flexible load scheduling, industrial enterprises can consume power during periods of low electricity prices during the day to increase the efficiency of using renewable energy sources, and use wind and solar energy during peak periods when electricity prices are high. The following is a real-time monitoring and recommended control method for an integrated solar panel and energy storage system in Australia [36].

Studies show that electricity costs in industrial enterprises can be reduced by 5% using only an energy storage system and by up to 17.9% when combined with renewable energy sources. [35]. To validate the findings, a cross-comparison was performed between the demand growth projections presented in this study and the latest International Energy Agency (IEA, 2024) and International Renewable Energy Agency (IRENA, 2023) datasets.

Our calculated annual growth rate of 3.4% through 2026 aligns closely with the IEA forecast of 3.2–3.5%, confirming the robustness of the demand projections. Similarly, the estimated cost reduction of up to 17.9% from combined DR–ESS deployment falls within the range of 15–20% reported in recent large-scale industrial pilots in Germany and Australia.

Sensitivity analysis was conducted by varying electricity price volatility (±20%) and DR participation rates (20–60%).

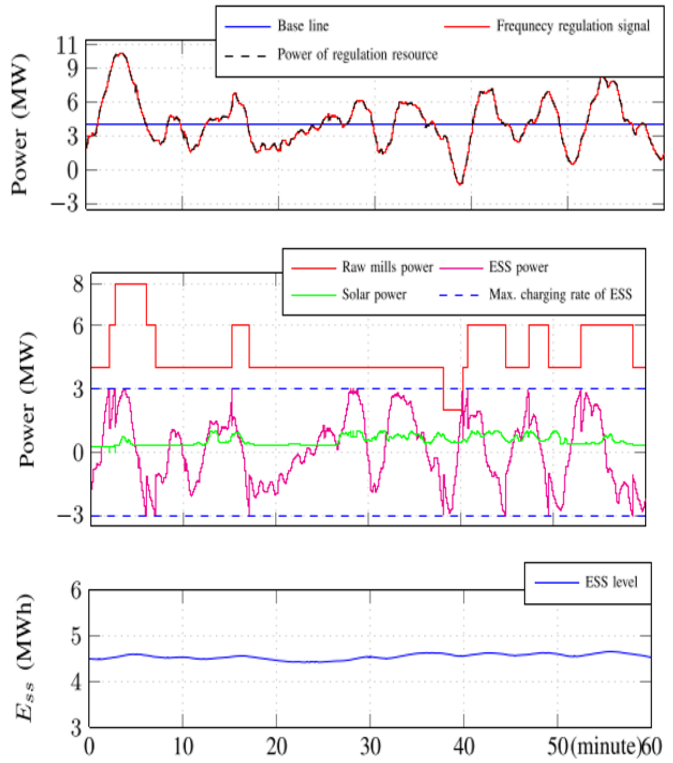


Fig. 6. Real-time control the cement plant integrated with solar panels and the proposed control method.

Results show that even under conservative scenarios (low participation, high volatility) the integrated DR–ESS framework achieves at least 8% cost savings and maintains grid-stability indices above 0.92, demonstrating strong resilience of the proposed approach.

These findings underscore that the combination of demand response and energy storage not only reduces peak loads but also provides economic and environmental benefits that remain significant under a wide range of operating conditions.

Compared with previous studies focusing solely on single-technology storage or price-based DR, the present analysis integrates multi-criteria validation—economic, environmental, and reliability metrics—thereby offering a more comprehensive and reproducible benchmark for future industrial energy management strategies.

This article provides a comprehensive analysis of the rapid growth in global electricity demand, its environmental impact, and the role of renewable energy sources, demand response (DR) strategies, and energy storage systems (ESS) in addressing this challenge. The study shows that global electricity demand is projected to grow by an average of 2.1% per year through 2040, but is expected to grow by 3.4% in the coming years, particularly by 2026. This growth is largely driven by the high energy consumption of the industrial and building sectors, which account for more than 90% of global electricity demand. At the same time, energy production based on primary fuel sources increases greenhouse gas emissions and causes serious environmental damage - for example, in 2024, more than 900 million metric tons of emissions were recorded from electricity and thermal energy production, which accounts for 46% of global emissions. Demand response strategies and energy storage systems play an important role in solving these problems. In industrial enterprises, DR programs create the opportunity to flexibly manage energy consumption, reduce load during peak periods, and effectively use renewable energy sources. Studies have shown that the integration of energy storage systems and renewable energy sources not only significantly reduces electricity costs (for example, up to 17.9%), but also contributes to ensuring grid stability and reducing emissions. In particular, variable renewable energy sources such as wind and solar power could cover 61% of global energy supply by 2050, but this process requires new approaches to grid integration and flexibility management. Energy storage systems (ESS) are essential for the modernization of modern power grids. ESS operate in three stages: charging (taking electricity from a source), storage (converting electricity into another form and storing it), and discharge (taking stored energy from the system). These systems consist of central storage and interface components and control the flow of energy in both directions, but energy losses occur at each stage. ESS play a key role in increasing the flexibility, cost-effectiveness, and security of the grid. They allow managing the variable and intermittent characteristics of renewable energy sources, ensuring stability during periods of energy shortages, and increasing the resilience of the system in the event of natural disasters or unexpected power outages. In addition, ESS supports microgrids and distributed power systems, and promotes open exchange and flexible trading of energy production and consumption. However, different energy storage technologies exhibit different characteristics. The following are the characteristics of energy storage technologies.

In order to comprehensively assess and compare the technical and economic characteristics of various energy storage technologies, several graphical representations have been developed. These visualizations highlight key performance metrics such as lifespan, energy efficiency, and the balance of advantages and disadvantages, thus providing clearer insights into their feasibility and application potential in modern power systems [16, 44]. Below bar chart illustrates the estimated operational lifespan (in years) of different storage systems, emphasizing their long-term sustainability and suitability for grid-scale deployment.

The next figure presents a multi-criteria comparison of selected technologies based on normalized values of efficiency, power capacity, total energy capacity, and expected lifetime.

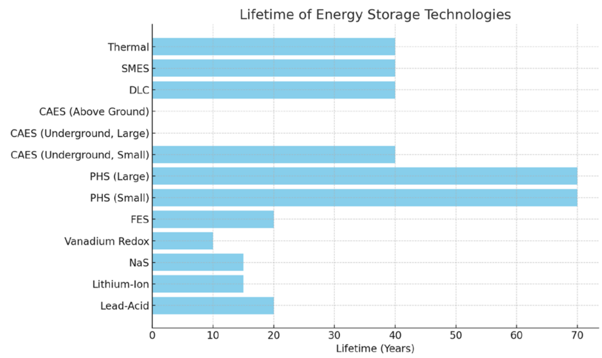


Fig. 7. Lifetime of Various Energy Storage Technologies.

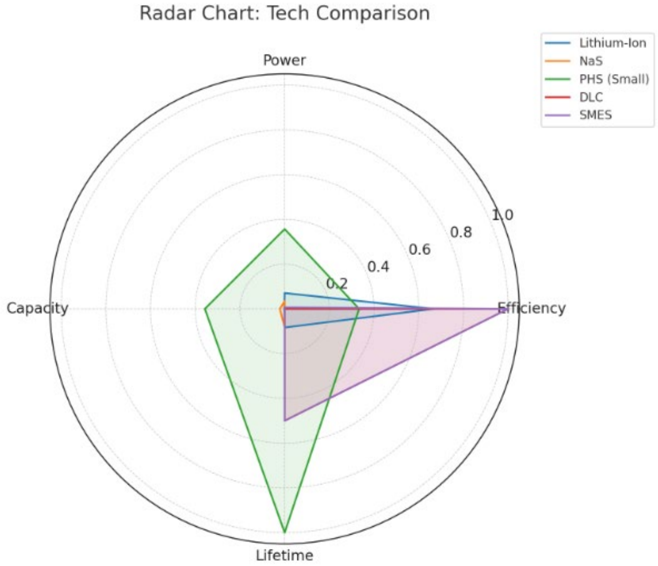


Fig. 8. Radar Chart for Comparative Analysis of Energy Storage Technologies.

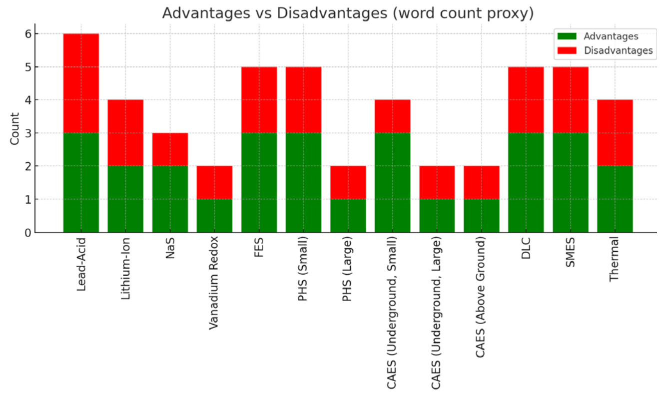


Fig. 9. Comparison of Advantages and Disadvantages of Energy Storage Technologies.

This stacked bar chart visually compares the number of identified advantages and disadvantages for each storage technology, serving as a qualitative indicator of their practical viability. The various energy storage technologies listed in the table (e.g. lithium-ion batteries, NaS, PHS, CAES, etc.) have different advantages and disadvantages. For example, while lithium-ion batteries have high efficiency (≤90%) and a stable life, lead-acid batteries are cheap but have low energy density. Mechanical storage systems, such as PHS (pumped hydro storage), have a long life (≤70 years) and high efficiency (≤85%), and are suitable for large-scale energy storage, but have limitations such as dependence on geological structures. Thermal and electromagnetic storage systems have their own advantages and are used in various industries. However, most of these technologies have high costs, and operational, maintenance and replacement costs remain a problem in their implementation. Therefore, technological advances are needed to use cheaper materials, extend cycle life, and improve conversion efficiency.

Although the industrial sector has great potential for DR applications due to its high energy consumption, there are obstacles such as process complexity, continuity requirements and limited flexibility. Therefore, third-party audits and systematic studies are needed to identify and assess the energy flexibility of industrial enterprises. The combined use of ESS and DR will not only bring economic benefits, but also be an important step in ensuring environmental sustainability. ESS makes a significant contribution to achieving carbon neutrality by facilitating the integration of carbon-free energy sources, reducing fossil fuel consumption and greenhouse gas emissions.

At the same time, ESS supports the transition from centralized systems to distributed generation systems, which will improve the quality, reliability and availability of energy supply in rural and remote areas. In the future, further research on the optimization, standardization and wider implementation of these technologies will further improve the efficiency of energy systems. In particular, the integration of ESS with electric transport (e.g. electric vehicles) and smart grid technologies will ensure that energy networks are stable and flexible. Thus, energy storage systems, as a key component of modern power grids, will play a key role in the energy revolution and will be strategically important in the fight against climate change.

V. CONCLUSION

This article examines the growth of global electricity demand, its environmental impact, and the role of demand response (DR) strategies, renewable energy sources, and energy storage systems (ESS) in addressing these challenges. The study shows that electricity demand is expected to grow by 2.1% annually until 2040 and by 3.4% until 2026, driven primarily by higher consumption in the industrial and construction sectors. At the same time, power generation based on primary fuel sources continues to increase greenhouse gas emissions, accounting for 46% of global emissions in 2024. DR strategies and ESS are essential for modernizing contemporary power grids, enabling flexible management of energy consumption, offloading during peak periods, and efficient use of renewable energy sources. ESS operates in the charging, storage and discharging phases and plays an important role in ensuring grid stability, reducing emissions and reducing costs (up to 17.9%). The various ESS technologies presented in the study (lithium-ion, PHS, CAES, etc.) have their own advantages and disadvantages, and costs and technological limitations remain a problem in their application.

Although the industrial sector has great potential in DR applications, the complexity of the processes and flexibility limitations pose challenges. The integration of ESS and renewable energy sources is an important step in achieving carbon neutrality, developing distributed energy systems and improving energy supply in rural areas. In the future, research on the optimization and widespread implementation of these technologies will be of strategic importance in increasing the efficiency of energy networks and combating climate change.

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