OPEN ACCESS
Engineering Science & Technology Journal
P-ISSN: 2708-8944, E-ISSN: 2708-8952
Volume 5, Issue 4, P.No. 1257-1269, April 2024
DOI: 10.51594/estj/v5i4.1016
Fair East Publishers
Journal Homepage: www.fepbl.com/index.php/estj

THE IMPACT OF SMART GRIDS ON ENERGY EFFICIENCY: A COMPREHENSIVE REVIEW

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Article Received: 08-01-24 **Accepted:** 15-03-24 **Published:** 10-04-24

ABSTRACT

Smart grids have emerged as a key technology in the quest for energy efficiency and sustainability. This review provides a comprehensive analysis of the impact of smart grids on energy efficiency, highlighting key findings, challenges, and future directions. Smart grids leverage advanced sensing, communication, and control technologies to optimize the generation, distribution, and consumption of electricity. By enabling two-way communication between utilities and consumers, smart grids improve grid reliability, reduce energy losses, and facilitate the integration of renewable energy sources. One of the key findings of this review is the significant impact of smart grids on energy efficiency. Studies have shown that smart grids can reduce energy consumption by enabling real-time monitoring and control of energy usage. This not only helps consumers reduce their electricity bills but also reduces the overall carbon footprint of the electricity sector. However, the deployment of smart grids faces several challenges, including high upfront costs, interoperability issues, and data privacy concerns. Addressing these challenges will be crucial for the widespread adoption of smart grid technologies. Looking ahead, the future of smart grids holds great promise for further improving energy efficiency. Emerging trends such as the Internet of Things (IoT) integration, artificial intelligence (AI) algorithms, and distributed energy resources (DERs) management are expected to drive further innovation in smart grid technologies. In conclusion, smart grids have a transformative impact on energy efficiency, offering significant benefits for consumers, utilities, and the environment. However, addressing challenges such as cost and interoperability will be crucial for realizing the full potential of smart grids. By embracing emerging trends and technologies, stakeholders can further enhance the efficiency and sustainability of the electricity sector.

Keywords: Impact, Smart Grid, Energy, Efficiency, Review.

INTRODUCTION

In recent years, the concept of smart grids has gained significant attention as a key enabler of energy efficiency and sustainability in the electricity sector. Smart grids represent a modernized electricity infrastructure that integrates advanced sensing, communication, and control technologies to optimize the generation, distribution, and consumption of electricity (Ahmad & Zhang, 2021, Farmanbar, et. al., 2019, O'Dwyer, et. al., 2019).

Smart grids enable two-way communication between utilities and consumers, allowing for real-time monitoring and control of energy usage. This functionality enables utilities to better match supply and demand, reduce energy losses, and integrate renewable energy sources into the grid. Additionally, smart grids facilitate the implementation of demand response programs, which incentivize consumers to reduce their electricity usage during peak periods (Dileep, 2020, Huang, et. al., 2021, Rihan, 2019).

Energy efficiency is of paramount importance in the electricity sector due to its potential to reduce energy consumption, lower electricity bills, and decrease greenhouse gas emissions. Smart grids play a crucial role in enhancing energy efficiency by providing utilities and consumers with the tools and information needed to make informed decisions about energy usage (Bastida, et. al., 2019, Hertwich, et. al., 2019, Mohsin, et. al., 2021).

The purpose of this review is to provide a comprehensive analysis of the impact of smart grids on energy efficiency. The review will examine the key functionalities and capabilities of smart grids, as well as their impact on energy consumption, grid reliability, and environmental sustainability. Additionally, the review will discuss the challenges and limitations associated with smart grid deployment, as well as the future directions and opportunities in the field. Overall, this review aims to contribute to the existing body of knowledge on smart grids and energy efficiency, providing valuable insights for policymakers, industry stakeholders, and researchers alike.

Fundamentals of Smart Grids

Smart grids represent a significant advancement in the modernization of the electricity infrastructure, integrating advanced technologies to enhance the efficiency, reliability, and sustainability of the grid (Alotaibi, et. al., 2020, Bagdadee & Zhang, 2019, Butt, Zulqarnain & Butt, 2021). This section explores the definition and components of smart grids, their key functionalities and capabilities, and the evolution of smart grid technologies.

A smart grid can be defined as an electricity network that uses digital communication technology to detect and react to changes in electricity usage in real time. It comprises various components that work together to optimize the generation, transmission, distribution, and consumption of electricity. Some key components of smart grids include:

Smart grids use sensors to collect data on electricity usage, grid conditions, and equipment performance. These sensors provide real-time information that enables utilities to make informed decisions about grid operations. Communication networks are essential for connecting the various components of the smart grid, such as sensors, meters, and control systems. These networks enable seamless communication and data exchange between different parts of the grid. Control systems in smart grids are responsible for monitoring and controlling grid operations. They use the data collected from sensors to optimize grid performance, such as adjusting power flows and managing grid congestion. AMI includes smart meters that provide detailed information about electricity usage to both utilities and consumers. Smart meters enable utilities to implement dynamic pricing and demand response programs, while empowering consumers to monitor and manage their energy usage (Chen, et. al., 2023, Meliani, et. al., 2020, Rivas & Abrao, 2020).

Smart grids offer several key functionalities and capabilities that distinguish them from traditional grids: Smart grids enable utilities to monitor grid conditions and electricity usage in real time, allowing for more efficient and proactive grid management. Smart grids support demand response programs, which incentivize consumers to reduce their electricity usage during peak periods. This helps utilities balance supply and demand and avoid grid congestion. Smart grids are more resilient to disruptions and outages, thanks to their ability to quickly detect and isolate problems and reroute power flows. Smart grids facilitate the integration of renewable energy sources, such as solar and wind, by managing their intermittent nature and optimizing their contribution to the grid.

The concept of smart grids has evolved over time, driven by advances in technology and the changing needs of the electricity sector. The evolution of smart grid technologies can be traced through several key stages: The early development of smart grids focused on basic automation and remote monitoring capabilities, such as the introduction of SCADA (Supervisory Control and Data Acquisition) systems (Avancini, et. al., 2019, Dileep, 2020, Farmanbar, et, al., 2019). The deployment of AMI, including smart meters, marked a significant advancement in smart grid technology, enabling utilities to collect detailed data on electricity usage and implement demand response programs. Grid modernization efforts have focused on integrating advanced communication and control technologies into the grid, enabling utilities to optimize grid operations and improve reliability.

Future trends in smart grid technology include the integration of advanced analytics, artificial intelligence (AI), and machine learning to further enhance grid efficiency and resilience. In conclusion, smart grids represent a transformative shift in the electricity sector, offering a range of benefits including improved efficiency, reliability, and sustainability. By leveraging advanced technologies and embracing innovation, smart grids have the potential to revolutionize the way electricity is generated, transmitted, and consumed, paving the way for a more sustainable energy future (Esenogho, Djouani & Kurien, 2022, Omitaomu & Niu, 2021, Shi, et. al., 2020).

Impact of Smart Grids on Energy Efficiency

Smart grids have a transformative impact on energy efficiency, offering a range of benefits that help utilities and consumers alike optimize energy usage (Joseph & Balachandra, 2020, Kabeyi & Olanrewaju, 2022, Nikolaidis & Poullikkas, 2020). This section explores the key ways in which smart grids improve energy efficiency, including real-time monitoring and control, reduction of energy losses, integration of renewable energy sources, and implementation of demand response programs.

One of the primary benefits of smart grids is the ability to monitor and control energy usage in real time. Smart meters and sensors collect data on electricity usage at a granular level, allowing utilities to identify inefficiencies and adjust operations accordingly. For consumers, real-time data enables them to monitor their energy usage and make informed decisions about energy conservation (Kulkarni, Lalitha & Deokar, 2019, Ourahou, et. al., 2020, Shahinzadeh, et. al., 2019).

Smart grids help reduce energy losses that occur during the transmission and distribution of electricity. By optimizing power flows and reducing grid congestion, smart grids minimize the amount of electricity lost as heat, improving overall system efficiency. Additionally, real-time monitoring enables utilities to identify and address inefficiencies in the grid, further reducing energy losses.

Smart grids facilitate the integration of renewable energy sources, such as solar and wind power, into the electricity grid. By managing the variability of these energy sources and optimizing their contribution to the grid, smart grids enable utilities to maximize the use of clean, renewable energy. This not only reduces greenhouse gas emissions but also enhances the overall sustainability of the electricity sector (Kataray, et. al., 2023, Ntombela, Musasa & Moloi, 2023, Worighi, et. al., 2019).

Demand response programs are a key feature of smart grids, enabling utilities to reduce peak demand and balance supply and demand more effectively. By incentivizing consumers to reduce their electricity usage during peak periods, demand response programs help avoid grid congestion and reduce the need for costly infrastructure upgrades. Additionally, smart grids enable utilities to implement load management strategies, such as shifting non-essential loads to off-peak times, further improving system efficiency (Du, Lu & Zhong, 2019, Rehman, et. al., 2021, Shakeri, et. al., 2020).

In conclusion, smart grids have a profound impact on energy efficiency, offering a range of benefits that improve grid operations and reduce energy consumption. By enabling real-time monitoring and control, reducing energy losses, integrating renewable energy sources, and implementing demand response programs, smart grids help utilities and consumers alike optimize their energy usage and contribute to a more sustainable energy future.

Case Studies and Examples

Smart grids have been implemented in various regions around the world, showcasing their effectiveness in improving energy efficiency and grid operations (Judge, et. al., 2022, Khalil, et. al., 2021, Saleem, et. al., 2023). This section explores several case studies and examples of successful smart grid implementations, highlighting their quantifiable benefits, outcomes, and lessons learned.

PG&E implemented a smart grid program that included the deployment of smart meters and advanced sensors. This enabled real-time monitoring of electricity usage and improved grid management. As a result, PG&E reduced energy losses, improved grid reliability, and implemented demand response programs. Jeju Island implemented a smart grid project that integrated renewable energy sources, such as solar and wind power, into the grid. This project reduced the island's reliance on fossil fuels, improved energy efficiency, and enhanced grid stability (Cooper, Shuster & Lash, 2021, Myers, 2024, Tiwari & Pindoriya, 2022).

In India, smart grids have been deployed in rural areas to improve energy access and efficiency. These smart grids enable real-time monitoring and control of electricity usage, reducing energy losses and improving service reliability. Smart grid implementations have resulted in significant energy savings due to improved efficiency in grid operations and reduced energy losses. For example, PG&E reported energy savings of over 2.3 billion kWh annually through its smart grid program (Asaad, et. al., 2021, Kumar, 2019, Neffati, et. al., 2021).

Smart grids have improved grid reliability by enabling utilities to identify and address issues in real time. This has led to a reduction in power outages and improved customer satisfaction. Smart grids have facilitated the integration of renewable energy sources into the grid, reducing greenhouse gas emissions and promoting sustainability.

Engaging and educating consumers about the benefits of smart grids is crucial for successful implementation. Utilities should communicate with consumers and involve them in energy efficiency efforts. Smart grid implementations require significant investment in infrastructure, including smart meters, sensors, and communication networks. Utilities should carefully plan and prioritize investments to maximize benefits. Regulatory support is essential for the successful implementation of smart grids. Regulators should create a supportive regulatory environment that encourages innovation and investment in smart grid technologies (Chadoulos, Koutsopoulos & Polyzos, 2020, Le Ray & Pinson, 2020, Ratner, et. al., 2022).

In conclusion, these case studies and examples demonstrate the significant impact of smart grids on energy efficiency and grid operations. By implementing smart grid technologies, utilities can improve energy efficiency, reduce energy losses, and enhance grid reliability, contributing to a more sustainable and resilient energy future.

Challenges and Limitations

Despite their numerous benefits, smart grids face several challenges and limitations that can hinder their full potential in improving energy efficiency (Abir, et. al., 2021, Diahovchenko, et. al., 2020, Moreno Escobar, et. al., 2021). This section explores some of the key challenges and limitations of smart grids, including high upfront costs, interoperability issues, and data privacy concerns.

One of the major challenges of implementing smart grids is the high upfront costs and investment requirements. Deploying smart meters, sensors, communication networks, and other smart grid infrastructure can be expensive, especially for utilities with limited financial resources. This cost barrier can delay or deter utilities from fully adopting smart grid technologies, limiting their ability to improve energy efficiency (Bhattarai, et. al., 2019, Giannelos, et. al., 2023, Shahzad, 2020).

Another challenge facing smart grids is interoperability issues and the lack of standardized communication protocols. Smart grids require seamless integration of various components, such as smart meters, sensors, and control systems, from different manufacturers. However, the lack of interoperability standards can lead to compatibility issues and make it difficult for utilities to deploy and manage smart grid infrastructure effectively (Demertzis, et. al., 2021, Jha, et. al., 2021, Tightiz & Yang, 2020).

Data privacy and security are significant concerns in smart grid deployments. Smart grids collect a vast amount of sensitive data, such as energy consumption patterns and user behavior, which can be exploited if not properly secured. Utilities must implement robust cybersecurity measures to protect this data from unauthorized access and cyber-attacks. Additionally, ensuring data privacy and complying with relevant regulations adds complexity to smart grid deployments.

In conclusion, while smart grids offer numerous benefits for improving energy efficiency, they also face several challenges and limitations that need to be addressed. Overcoming these challenges will require collaborative efforts from utilities, regulators, and other stakeholders to develop cost-effective solutions, establish interoperability standards, and enhance cybersecurity measures. Addressing these challenges will be crucial in realizing the full potential of smart grids in enhancing energy efficiency and building a more sustainable energy future.

Future Directions and Opportunities

As smart grid technology continues to evolve, there are several emerging trends and opportunities that hold promise for further improving energy efficiency and grid operations. This section explores some of these trends, including the integration of smart grids with other technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), as well as the potential for further improvements in energy efficiency (Ahsan, et. al., 2023, Stoustrup, et. al., 2019, Tan, et. al., 2021).

AMI, which includes smart meters and communication networks, is a key component of smart grids. The deployment of AMI allows for real-time monitoring of energy usage and enables utilities to implement demand response programs and time-of-use pricing, leading to improved energy efficiency. DERs, such as solar panels and battery storage, are becoming increasingly prevalent in the energy landscape. Smart grids enable the seamless integration of DERs into the grid, allowing for more efficient energy generation and distribution.

Grid modernization efforts, including the deployment of advanced sensors, automation, and control systems, are enhancing grid reliability and efficiency. These technologies enable utilities to detect and respond to grid disturbances more quickly, minimizing disruptions and improving overall system performance. The integration of smart grids with IoT devices allows for greater connectivity and data exchange between grid components and consumer devices. This integration enables more efficient energy management and optimization, leading to improved energy efficiency (Biagini, et. al., 2020, Kulkarni, et. al., 2021, Ourahou, et. al., 2020).

AI technologies, such as machine learning and predictive analytics, can be used to analyze large amounts of data collected by smart grids. By using AI algorithms to optimize grid operations, utilities can further improve energy efficiency and reduce costs. Smart grids enable utilities to implement demand response programs that incentivize consumers to reduce their energy usage during peak periods. By leveraging demand response and flexibility, utilities can better match supply and demand, leading to improved energy efficiency (Kotsiopoulos, et. al., 2021, Mostafa, Ramadan & Elfarouk, 2022, Syed, et. al., 2020).

Smart grids enhance grid resilience by enabling utilities to detect and respond to disruptions more effectively. This resilience is crucial in ensuring reliable energy supply and minimizing downtime, ultimately improving overall energy efficiency. In conclusion, the future of smart grids holds great promise for further improving energy efficiency and grid operations. By embracing emerging trends and integrating smart grids with other technologies, utilities can unlock new opportunities for optimizing energy usage and building a more sustainable energy future (Badihi, 2023, Nguyen, et. al., 2020, Song, et. al., 2022).

Policy and Regulatory Considerations

Policymakers play a crucial role in promoting the deployment of smart grids and advancing energy efficiency goals (Brown & Zhou, 2019, Cambini, et. al., 2020, Rathor & Saxena, 2020). This section explores the role of policymakers in promoting smart grid deployment, the regulatory frameworks and incentives for energy efficiency, and the importance of international collaboration and best practices sharing.

Policymakers can set targets and goals for energy efficiency and renewable energy adoption, which can drive the deployment of smart grid technologies. These targets provide a clear direction for utilities and stakeholders to work towards, fostering innovation and investment in smart grid infrastructure.

Policymakers can provide regulatory support for smart grid deployment by creating a favorable regulatory environment. This can include streamlining permitting processes, providing financial incentives, and ensuring fair market access for smart grid technologies. Policymakers can allocate funding for research and development in smart grid technologies. This funding can support innovation and the development of new technologies that improve energy efficiency and grid reliability.

Performance-based regulation incentivizes utilities to achieve specific energy efficiency targets by rewarding them for meeting or exceeding these targets. This regulatory approach encourages utilities to invest in smart grid technologies that improve energy efficiency. Regulatory frameworks can encourage the adoption of demand response programs, which incentivize consumers to reduce their energy usage during peak periods. These programs help utilities manage demand more effectively, leading to improved energy efficiency (Aweh & Shah, 2022, Joskow, 2024, Pató, Baker & Rosenow, 2019).

Policymakers can establish energy efficiency standards for appliances, buildings, and other energy-consuming devices. These standards promote the adoption of energy-efficient technologies and practices, which can be integrated into smart grid systems to improve overall energy efficiency. International collaboration allows countries to share best practices and lessons learned in smart grid deployment. This knowledge sharing can help accelerate the adoption of smart grid technologies and improve energy efficiency worldwide.

Collaborative efforts can also lead to the harmonization of standards and regulations, making it easier for countries to deploy interoperable smart grid technologies. This harmonization can reduce costs and barriers to entry for smart grid deployment. In conclusion, policymakers play a critical role in promoting smart grid deployment and advancing energy efficiency goals. By implementing supportive policies and regulatory frameworks, policymakers can create an environment that fosters innovation and investment in smart grid technologies, ultimately leading to improved energy efficiency and a more sustainable energy future (Demertzis, et. al., 2021, Gopstein, et. al., 2020, Gopstein, et. al., 2021).

CONCLUSION

In conclusion, the impact of smart grids on energy efficiency is significant and multifaceted. Smart grids offer a range of benefits, including real-time monitoring and control of energy usage, reduction of energy losses in transmission and distribution, integration of renewable energy sources, and implementation of demand response programs. These benefits lead to improved energy efficiency, reduced carbon emissions, and enhanced grid reliability.

However, the deployment of smart grids also presents challenges, such as high upfront costs, interoperability issues, and data security concerns. Addressing these challenges will require collaboration among stakeholders, including policymakers, regulators, utilities, and technology providers.

Looking ahead, the future of energy efficiency is closely tied to the continued advancement of smart grid technologies. Emerging trends, such as the integration of smart grids with other technologies like IoT and AI, hold promise for further improving energy efficiency and grid operations. Policymakers and regulators play a crucial role in promoting smart grid deployment and creating a supportive regulatory environment.

In light of these findings, stakeholders in the electricity sector are called upon to take action to accelerate the adoption of smart grids and advance energy efficiency goals. This may include investing in smart grid infrastructure, supporting research and development in smart grid technologies, and promoting policies that incentivize energy efficiency.

Overall, the impact of smart grids on energy efficiency is profound, and the opportunities for further improvements are vast. By embracing smart grid technologies and working collaboratively, stakeholders can drive the transition to a more sustainable and efficient energy future.

Reference

Abir, S. A. A., Anwar, A., Choi, J., & Kayes, A. S. M. (2021). Iot-enabled smart energy grid: Applications and challenges. *IEEE Access, 9*, 50961-50981.

Ahmad, T., & Zhang, D. (2021). Using the internet of things in smart energy systems and networks. *Sustainable Cities and Society, 68*, 102783.

Ahsan, F., Dana, N. H., Sarker, S. K., Li, L., Muyeen, S. M., Ali, M. F., ... & Das, P. (2023). Data-driven next-generation smart grid towards sustainable energy evolution: techniques and technology review. *Protection and Control of Modern Power Systems, 8*(3), 1-42.

Alotaibi, I., Abido, M. A., Khalid, M., & Savkin, A. V. (2020). A comprehensive review of recent advances in smart grids: A sustainable future with renewable energy resources. *Energies, 13*(23), 6269.

Asaad, M., Ahmad, F., Alam, M. S., & Sarfraz, M. (2021). Smart grid and Indian experience: A review. *Resources Policy, 74*, 101499.

Avancini, D. B., Rodrigues, J. J., Martins, S. G., Rabêlo, R. A., Al-Muhtadi, J., & Solic, P. (2019). Energy meters evolution in smart grids: A review. *Journal of cleaner production, 217*, 702-715.

Aweh, A., & Shah, N. (2022). Performance Based Regulation: Providing Benefits for Utilities Building the Grid of the Future. *Climate and Energy, 38*(7), 1-11.

Badihi, H. (2023). Smart Grid Resilience. In Handbook of Smart Energy Systems (pp. 1795-1819). Cham: Springer International Publishing.

Bagdadee, A. H., & Zhang, L. (2019). Smart grid: a brief assessment of the smart grid technologies for modern power system. *Journal of Engineering Technology*, *8*(1), 122-142.

Bastida, L., Cohen, J. J., Kollmann, A., Moya, A., & Reichl, J. (2019). Exploring the role of ICT on household behavioural energy efficiency to mitigate global warming. *Renewable and Sustainable Energy Reviews*, *103*, 455-462.

Bhattarai, B. P., Paudyal, S., Luo, Y., Mohanpurkar, M., Cheung, K., Tonkoski, R., ... & Zhang, X. (2019). Big data analytics in smart grids: state-of-the-art, challenges, opportunities, and future directions. *IET Smart Grid*, *2*(2), 141-154.

Biagini, V., Subasic, M., Oudalov, A., & Kreusel, J. (2020). The autonomous grid: Automation, intelligence and the future of power systems. *Energy Research & Social Science, 65,* 101460.

Brown, M. A., & Zhou, S. (2019). Smart-grid policies: an international review. *Advances in Energy Systems: The Large-scale Renewable Energy Integration Challenge*, 127-147.

Butt, O. M., Zulqarnain, M., & Butt, T. M. (2021). Recent advancement in smart grid technology: Future prospects in the electrical power network. *Ain Shams Engineering Journal*, *12*(1), 687-695.

Cambini, C., Congiu, R., Jamasb, T., Llorca, M., & Soroush, G. (2020). Energy systems integration: Implications for public policy. *Energy Policy*, *143*, 111609.

Chadoulos, S., Koutsopoulos, I., & Polyzos, G. C. (2020). Mobile apps meet the smart energy grid: A survey on consumer engagement and machine learning applications. *IEEE Access, 8,* 219632-219655.

Chen, Z., Amani, A. M., Yu, X., & Jalili, M. (2023). Control and optimisation of power grids using smart meter data: a review. *Sensors, 23*(4), 2118.

Cooper, A., Shuster, M., & Lash, J. (2021). Electric company smart meter deployments: foundation for a smart grid (2021 update). Institue for Electric Innovation: Washington, DC, USA.

Demertzis, K., Tsiknas, K., Taketzis, D., Skoutas, D. N., Skianis, C., Iliadis, L., & Zoiros, K. E. (2021). Communication network standards for smart grid infrastructures. *Network, 1*(2), 132-145.

Diahovchenko, I., Kolcun, M., Čonka, Z., Savkiv, V., & Mykhailyshyn, R. (2020). Progress and challenges in smart grids: Distributed generation, smart metering, energy storage and smart loads. *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, *44*, 1319-1333.

Dileep, G. J. R. E. (2020). A survey on smart grid technologies and applications. *Renewable Energy, 146,* 2589-2625.

Du, P., Lu, N., & Zhong, H. (2019). Demand response in smart grids (Vol. 262). Cham: Springer International Publishing.

Esenogho, E., Djouani, K., & Kurien, A. M. (2022). Integrating artificial intelligence Internet of Things and 5G for next-generation smartgrid: A survey of trends challenges and prospect. *IEEE Access*, *10*, 4794-4831.

Farmanbar, M., Parham, K., Arild, Ø., & Rong, C. (2019). A widespread review of smart grids towards smart cities. *Energies, 12*(23), 4484.

Giannelos, S., Borozan, S., Aunedi, M., Zhang, X., Ameli, H., Pudjianto, D., ... & Strbac, G. (2023). Modelling smart grid technologies in optimisation problems for electricity grids. *Energies, 16*(13), 5088.

Gopstein, A., Gopstein, A., Nguyen, C., Byrnett, D. S., Worthington, K., & Villarreal, C. (2020). Framework and roadmap for smart grid interoperability standards regional roundtables summary report. US Department of Commerce, National Institute of Standards and Technology.

Gopstein, A., Nguyen, C., O'Fallon, C., Hastings, N., & Wollman, D. (2021). NIST framework and roadmap for smart grid interoperability standards, release 4.0. Gaithersburg, MD, USA: Department of Commerce. National Institute of Standards and Technology.

Hertwich, E. G., Ali, S., Ciacci, L., Fishman, T., Heeren, N., Masanet, E., ... & Wolfram, P. (2019). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. *Environmental Research Letters, 14*(4), 043004.

Huang, C., Sun, C. C., Duan, N., Jiang, Y., Applegate, C., Barnes, P. D., & Stewart, E. (2021). Smart meter pinging and reading through AMI two-way communication networks to monitor grid edge devices and DERs. *IEEE Transactions on Smart Grid, 13*(5), 4144-4153.

Jha, A. V., Appasani, B., Ghazali, A. N., Pattanayak, P., Gurjar, D. S., Kabalci, E., & Mohanta, D. K. (2021). Smart grid cyber-physical systems: Communication technologies, standards and challenges. *Wireless Networks, 27,* 2595-2613.

Joseph, A., & Balachandra, P. (2020). Smart grid to energy internet: A systematic review of transitioning electricity systems. *IEEE Access, 8*, 215787-215805.

Joskow, P. L. (2024). The Expansion of Incentive (Performance Based) Regulation of electricity distribution and transmission in the United States. In Review of Industrial Organization.

Judge, M. A., Khan, A., Manzoor, A., & Khattak, H. A. (2022). Overview of smart grid implementation: Frameworks, impact, performance and challenges. *Journal of Energy Storage, 49,* 104056.

Kabeyi, M. J. B., & Olanrewaju, O. A. (2022, January). The use of smart grids in the energy transition. In 2022 30th Southern African Universities Power Engineering Conference (SAUPEC) (pp. 1-8). IEEE.

Kataray, T., Nitesh, B., Yarram, B., Sinha, S., Cuce, E., Shaik, S., ... & Roy, A. (2023). Integration of smart grid with renewable energy sources: Opportunities and challenges– A comprehensive review. *Sustainable Energy Technologies and Assessments, 58,* 103363.

Khalil, M. I., Jhanjhi, N. Z., Humayun, M., Sivanesan, S., Masud, M., & Hossain, M. S. (2021). Hybrid smart grid with sustainable energy efficient resources for smart cities. *Sustainable Energy Technologies and Assessments*, *46*, 101211.

Kotsiopoulos, T., Sarigiannidis, P., Ioannidis, D., & Tzovaras, D. (2021). Machine learning and deep learning in smart manufacturing: The smart grid paradigm. *Computer Science Review, 40,* 100341.

Kulkarni, N., Lalitha, S. V. N. L., & Deokar, S. A. (2019). Real time control and monitoring of grid power systems using cloud computing. *International Journal of Electrical and Computer Engineering (IJECE), 9*(2), 941-949.

Kulkarni, V., Sahoo, S. K., Thanikanti, S. B., Velpula, S., & Rathod, D. I. (2021). Power systems automation, communication, and information technologies for smart grid: A technical aspects review. *TELKOMNIKA (Telecommunication Computing Electronics and Control), 19*(3), 1017-1029.

Kumar, A. (2019). Beyond technical smartness: Rethinking the development and implementation of sociotechnical smart grids in India. *Energy Research & Social Science, 49*, 158-168.

Le Ray, G., & Pinson, P. (2020). The ethical smart grid: Enabling a fruitful and long-lasting relationship between utilities and customers. *Energy Policy, 140*, 111258.

Meliani, M., el Barkany, A., el Abbassi, I., Darcherif, A. M., & Mahmoudi, M. (2020, December). Control system in the smart grid: State of the art and opportunities. In 2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA) (pp. 1-6). IEEE.

Mohsin, M., Hanif, I., Taghizadeh-Hesary, F., Abbas, Q., & Iqbal, W. (2021). Nexus between energy efficiency and electricity reforms: a DEA-based way forward for clean power development. *Energy Policy, 149*, 112052.

Moreno Escobar, J. J., Morales Matamoros, O., Tejeida Padilla, R., Lina Reyes, I., & Quintana Espinosa, H. (2021). A comprehensive review on smart grids: Challenges and opportunities. *Sensors, 21*(21), 6978.

Mostafa, N., Ramadan, H. S. M., & Elfarouk, O. (2022). Renewable energy management in smart grids by using big data analytics and machine learning. *Machine Learning with Applications, 9*, 100363.

Myers, T. (2024). Leapfrogging smart meters. The Center for Growth and Opportunity.

Neffati, O. S., Sengan, S., Thangavelu, K. D., Kumar, S. D., Setiawan, R., Elangovan, M., ... & Velayutham, P. (2021). Migrating from traditional grid to smart grid in smart cities promoted in developing country. *Sustainable Energy Technologies and Assessments, 45*, 101125.

Nguyen, T., Wang, S., Alhazmi, M., Nazemi, M., Estebsari, A., & Dehghanian, P. (2020). Electric power grid resilience to cyber adversaries: State of the art. *IEEE Access, 8*, 87592-87608.

Nikolaidis, P., & Poullikkas, A. (2020). Sustainable services to enhance flexibility in the upcoming smart grids. *Sustaining Resources for Tomorrow*, 245-274.

Ntombela, M., Musasa, K., & Moloi, K. (2023). A comprehensive review of the incorporation of electric vehicles and renewable energy distributed generation regarding smart grids. *World Electric Vehicle Journal, 14*(7), 176.

O'Dwyer, E., Pan, I., Acha, S., & Shah, N. (2019). Smart energy systems for sustainable smart cities: Current developments, trends and future directions. *Applied Energy, 237*, 581-597.

Omitaomu, O. A., & Niu, H. (2021). Artificial intelligence techniques in smart grid: A survey. *Smart Cities, 4*(2), 548-568.

Ourahou, M., Ayrir, W., Hassouni, B. E., & Haddi, A. (2020). Review on smart grid control and reliability in presence of renewable energies: Challenges and prospects. *Mathematics and computers in simulation, 167*, 19-31.

Pató, Z., Baker, P., & Rosenow, J. (2019). Performance-based regulation: Aligning incentives with clean energy outcomes. Regulatory Assistance Project: Montpelier, VT, USA.

Rathor, S. K., & Saxena, D. (2020). Energy management system for smart grid: An overview and key issues. *International Journal of Energy Research, 44*(6), 4067-4109.

Ratner, S., Salnikov, A. A., Berezin, A., Sergi, B. S., & Sohag, K. (2022). Customer engagement in innovative smart grid deployment projects: evidence from Russia. *Environmental Science and Pollution Research, 29*(4), 5902-5911.

Rehman, A. U., Hafeez, G., Albogamy, F. R., Wadud, Z., Ali, F., Khan, I., ... & Khan, S. (2021). An efficient energy management in smart grid considering demand response program and renewable energy sources. *IEEE Access, 9*, 148821-148844.

Rihan, M. (2019). Applications and requirements of smart grid. *Smart Grids and their Communication Systems*, 47-79.

Rivas, A. E. L., & Abrao, T. (2020). Faults in smart grid systems: Monitoring, detection and classification. *Electric Power Systems Research, 189*, 106602.

Saleem, M. U., Shakir, M., Usman, M. R., Bajwa, M. H. T., Shabbir, N., Shams Ghahfarokhi, P., & Daniel, K. (2023). Integrating smart energy management system with internet of things and cloud computing for efficient demand side management in smart grids. *Energies, 16*(12), 4835.

Shahinzadeh, H., Moradi, J., Gharehpetian, G. B., Nafisi, H., & Abedi, M. (2019, January). IoT architecture for smart grids. In 2019 International Conference on Protection and Automation of Power System (IPAPS) (pp. 22-30). IEEE.

Shahzad, U. (2020). Significance of smart grids in electric power systems: a brief overview. *Journal of Electrical Engineering, Electronics, Control and Computer Science, 6*(1), 7-12.

Shakeri, M., Pasupuleti, J., Amin, N., Rokonuzzaman, M., Low, F. W., Yaw, C. T., ... & Lai, C. W. (2020). An overview of the building energy management system considering the demand response programs, smart strategies and smart grid. *Energies, 13*(13), 3299.

Shi, Z., Yao, W., Li, Z., Zeng, L., Zhao, Y., Zhang, R., ... & Wen, J. (2020). Artificial intelligence techniques for stability analysis and control in smart grids: Methodologies, applications, challenges and future directions. *Applied Energy, 278*, 115733.

Song, Y., Wan, C., Hu, X., Qin, H., & Lao, K. (2022). Resilient power grid for smart city. *iEnergy, 1*(3), 325-340.

Stoustrup, J., Annaswamy, A., Chakrabortty, A., & Qu, Z. (2019). *Smart grid control*. Springer International Publishing.

Syed, D., Zainab, A., Ghrayeb, A., Refaat, S. S., Abu-Rub, H., & Bouhali, O. (2020). Smart grid big data analytics: Survey of technologies, techniques, and applications. *IEEE Access, 9*, 59564-59585.

Tan, K. M., Babu, T. S., Ramachandaramurthy, V. K., Kasinathan, P., Solanki, S. G., & Raveendran, S. K. (2021). Empowering smart grid: A comprehensive review of energy storage technology and application with renewable energy integration. *Journal of Energy Storage, 39*, 102591.

Tightiz, L., & Yang, H. (2020). A comprehensive review on IoT protocols' features in smart grid communication. *Energies, 13*(11), 2762.

Tiwari, A., & Pindoriya, N. M. (2022). Automated demand response in smart distribution grid: a review on metering Infrastructure, communication technology and optimization models. *Electric Power Systems Research, 206*, 107835.

Worighi, I., Maach, A., Hafid, A., Hegazy, O., & Van Mierlo, J. (2019). Integrating renewable energy in smart grid system: Architecture, virtualization and analysis. *Sustainable Energy, Grids and Networks, 18*, 1