iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 **Issue:** XI **Month of publication:** November 2024

DOI: https://doi.org/10.22214/ijraset.2024.65004

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue XI Nov 2024- Available at www.ijraset.com

Blockchain Impact on AI Powered Virtual Power Plant (AI-VPP)

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***Abstract:** AI and blockchain will play a key role in our economy to deliver a data-driven approach to promote and enhance sustainability. Collection of data sets from different areas like energy, environmental, health care, food, and public safety to analyze consumer spending, predictive analysis, and regulatory compliance are key factors in developing an innovative strategy for sustainability challenges. These KPIs and analytics will help the public, government, and corporations to ensure optimized ways to maintain ethical standards, identify potential risks, and drive innovative ideas to overcome the challenges. Block chain (distributed ledger) for data sharing is more relevant to sharing critical information with the public and private sectors. Block chain delivers an effective track-and-trace approach to understand the root cause and shift the focus towards a sustainable future and circular economy. The energy sector is the most promising and is awarding AI and blockchain technology frameworks for the net zero and climate change agendas. Energy generation, distribution, and utilization data sets collected and analyzed over a period at different regions are the critical elements to plan a greener economy and sustainable future for everyone. Understanding the consumer's energy utilization behavior and their contribution to the greener economy is the most important factor. Keeping humans in loop strategies on automated demand response (ADR) programs that feed useful data to the AI platform is needed. Developing AI agents to help and designing deep learning models are the initial steps to establish an optimal baseline to work on. Let's contribute and enhance AI capabilities for sustainability.*

I. INTRODUCTION: AI AND BLOCKCHAIN ON SUSTAINABILITY

Artificial intelligence (AI) can impact a wider range of sectors to achieve a sustainable future. The most important applications are green energy microgrids that would impact climate change. Deep learning analytics on food, agriculture, and the supply chain would impact the food ecosystem; environmental monitoring, weather and disaster prediction, and management can impact economic fallouts. The major focus would be on power generation, water, agriculture, and transportation. Leveraging AI and blockchain technologies would not only provide efficiency and productivity but also improve a better lifestyle, increase in global GDP, and create close to 38 million jobs before 2030, according to PwC (https://www.pwc.co.uk/). On the other hand, blockchain is a distributed ledger that maintains and safeguards critical data infrastructure through a peer-to-peer network. Mainly blockchain was introduced on cryptocurrency to authenticate ownership of NFTs, which are digital assets, to give transparency to enhance digital transactions around the world.

II. KEY FOCUS: AI AND BLOCK CHAIN ON ESG

This research would focus mainly on the net zero and climate change agendas through AI and blockchain innovation and its challenges. Large-scale data collection, machine learning, deep learning, and neural networks are the major subsets of artificial intelligence. The logical and analytical position of the data set can give us a lot of insights to measure energy consumption on a granular and large scale. Blockchain using distributed ledger technology can capture the information and convert that information to provide transparency.

Environmental, Social, and Governance (ESG) is a set of standards that is useful to measure the impact of certain measures on the economy. The data collected over a period can give us a clear indication of urgency and its action plan at both regional and global levels based on environmental impact.

III. REVIEW OF THE LITERATURE

Recent technological, political, and economic factors have pushed the energy system toward the smart grid paradigm, revolutionizing not only the planning and operation of the electricity system but also its design (Pilo et al., 2013). Specifically, the architecture of the electricity system is shifting from a centralized to a decentralized model. Strategic policies and regulations, such as economic liberalization and emission reduction plans, are driving this transition by promoting the phase-out of large coal- and oil-powered energy plants in favor of localized grid management systems (Bruinenberg et al., 2012).

This shift facilitates the integration of renewable energy sources. Consequently, the future power system will need to fully utilize the flexibility of all participants to ensure a reliable and cost-effective energy supply (Kazmi et al., 2017). One of the most challenging aspects of maintaining electricity grids is balancing supply and demand, especially during peak hours. Demand response (DR) programs play a crucial role in addressing this issue by encouraging customers to reduce electricity usage during high-demand periods (Albadi and El-Saadany, 2008). However, the centralized management model of DR often faces difficulties, including concerns about the reliability of centralized databases, transparency of measurement data, privacy risks for demand-side users, delays in DR subsidy settlements, and the high costs of business management (Wang et al., 2019; Yu et al., 2020). A blockchain-based system can address these problems by providing an open and immutable record of all DR activities, such as energy savings and customer reimbursements. This approach has the potential to increase customer trust in the DR program and encourage greater participation. According to recent research, distributed ledger (DL) technology, with blockchain as a leading implementation, offers the most promising solution for developing peer-to-peer (P2P) frameworks (White Paper, 2022; Dick and Praktiknjo, 2019; Noor et al., 2018b). Decentralized data systems or ledgers, like blockchains, allow secure storage of digital transactions without the need for a central authority. Blockchains also enable P2P networks to execute smart contracts automatically (Hatziargyriou, 2013). Blockchain technology can be viewed as a repository that allows multiple users to edit the ledger simultaneously, potentially leading to variations in the chain. Instead of relying on a single trusted center to manage the ledger, each network member maintains a copy of the data chain and uses a consensus mechanism to verify the ledger’s legitimacy. Blockchain technologies are resilient and secure, thanks to cryptography that links new transactions to previous ones. This ensures that all users in the network can independently verify the authenticity of transactions, guaranteeing transparency and tamper-proof records (Andoni et al., 2019). Several review articles have been published analyzing the current state and potential of blockchain technology in the energy sector. These reviews provide a detailed analysis of the existing literature, identify key challenges, and suggest practical solutions for implementing blockchain technology in energy systems. Hasankhani et al. (2021) provide a comprehensive overview of blockchain technology in the context of smart grids and propose several potential use cases. However, their article lacks sufficient empirical evidence to support some of its claims and offers limited analysis of the challenges involved in applying blockchain technology to smart grids. Similarly, Bao et al. (2020) present a detailed review of various blockchain applications in the energy sector, highlighting their potential to solve industry challenges and emphasizing the benefits of efficiency, transparency, and security. However, their report mainly provides a high-level overview of these applications without delving into technical details or critically assessing the limitations of blockchain technology in the energy industry. Wang (2019) outlines the key technologies driving blockchain adoption in energy markets, focusing on distributed energy resources and AI optimization. The study by Jie et al. (2016) explores frequency response in virtual power plants (VPP) using a distributed control strategy. Assad et al. (2022) contribute valuable insights into optimizing frequency response and distributed energy control in VPPs using a genetic algorithm-based approach. While consideration of battery depreciation is an important addition to the field, further clarification on the algorithm's performance and the implications of its results would strengthen the study.

IV. ENERGY OPTIMIZATION, DISTRIBUTION AND CONTROL ECOSYSTEM USING AI AND BLOCKCHAIN

The research paper will dive deeper into the innovation, technology, and challenge of the energy ecosystem that results in greenhouse gas emissions and environmental sustainability. Enormous efforts are put forth in terms of investment, technology, and innovation to build a green energy future, but still less than 1% of electric fleets contribute to the global transportation sector. Almost 70–80% of produced energy is wasted along the generation, distribution, and utilization cycle. The faster we act on technological innovation like harnessing AI capability for decision-making and block chain for transaction metrics on how we utilize our resources are key to energy independence. This approach includes everything from mining on oil and gas to burning fossil fuels to focusing on renewable and alternate energy with a decentralized model.

A. Problem Statement on Research, Technology, and Accommodation

The research paper aims to study the benefits and challenges of adopting the next generation of innovation and technology for embedded energy frameworks on AI and blockchain. The real challenge is the limitation of integrated research for AI and blockchain on energy policies. The focus area should address the gap between the data sets collected from the operational aspects and evolve to deliver a viable techno-commercial aspect and a better payback period.

213

V. CHALLENGES AND SOLUTION OF AI IN ENERGY

The energy sector's key challenges are adaptation of new policies, trying out smart technology interventions at a smaller scale, and faster implementation with continuous learning. Machine learning (ML) and deep learning (DL) algorithms to enhance AI capabilities give us advancing analytics, integration approaches to green energy, grid resilience, and new possibilities for smart microgrids. The new strategies should include trying out integrated green energy micro or nanogrid solar/windmill/hydro farms into legacy infrastructure that can drive data into machine learning algorithms to deliver insights on demand flexibility and energy optimization techniques.

VI. AUTOMATED SOLUTION APPROACH TO OPTIMAL ENERGY UTILIZATION

To better understand optimal energy consumption and utilization, we must look at 3 major aspects.

1) Energy efficiency is an optimal energy usage by a facility by decreasing the peak demand. At any point, the facility can have a certain degree of demand flexibility. The facility should have a short-term ability to reduce or shift its demand without affecting the occupant's comfort or service to the facility.
2) Demand response, an automated approach to achieve demand flexibility on a demand basis through a smart tariff algorithm by collecting demand and flexibility datasets on both the consumer energy profile and the utility company's ability to generate and distribute energy with better pricing and operations.
3) Distributed energy resources (DERs), an integrated and decentralized approach to generate energy at the microscale level that could then feed to the grid on a needed basis to reduce generation costs and maintain grid resilience.

Penetration of renewable energy is growing at the faster phase and will continue to grow in the future. AI and blockchain inclusion will deliver an automated, seamless operation when the data collected at both the consumer level and the utility level can effectively introduce DERs to reduce energy costs and prioritize green energy. Ultimately, grid-interactive, energy-efficient buildings are the next generation of electrification. AI and blockchain can expedite the process by introducing energy management and control algorithms at the consumer level, and at the same time, demand response trigger events from utilities to consumers can automate the demand flexibility.

A. Machine Learning, Deep Learning, and AI on Connected Devices

The next generation of devices either it is household equipment or a sensor counter at an industrial 4.0 facility, the edged intelligence of these devices with better computation power can give these devices the ability to sense, analyze, learn, reason, and take action to deliver an effective business operation autonomously.

Artificial intelligence (AI) plays an important role in delivering seamless data-driven decisions by understanding the multi-dimensional data set from these intelligent connected devices to deliver automation and scalability in real time faster than ever.

When there is a combination of millions of connected devices using a multi-scale computing platform with more advanced and faster communication capabilities, it increases the level of complexity beyond human's ability to control and operate accurately. This kind of operational capability surly required a higher degree of smart automation.

Thanks for the innovation and technological advancement in AI and blockchain to adopt vast data sets from different parts of the world that can be fed into multiple models to learn and derive detailed insights. These inputs can be used to strategize and leverage to optimize and fed into the same system to learn from the existing outcomes to further improvise.

VII. LOAD OPTIMIZATION WITH AI IMAGING ON OCCUPANY USING EDGE DEVICES

Digital thermostats and digital breaker are key to adopting HVAC automation using an AI-enabled platform. When the digital thermostats collect data via cloud infrastructure, they can learn, analyze, and respond to facilities based on the building's thermal behavior and occupancy comfort. Furthermore, AI-imagining technology using image-based JSON files sends to the cloud on occupancy in real time. Now the combination of occupancy, outside temperature, indoor ambient, and smart tariff from the utility can deliver the most optimal HVAC operating conditions to save energy and prioritize green power.

Shifting HVAC is critical due to dependency on weather and occupancy. But the facilities can use thermal mass/storage to shit the operation based on peak period, delivering no impact to the occupant's comfort. This approach needs an efficient data-driven computation approach using smart algorithms that can be scalable.

Load shedding and load shifting on other loads such as water heaters, pool pumps, and daily appliances that have flexible duty cycles and can be scheduled and automated outside the peak demand periods without affecting consumer comfort by introducing demand response incentives to the consumers.

Solar PV and portable windmills can generate electricity to reduce facility demand with smart algorithms to charge and discharge based on the TOU (time of use) tariff. When the demand is lower than expected during off-peak, the generated power can be fed to the grid or stored on the battery for further load shifting.

A. *Demand Response Using AI and Block Chain*

Success of an automated demand response program depends on a human-in-loop inclusion approach by constantly educating the consumers to take advantage of effective power utilization based on smart tariffs without losing their comfort. The focus is to aim not just to automate the power optimization scenario and reduce stress on the grid infrastructure but also to create a framework for consumers to predict, participate in, and understand the logic behind power utilization and savings on demand response programs. The blockchain framework will help to better communicate via a secured platform and modernize the way we utilize power.

To integrate consumer's energy patterns with demand flexibility, the demand response platform should aggregate and control building-level demand curves to satisfy grid-level demand response needs based on smart tariffs (most cost-effective power utilization). Using blockchain technology for smart contracts for demand response events and increasing utility-consumer communication via blockchain gateways for carbon credit and payment remittance based on ADR (automated demand response).

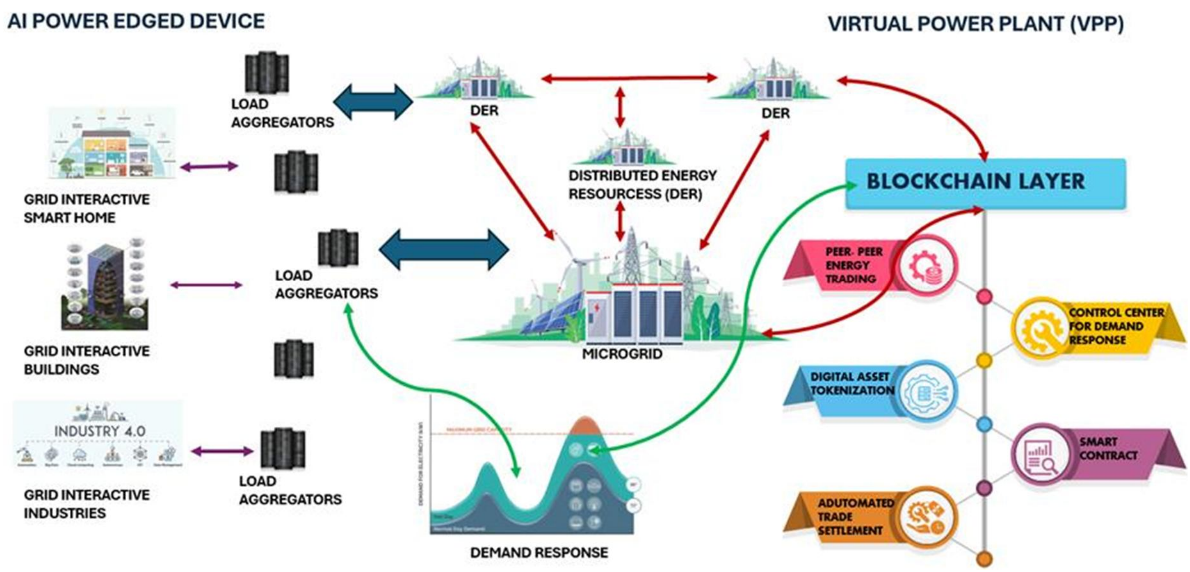

Figure 1: The framework combines DERs and automated demand response with AI blockchain technology.

The approach can use a deep learning algorithm to deliver a predictive demand response AI platform that gives flexibility to control and save building level KW utilization. The intelligent algorithm with further help in integration of storage devices and renewable energy components, including sola and portable windmill. This approach would charge at non-peak tariff and deliver solar priority compensation (renewable energy + storage + grid) on peak tariff that could save energy to the consumers. The blockchain framework will initiate an automated smart contract that gets further approval from the consumers. The blockchain infrastructure will capture before and after consumption data to calculate the savings based on renewable energy, energy efficiency interventions, and DR events. The blockchain gateway will automate sending out carbon credits and savings remittances and updating the consumer portal.

The major component of this platform includes

- The AI and deep learning-based rule engine collect data on all connected devices at the multi-facility level.
- Aggregator integration hardware/analytics framework to communicate with grid infrastructure
- Blockchain framework for smart contracts, carbon credit, and payment gateways.

AI's future is promising in energy optimization, generation, distribution, and consumption. AI-driven approaches can improve grid stability, reduce greenhouse gas emissions, and prioritize the green energy transition. Smart microgrids and automated demand response infrastructure can be rewarding by keeping "humans in loop" to achieve energy independence and reduced energy prices.

B. Key Findings and Challenges Related to AI Innovation in Energy

1) *Specialized Skill Set:* To implement AI and blockchain automation in the energy sector, we need the right talent who can understand the energy ecosystem better and has expertise in machine learning, data science, programming, and neural networks.
2) *High Capex and Return on Investment:* The high capex and longer return on investment are other challenges to AI adoption in the energy sector. Integrating it with existing legacy infrastructure needs a transition approach, where in some cases the existing infrastructure is almost 30-40 years old with a traditional system that doesn't support upgrades.
3) *Security and cyber threats:* The AI and blockchain approach need a very strong security platform to protect against cyber threats and hacking. The sensitive data collected on grid, consumer, operational, and distribution tariff data needs to be protected from its hackers and its competition
4) *Compliance and data privacy:* Collection of data from multiple sources needs an extra layer of protection to comply with the local data privacy act. A large amount of data collected should not be used for any other trade-off activity with respect to public and private norms
5) *Energy pricing and trends:* AI analytics delivers more sophisticated real-time KPIs on pricing, supply, and demand that help energy companies make decisions ahead to create a profitable trading decision. This helps energy companies make decisions on market volatility and on-demand operational decisions.

Despite challenges, the AI framework optimizes the carbon capture process through a large volume of data sets from multiple sources, does environmental monitoring, and has impacts that suggest and automate tasks for improvised decision-making.
Smart homes, grid-interactive buildings, and AI-controlled microgrid

VIII. DEMAND RESPONSE

IOT devices with multiple data collections enable machine learning and deep learning algorithms to take shape. The continuous real-time data collection enables self-learning mechanisms using neural networks and adoptive AI techniques. The combination of ML, deep learning, and neural networks subsets allows AI to make data-driven decisions to

1) Create demand response events.
2) Load shifting event based on peak demand
3) DERs to shift load, charge/discharge during TOU (time of use)

The above 3-step approach not only impacts the overall energy optimization strategy, but it delivers insights to energy companies to plan and organize their energy production planning activities.
When AI takes charge of an HVAC system by considering multiple variables like user comfort, occupancy patterns, and real-time availability, updates can be made available instantly to deliver an accurate temperature setting with better indoor air quality and comfort to reduce excess energy and cost.

IX. VIRTUAL POWER PLANT AND MICRO GRIDS

Microgrids help consumers as well as utilities to bring demand flexibility and reduce carbon emissions. Introducing DERs at the community level can lower transmission and distribution losses. It gives equal opportunity to distributed and decentralized green power into the energy markets and predicts energy pricing volatility.
Interconnecting multiple microgrids can improve the DER's operating quality, which is a better way. AI can help to manage this process of creating a smart grid environment by using digital communication to detect and react to usage changes ahead of time using the historic consumption pattern and real-time data. This approach gives the utility companies the ability the ability to allocate resources and optimize their costs. The AI platform can also detect faults, outages, and failures with accuracy to minimize backouts and improve grid stability. When multiple microgrids are connected through a distribution line with a control layer to communicate between DERs, it can enable both consumers and utility companies to create microvirtual power plants (VPP). AI capability on data collection, demand response, predictive analytics/maintenance combined with DERs, and BESS (battery energy storage system) can deliver a seems less operation in energy generation and distribution.

X. ENERGY FORCASTING AND STORAGE

To forecast the energy utilization and distribution in real time, the AI model should deliver output with higher speed and accuracy with a lower cost of computation power to get a better return on investment. While connected with multiple DERs, the local system should have enough intelligence to send and receive real-time events for accurate decision-making. MPPT and battery management capabilities are good enough to make such a decision to create an intelligent platform for energy forecasting.

To train the machine learning model, the data quality is very important. The data collected over a period, the usage pattern and its changes due to recent developments, etc. are critical factors to improve the value of the data set. Interconnected Edge intelligent devices can improve data collection and deliver a better value-added model to capture grid resilience.

When it comes to storage, the life span of the battery and its management infrastructure are critical.

HV lithium batteries can only last for 8-10 years, while flow batteries can last longer, more than 25 years. Both have their pros and cons; selecting a combination of instant discharge lithium and long-term storage flow batteries is critical. ML data sets on the battery charge and discharge can give better insight on operating schedules to do better renewable energy forecasting.

XI. BLOCK CHAIN INTEGRATION WITH AI SMART MICROGRID INFRASTRUCTURE

A blockchain-based distributed ledger helps to maintain security and transparency for signed parties over the contract, digital assets, and its transactions. Energy companies collect large datasets on power plants, solar and wind farms, storage solutions, and other alternative energy sources. The data is critical but not as critical compared to the financial and banking industries. Moreover, sharing operational data is good enough to make decisions on optimization and business operations. So, the energy company is more than willing to share the dataset for optimization and business innovation that gives a better opportunity to implement blockchain distributed ledgers.

Blockchain combined with connected IOT devices are designed for consumers to do peer-to-peer transactions with the community-based retailers or purchase energy directly from the grid when it's available at lower prices. This can create consumer awareness and give a better participation edge over utility companies on a long-term basis. Not just the utility company, but also when the retailer gains the benefits on the blockchain platform, they have the opportunity to negotiate better pricing on a volatile market and pass on the benefits to the consumers to reduce the consumer energy bills.

Combining blockchain with AI that can understand the digital assets, their performance, and their value addition to the energy ecosystem. A platform to explore and promote more opportunity in terms of AI with data interoperability, improved transparency, data integrity, and insights for further development and actionable insights. AI capabilities to read, understand, and correlate datasets at faster computational power can deliver intelligence to the legacy environment that can impact business operations and mitigate risk.

A. Local Policy and Governance on AI and Blockchain Framework

The focus for policymakers is to understand the ethical use of the technology and its negative impact on society. But still, there is a gap for policymakers to connect with the technology. its multiple use cases and impact. There are several publications around the world that talk about ethical initiative and explore the overlap between AI and blockchain technologies. AI governance efforts from local governments and policymakers around the world are very different. If there is a standard evaluation committee based on sector-wise business case scenarios, it can help to speed track the implementation efforts.

There is an increase in effort on the collection of data from multiple sources, exploring, and analyzing for process automation. But are we utilizing quality and adequate data from consumer demand, generation capability, distribution patterns based on climatic conditions, and resource planning that are equally considered for future growth strategies? Understanding supply and demand for optimization and minimizing losses can only be achieved by combining domain expertise, technology expertise, and innovation to deliver flawless operation. AI-integrated energy policy is very important to take steps to achieve overall results. The standardized and tailormade approach by policymakers can enable and utilize AI to create an integrated roadmap for future energy policies.

XII. AI AND BLOCKCHAIN GOVERNANCE - OECD

“The Organisation for Economic Co-operation and Development (OECD) has developed a set of principles for the responsible development and use of AI, known as the “OECD AI Principles." These principles are designed to promote transparency, accountability, and human-centricity in the development and use of AI. G20 countries used these principles as a basis for their own, also adopted in 2019” – Reference from OECD “Blockchain governance, on the other hand, deals with issues such as scalability, security, and the management of decentralized networks. Initiatives such as the Web3 Governance Forum and the Decentralized Autonomous Organization (DAO) address these issues by promoting decentralized decision-making and community-based governance." Reference from OECD AI and blockchain technologies have the potential to revolutionize sustainability efforts, particularly in sectors such as green energy microgrids, food supply chains, and environmental monitoring. By leveraging AI and blockchain, we can improve efficiency, productivity, and lifestyle while also creating millions of jobs by 2030. The focus is on power generation, water management, agriculture, and transportation sectors.

217

A. Summary, Facts, and Emotional Evidence

AI and blockchain play a crucial role in Environmental, Social, and Governance (ESG) standards, allowing for better measurement of impacts on the economy. Energy optimization, distribution, and control ecosystems are key areas where AI and blockchain technologies can make a significant impact by reducing greenhouse gas emissions and enhancing environmental sustainability. Challenges in adopting AI and blockchain in the energy sector include the need for specialized skill sets, high capital expenditure, security concerns, data privacy, and energy pricing trends. However, despite these challenges, AI innovations in energy can optimize carbon capture processes, improve environmental monitoring, and facilitate automated decision-making for more sustainable energy practices. AI-driven approaches can enhance grid stability, reduce emissions, and prioritize the transition to green energy. By implementing smart homes, grid-interactive buildings, and AI-controlled microgrids, demand response events can be created, load shifting can be optimized, and distributed energy resources can be leveraged to reduce costs and emissions.

The integration of blockchain with AI in smart microgrid infrastructure can ensure transparency, security, and efficiency in energy transactions. Blockchain facilitates peer-to-peer transactions, consumer participation, and improved data interoperability in energy markets, leading to reduced energy bills and enhanced operational insights. Local policy and governance play a crucial role in the ethical and effective use of AI and blockchain technologies. By establishing standardized evaluation committees and sector-specific business cases, policymakers can accelerate the implementation of AI-integrated energy policies for sustainable development. Overall, AI and blockchain technologies hold immense potential to drive sustainability efforts, optimize energy systems, and create a more efficient and environmentally friendly future.

XIII. CONCLUSION

In conclusion, the integration of artificial intelligence (AI) and blockchain technologies in the energy sector presents a promising opportunity for energy optimization, generation, distribution, and consumption. By leveraging AI capabilities, grid stability can be improved, greenhouse gas emissions can be reduced, and a transition to green energy can be prioritized. Smart microgrids and automated demand response infrastructures, with the inclusion of human interaction, can lead to energy independence and lower energy prices. Challenges such as specialized skill sets, high capital expenditure, security threats, compliance, and data privacy issues must be addressed to ensure successful implementation. Additionally, the combination of AI and blockchain can empower consumers to make informed decisions, participate in peer-to-peer transactions, and promote energy efficiency. Policymakers must focus on ethical considerations, governance efforts, and standard evaluation committees to accelerate the adoption of AI and blockchain technologies in the energy sector, ultimately leading to a more sustainable and efficient energy future.

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