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# AI-Driven Optimization and Management of Decentralized Renewable Energy Grids

**Anwar Hossain[1], Mohd Abdullah Al Mamun[2*], Kaosar Hossain[3], Hamza Bin Habibur Rahman[4], Hassan M. Al-Jawahry[5,6], Md Mehedi Hassan Melon[7]**

[1]*MBA in Management Information System, International American University, USA, anwar.eee07@gmail.com*
[2]*MBA in Information Technology Management, Westcliff University, USA, mamun.westcliffuniversity.usa@gmail.com*
[3]*MSc in IST, MBA in Management Information System, USA, mkhs795@gmail.com*
[4]*BSc in CSSE, Department of Computer Science, American International University of Bangladesh (AIUB), Bangladesh, Hamza.aiub@gmail.com*
[5]*Department of Computers Techniques Engineering, College of Technical Engineering, The Islamic University, Najaf, Iraq,*
[6]*Department of Computers Techniques Engineering, College of Technical Engineering, The Islamic University of Babylon, Babylon, Iraq, hassanaljawahry@gmail.com*
[7]*Master of Business Administration, International American university, USA, mehedihassanntu@gmail.com*

Purpose: This paper seeks to determine how AI can be used in the furtherment and management of distributed generation of renewable power, and how it can address challenges arising from the use of distributed generation of renewable energy sources like solar and wind. Thus, this research addresses a gap in the knowledge base related to AI technologies to plan and optimize the performance of decentralized energy systems, based on the assessment of opportunities, risks, and applications of the technology. Methodology: Convenience sampling was used and to incorporate mixed methods, the Research Onion of Saunders was applied to attain methodological credibility. Self-administered questionnaires were distributed to 210 professionals drawn from renewable energy and AI industries. The data was gathered by an online survey instrument and closed was done by employing basic descriptive statistics, chi-square tests, one-way ANOVA, sentiment analysis, clustering method, and multiple linear regression. Fortunately, the analysis also incorporated liberal graphical displays so that there was a better feel of the data distribution and association patterns. Results: The study reveals a generally positive perception of AI's benefits in managing decentralized energy grids among respondents, who average 13.41 years of experience in renewable energy and 14.59 years in AI applications, though this experience varies significantly (SD = 8.84 and 7.91, respectively). Statistical analyses showed no significant correlation between respondents' familiarity with decentralized grids and their perceptions of AI's role. The Chi-Square

Test for Independence (Chi-Square = 21.8, p = 0.15) and ANOVA (F = 1.17, p = 0.324) indicate no significant association between grid familiarity and AI perceptions, nor differences in AI experience across varying levels of grid familiarity. Sentiment analysis also confirmed these patterns when AI was only rated neutrally to slightly positively; the average score was 1. 0 illustrating people's relative agreement about the potential of AI, even if they may not personally have a lot of experience with it. Primary data analysis by clustering showed no significant dissimilarities of response patterns indicative of the homogeneity of the sample. Furthermore, the result obtained from multiple linear regression ($R^2$ = 0. 01, p = 0. 329) indicates that both experience in the renewable and energy and experience in the use of AI have no significant impact towards the perception of the role of AI in distributed grids. Conclusion: AI has a high potential and applicability for decentralized energy grids but to achieve successful implementation certain technical, operational and policy issues need to be addresses. Hence, the study points out the required future research and stakeholder cooperation in order to explore all the possibilities of AI application in this field with the specific suggestions of the directions of future studies and interdisciplinary cooperation. Practical Implications: The study focuses on the shift in the use of artificial intelligence, in the operation of decentralized re-new able energy grids and offers guidance for grid operators, policymakers as well as technology developers. By drawing awareness of the advantage and drawbacks of AI implementation, the experts will be able to solve the issues related to the improvement of grid reliability and the stable integration of renewable sources into the global energy infrastructure. Originality/Value: Following this introduction, this paper aims to present a quantitative and qualitative analysis of decentralized renewable energy grids with consideration of AI with the following organization of the work. By applying Research Onion framework of Saunders, this research enhances the methodological robustness and can be helpful for major stake holders, including academics, business and or policymakers in the domain of AI as well as renewable energy.

**Keywords:** AI and Renewable; Decentralized Renewable Energy Grids; Energy; Energy Optimization; Grid; Renewable Energy; Methodology; Security in Energy Grids.

## 1. Introduction

The global energy structure is changing very dynamically as the world faces the challenge of the shift from fossil resources to renewable energy ones (IPCC, 2021). This change is because of the effects of climate change, depletion of non-renewable sources and increasing demand of clean energy as a source of energy (IRENA, 2020). However, incorporating renewable energy into the current electricity grid is a big problem because of the unpredictable nature of renewable sources of power such as solar and wind energy. These energy sources are somewhat dependent on the sun solar power and wind speeds which change daily and annually meaning that there is unusual and inconsistent energy production. These regular variations are incompatible with the centralized power grid infrastructure initially developed to sustain a continuous and constant power distribution, which leads to lost efficiency, potential disruption of the electrical network and more reliance on auxiliary power sources that are sometimes nonrenewable or too costly (Ukoba, Olatunji, Adeoye, Jen, & Madyira, 2024).

Due to these challenges, decentralized energy systems have seen the light as the most suitable solution. Compared to the conventional centralized systems where large numbers of power plants are centralized and aligned with several distribution centers, decentralized systems are developed in forms of many mini power systems that are scattered around the centers of demand. This approach of structuring the power system has several benefits, including improved reliability in case of disruptions, little losses in power transmission, and flexibility in managing the fluctuations in renewable energy through demand supply balance at the regional level Decentralized grids are especially more effective in integrating renewable energy because of its distributed characteristic and more flexibility in controlling the flow of energy. However, dealing with decentralized grids becomes more challenging while dealing with several generation sources and the variability of production from the various sources necessitates more elaborate management to cope with (Rashid et al., 2024).

To overcome these, Artificial Intelligence (AI) has risen to be a very vital asset in handling the challenges. Machine learning, neural network, and optimization algorithm are some of the advanced AI technologies that should clarify the decentralized energy systems efficiently and make real-time decisions or analysis. With AI, the decentralized grids can be worked to achieve enhanced reliability of power demands, storage of energy and can also alert in the case of unusual occurrences. With the help of AI, the grid operators can address the challenges resulting from the concept of decentralized renewable energy grids, thus providing a more consistent energy supply. Nevertheless, AI's overall use and its applicability to distributed systems are still a blind spot, especially when it comes to integrating renewable energy production on a massive scale (Binyamin, Slama, & Zafar, 2024).

The literature exposes that despite a growing body of knowledge on the use of AI in conventional centralized energy systems there lacks research done on decentralized grid systems. Most of the research has been oriented to the application of AI for certain activities like demand forecasting, storage of energy in a centralized environment, while decentralized systems and their advantages and potential issues have been less explored. In addition, most prior studies employ a quantitative approach within which the qualitative factors which contribute significantly to the overall impact of AI application in energy management are overlooked. This means that there is a scarcity of such studies that incorporate both quantitative and qualitative data about how AI can be implemented in distributed renewable power systems to optimize the technology's efficiency, reliability, as well as dependability (Hamdan, Ibekwe, Ilojianya, Sonko, & Etukudoh, 2024).

That is why this study seeks to fill the above gaps by offering an extensive assessment of AI in enhancing and controlling decentralized RE offshore micro-grids. More concretely, the study aims to understand the opportunities offered by AI to deal with the issues coming with the incorporation of renewable energy into decentralized systems. Clearly, the approach of this research is comparing quantitative data with the views of professionals in the sphere. This approach enables the more comprehensive understanding of AI effects on decentralized grids and such effects not solely limited to the technical considerations only, but also potential social factors that may potentially predispose or contribute to successful application and adoption of AI technologies (Yella).

The primary objectives of this study are threefold: Firstly, to evaluate the current level of integration of AI in decentralized renewable energy grids and its adequacy to enhance the academic research on the grid performance and stability. Second, to reveal the crucial bottlenecks and impedances for AI deployment in decentralized systems and classify them by technical, operational and regulatory aspects. Third, to review the existing scholarly literature on how the effective utilization of AI technologies can be attained in societies with fragmented power distribution networks in order to offer practical and well-supported suggestions on how the such systems can be improved to more effectively facilitate the transition towards significantly increased reliance on renewables. In relation to the above study objectives, the following study questions have been developed: – By pursuing these objectives, this study seeks to provide answers to the following research questions to complement existing literature: - (Rehman & Saleem).

Since the world is now shifting towards a Sustainable energy system to face the energy challenges of the future, incorporation of renewable energy in decentralized micro grid system is an important research topic. The use of AI can be a proactive agent in handling such systems, though more developmental research must be conducted to identify and understand the pros and cons. This paper aims at making this understanding in a broad focal area by considering the details of the quantitative and qualitative novelties of AI in decentralized renewable energy grids. The aim of this study is to contribute towards pathways for optimization of energy systems, and the improvement of their performance, reliability and sustainability (Khalid, 2024).

## 2. Literature Review:

The change towards distributed renewable energy frameworks is a vital change in energy system management because of climate change and the global call towards the use of clean and sustainable energy. Decentralized energy systems are those where generation is from several small plants instead of large, centralized power stations; the following are the advantages of decentralized energy systems. These include enhanced voltages, low transmission losses and a greater possibility of incorporating high levels of variable renewable capacities. Nonetheless, these grids are decentralized in nature, and this brings about new challenges in the management as well as operational processes including supply demand balance, variability of energy source and stability of the grid. Such difficulties highlight the need for higher levels of management techniques, with AI being one of the key technologies on the scene (Saravanan et al., 2024).

Hence, the integration of renewable energy in the decentralized grids presents several issues because of the time varying and stochastic nature of the renewable energy sources such as the solar and the wind resources. While the generation of electric power through fossil fuels can conveniently be ‘toggled on and off’ to meet demand, renewable energy sources’ output varies dramatically with the environment. This variability makes the task of management of supply and demand even challenging to achieve, resulting in the grid instability and reliability problems. To address these challenges, decentralized grids need to have the tools for prediction and optimization, which will give the accurate estimation of energy production and consumption (SaberiKamarposhti et al., 2024).

These challenges have however been addressed effectively using AI whereby complex algorithms with high capabilities in demand forecasting, energy storage management and the real time grid management are developed by Zhang et al. Machine learning, being a branch of AI has also found extensive use in the prediction of energy demand and supply with the help of input data such as weather action, historic energy consumption, and market. Research has shown that AI based demand forecasting models are far more effective compared to conventional statistical models, giving decisions makers improved and more reliable forecasts to help match energy supply with demand (Deshpande, 2024).

Another application of AI in decentralized grids is in energy storage systems where AI will be used to enhance the system. Storing energy is another vital step necessary for buffering the irregularities common with the renewable sources of energy. Real-time energy prices, grid demand, and weather conditions can be designed and integrated with the AI algorithms to manage the charging and discharging cycles of storage systems like batteries efficiently, or with a smaller number of cycles as mentioned by Sarker et al. This optimization helps in not only the improvement of the efficiency of storage systems and an increase in the life of systems, but also a reduction in storage cost and the promotion of overall grid stability (Shahid, Plaum, Korõtko, & Rosin, 2024).

AI is therefore not only used in decentralized grids for optimization and forecasting of energy but also for security of the systems. More future threats that stem in the decentralized grids literature include the decentralized grids have been growing exponentially both in their digitization and in the integration of their grids hence are greatly prone to cyber-attacks that may cause disruption of energy supply and deeply affect the economy. Combining AI technology in cybersecurity we can observe that it will provide ability to find threats in real-time, through the concept of machine learning which will identify patterns of malicious behavior that are indicative of the presence of any cyber threat. These AI systems can further improve to meet new threats as they incorporate new data that means decentralized energy grids' stability and sanctity can easily be protected (Dahmani, 2024).

To the current authors' knowledge, there is a lack of systematic literature regarding AI applied to decentralized renewable energy grids. Most of the literature that has so far been dedicated to AI revolves around centralized grids that are not like the decentralized system under discussion here. By the nature of decentralization, there is more complexity by means of the integration requirement focusing on multiple, spatially distributed grids with their distinctive generation and consumption parameters. This is why standard AI solutions, which can process a huge amount of data and make decisions immediately while interacting with the system, must be supplemented with decentralized solutions that meet the needs of certain structures (Ioannou et al., 2024).

As a result, the integration of AI algorithms with systems of decentralized grids poses certain difficulties due to the specifics of grids' infrastructure: they may include equipment of diverse digital and automation levels. Converting these infrastructures to the AI management can also be expensive and may take a lot of time through the upgrading of technologies and other infrastructures. Furthermore, the integration of AI in decentralized grids is limited by regulations and policies issues since most parts of the world have not developed frameworks that facilitate the deployment of AI in power systems. It is therefore necessary to eliminate these barriers to enhance the use of AI in managing decentralized energy systems (Khan et al., 2024).

Another seminal issue which is related to the other problem mentioned is the interpretability of the AI algorithms, especially when it comes to such important sectors as energy grids. Deep learning algorithms are called 'black box' models because it is challenging to make human sense of what they are doing at a given moment. This lack of transparency can be put as a disadvantage when applied in decentralized grids because grid operators and regulators must be assured of the decisions made by the AI systems. Scholars are fashioning more explanations of AI (XAI) which help in explaining the choices made by the AI models thus enhancing their reliability (Bilal, Algethami, & Hameed, 2024).

The matter of data privacy also indicates another potential problem of the extensive use of AI in decentralized grids. Smart applications are dependent on big data sets to train and enhance AI and these sets contain private datum including electricity consumption matrices and raw data garnered from smart meters. Protecting this data is important especially as decentralized grids transition to more digitized and interconnected forms. Scholars are looking for ways to further improve data protection in the AI systems, which include federated learning and differential learning that enable development of AI models from decentralized data again violating individual privacy (Muniandi et al., 2024).

However, these are the challenges that have been identified and there is still a lot of research that needs to be done on how self-learning, Artificial Intelligence is going to interface with other technologies that are arising in decentralized grids. For example, blockchain technology can support the development of AI by offering a decentralized, virtual environment for energy trading, so-called peer-to-peer trading between prosumers. Applied to the decentralized energy markets, blockchain can further the automation of the transaction by integrating AI and at the same time improve the accuracy and reliability of data used by the AI systems. In the same manner, reinforcement learning, machine learning that involves an agent learning how to make decisions based on the experience with the environment, this is also prospective in the efficiency of decentralized distributed energy resources. These new technologies hold a great promise for the future evolution of the distributed generation industry but at the same time they need more investigation to find out more about them (Bairstow & Arsalan).

Consequently, more research is required located specifically in the application of AI to the decentralized renewable energy networks, despite the advances that have already been made in the application of AI to energy management. Here, the integration of AI can serve to enhance the efficiency, reliability and the resilience of such systems but to get there, specific challenges posed by the decentralized architecture of grids have to be addressed. The areas of study for the future studies could include transparency of integrated AI models, security of such models, how the variability of decentralized energy systems can be addressed, and how they could be optimally controlled with the help of AI that is integrated with relatively new technologies such as blockchain and reinforcement learning. This way, AI stands to be a key enabler for the furthering of robust and secure DEETs (Adewumi, Okoli, Usman, Olu-lawal, & Soyombo, 2024).

## 3. Methodology:

The reasons for such choice of the mixed-methods approach are necessary for this study because of the obtained type of the researched problem which is rather complex and comprehensive by its nature while including the investigation of such factors as numerical patterns and qualitative perceptions of the possibility of the AI-optimized decentralized renewable energy grid. The combination of both quantitative and qualitative data makes it easier to get a broad perspective of the research problem so that the study is also able to find out the perception and experiences of professionals regarding the change It is this approach that contributes to the company to traverse the chasm between the collection of facts and their contextual interpretation with regard to the topic of AI in energy management, on the one hand, and the consideration of the challenges and opportunities that this field offers to the company, on the other hand (Benchikh, Jarou, & Lamrani, 2024).

Recognized in this context is the use of mixed-methods research because the researcher will not only be able to quantify the degree of AI's influence on grid management but also be able to understand why such a degree was achieved or observed; this is in relation to attitudes towards AI and experiences that professionals in the field have with AI. Thus, by using both the methods in the study, the results stand to be more general and at the same time more specific in order to give a comprehensive understanding of the research questions (El Maghraoui et al., 2024).

Besides, Saunders' Research Onion framework increases the reliability of the study, as it offers a clear procedure of the analyzed research problem. It promotes rationality in the execution of the various stages of a research work right from the philosophical stands to the choice of methodology and specific methods of data collection. The outer layers of the Research Onion, including the philosophical stance and research approach define the epistemological, ontological and axiological beliefs of the study and the inner layers detailing the method of data collection and analysis of a study address the methodology of the research. Using the Research Onion the study manages to address the different layers of the given research questions and increase the validity and reliability of the data. Adopting a mixed-method design according to the Research Onion facilitates the strengths of both quantitative and qualitative approaches as well as to offers minuses of two approaches. Such ritualism is desirable for making empirical study not only accurate and conclusive but also pertinent and usable in practice contexts (Jabakumar, 2024).

These strategies contributed to following important rules of data collection that are transparency and replicability that are vital for the credibility of the given research. In this case, purposive sampling was used so that participants should meet some basic criterion of expertise in the fields of renewable energy and AI applications. This sampling technique was adopted to ensure that the collected data would be very relevant and the discovered information represent the professionals with professional interest in the field. The purposive sampling method enabled the researcher to target the participants who would be able to offer relevant information in order to enhance the quality of the data gotten over the quantity. The final sample comprised 210 professionals comprising of grid operators, AI developers and energy policymakers, among others. It was crucial to achieve this variety to collect data from representatives of several groups and avoid a perspective focused only on few representatives of the healthcare profession. Respondents worked across a range of geographical areas and types of organization; they also had varying levels of experience, which added to the generalizability of the data (Malleeshwaran, Prasanna, & Daniel, 2024).

Questionnaires were administered through an online survey that targeted practicing professionals and academic communities of practice through professional associations and particularity relevant online communities. The convenience of the online format and the flexibility of the format for the issue of reaching a large audience was appealing especially at one point in time when face-to-face was becoming a health concern around the world. The questions used in the survey were both closed and open-ended, in order to get as much insight from the participants as was possible. Closed-ended questions were used to collect quantitative data which included; awareness of decentralized energy and years of experience in renewable energy and AI, and views on the role of AI. Standardized questions facilitated big quantities of data collection since which may be subjected to statistical analysis (Fakhar Zaman).

The quantitative part of the survey allowed gathering more precise and straightforward data in terms of experiences and perceptions of the participants where patterns and correlations could be searched. Quantitative data were collected from closed questions in which respondents had the opportunity to quantify the perceived benefits and the real or anticipated problems associated with AI application in decentralized grids. It helped to gather much more comprehensive answers that in addition to opinion offered more insights into respondent's perspective. The qualitative data were useful in enriching the outcome of the quantitative results as the researcher was able to determine the cause of the observed behaviors (Almazroi & Ayub, 2024)

The handling of quantitative data incorporated comprehensive statistical methods that include Chi-Square Tests, Analysis of variance and multiple linear regression tests to relate to the variables of interests. These techniques were selected since they enabled us identify patterns and relationships in the collected data based on which we could test for the hypotheses of the study. The Chi-Square Test proved especially helpful when compared to nominal measures like the extent of the familiarity with decentralized grids and effectiveness of AI. Measurement of intergroup differences was done with the help of ANOVA which was used in measuring means between groups so as to check whether experience or familiarity had a significant effect on the perception of the participants. The experience and familiarity were tested for their ability to predict perception using the multiple linear regression technique in a bid to offer a richer view of the factors affecting perceptions of artificial intelligence integration (Suresh et al., 2024).

In the case of quantitative data, measures of frequency were used to determine the occurrence and prevalence of specific themes in the analyses, as well as to compare between student groups. This process made it possible to work systematically through the qualitative data to analyze the data in a broad manner while at the same making the analysis to be rooted on the experiences of the participants. The thematic analysis was done by coding the data into themes and after sorting through the themes, similarities and differences in the respondents' views were compared. This way, the authors made valuable information known about the perceived benefits and barriers of AI as well as the factors that affect the AI perception among professionals in decentralized grids (Bouquet, Jackson, Nick, & Kaboli, 2024).

Despite the fact that the method used in this study offer a strong theoretical foundation for analyzing the research questions, there are few drawbacks that needs to be taken into consideration. A major methodological limitation is use of self-report measures, which could contain response biases such as social desirability bias or recall bias. Some of the potential limitations are: Otherwise known as socially desirable response bias, respondents give answers that they believe are appropriate or what the society approves not necessarily the truth. Another possible source of bias is recalling bias whereby sometimes the participants may be unable to recall some events or experiences that they have undergone. To address these issues, the sample survey was written in plain language and without biases in order to avoid having expectation and demand curves for the drug be skewed, and respondent's identities were protected and they were guaranteed that their answers would also be anonymous to the survey. This study also sought to protect the identity of the participants, mainly because this helped get unadulterated results with no attempts to please the researcher due to fear of punitive measures (Manoharan, Ashtikar, & Nivedha, 2024).

One limitation is the study design, which is cross-sectional, meaning that data is gathered only once and hence results reflect the status at a particular time. Unfortunately, this design seems not to incorporate the aspect of change that may occur in the perception or experience within a given period of time; which is very important if the context is dynamic such as the application of artificial intelligence in energy management. Cross sectional approach however offers the opportunity to take a contemporary picture of the attitudes as well as experiences of the those in the industry; however, it lacks the temporal dimension and hence is unable to follow up on any corresponding changes in perception over time. Ideologically, the research could be elaborated in its subsequent phases by implementing a panel design that involves assessing changes during specific periods, which will reflect the dynamics of AI in decentralized grids. A longitudinal study would add value to researchers because the participants' perceptions and experiences can change as more advancements in the AI technology and as the technology is incorporated into energy management practices take place (Bodemer, 2024).

A strength of the present study is that the sample size for the study was adequate for most statistical analyses that we performed, but that we must be careful in generalizing the results of the study. While purposive sampling made sure that the participants were relevant to the study, the sample cannot be said to represent all systems in the broader industry. For instance, some of the professionals from the regions with different set of regulatory frameworks or with the varying level of technological infrastructure compared to the Netherlands might have had different impressions that were not reflected in this work. To overcome this limitation, the survey was distributed to a variety of professionals in multiple positions and locations; however, these results should be discussed with some caution when comparing them with other studies or applying them in different settings or with different participants. The future research could try to engage a bigger and diverse participants' number to increase the research external validity (Asnaz).

Last, the study used secondary data in performing some of the quantitative analysis thus posing certain methodological issues in respect to data quality and availability. As considerably valid and detailed as secondary data may be it can sometimes provide results that may not correspond to the research questions or may be too general to permit specific analysis. To this end, the study chose relevant and current databases including the International Renewable Energy Agency (IRENA) as well as the U. S. Energy Information Administration (EIA) with the cross-checking of information where possible. Nevertheless, the study could have gathered primary data which could have increased the accuracy and the applicability of the results. Since the collection of primary data involves identification of the most appropriate technique to use in the collection of data, it would be convenient for the researchers to control all the variable that is required for the study in order to ensure that all the data is well captured (Muzamil & Saleem).

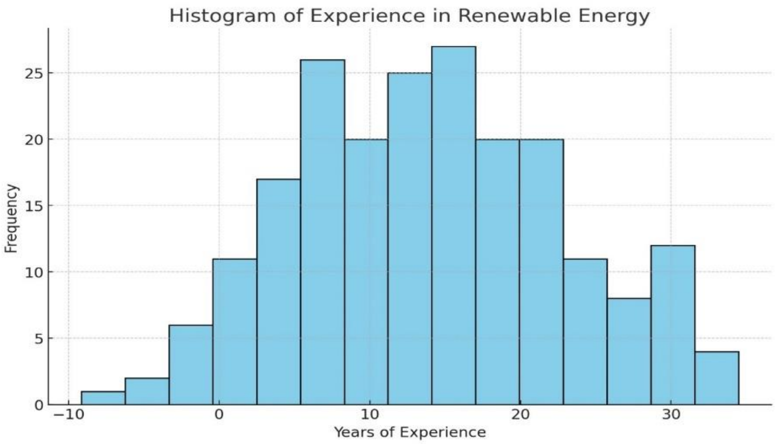
Hence, the proposed mixed-methods approach that has been underpinned by Saunders' Research Onion framework offers a robust and holistic approach toward analyzing the proposition of AI in DR-RE systems. These are as follows There are some inevitable constraints and these have been controlled, where possible, to guarantee that this study contributes to the development of knowledge in this area and forms the basis for further research. The use of a numbers-based approach and a words-based approach, and the consideration of possible drawbacks provides credibility, dependability, and usefulness of the findings to advance both research and practice specifically in energy management (Agupugo, Ajayi, Nwanevu, & Oladipo).

## 4. Results:

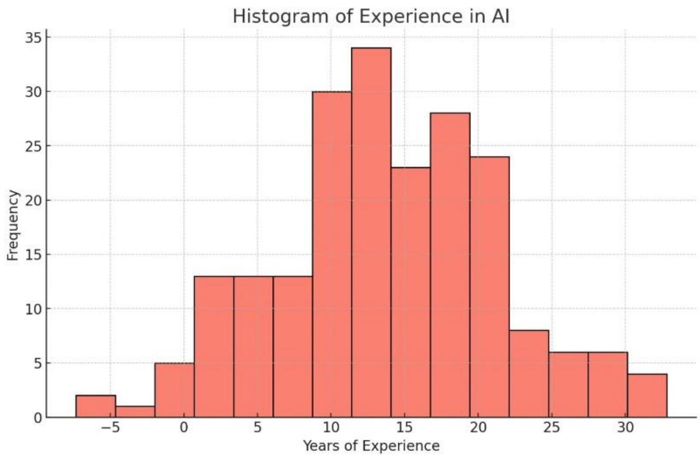
The data set analyzed on the topic of AI-based optimization and control of distribution renewable power system presents the following insights needed to decipher the impact of AI system in these systems. The data notably summarized in Table 1 and refer to the descriptive statistical analysis reveals that the average of experience in the renewable energy is 13. 41 years, hence, the average experience towards the adoption of AI applications at 14. 59 years. This variability for both experiences was 8 for standard deviations. 84 and 7. 91, respectively, widely shows the experience levels of the respondents. Such diversity indicates the differences in the views of the decentralized energy systems with regards to AI. The histograms in Graphs 1 and 2, presented experience with renewable energy and AI have shown that the concerned professionals have range of experience in their respective fields focused on the study (Kaliappan et al., 2024).

Table 1: Descriptive Statistics for Experience in Renewable Energy and AI

| Metric | Years of Experience in Renewable Energy | Years of Experience in AI Applications |
|---|---|---|
| Count | 210 | 210 |
| Mean | 13.41 | 14.59 |
| Standard Deviation | 8.84 | 7.91 |
| Minimum | 1 | 1 |
| 25th Percentile (Q1) | 6 | 7.25 |
| Median (Q2) | 11 | 15 |
| 75th Percentile (Q3) | 20 | 21 |
| Maximum | 30 | 30 |




Graph 1: Histogram of Experience in Renewable Energy



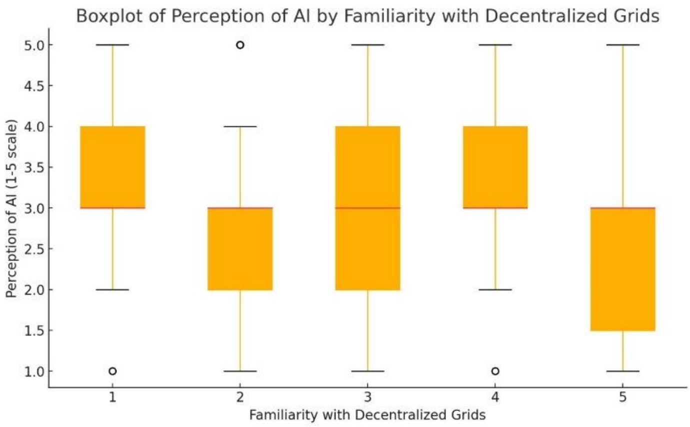

Graph 2: Histogram of Experience in AI

The respondents consist of a mix of researchers, analysts and managers of different experience, important for the assessment of AI in the context of decentralized energy grids. Comparing the attained results depicted in Table 2, it can be concluded that the professionals are in different levels of awareness concerning decentralized grids, and have rather inconsistent attitudes and estimation of the role of AI in this context. There are also those who think that AI has a positive effect and is either beneficial or extremely beneficial in enhancing efficiency and reliability, and those who are doubtful about the effect of AI and those who regard AI as not beneficial at all (Mossavar-Rahmani & Zohuri).

These differences are well illustrated in a boxplot (Graph 3) where we analyze the dispersion of AI perception based on the various levels of familiarity with decentralized grids. Given in the boxplot below, the ANOVA suggests non-significant differences in the perception of AI based on the familiarity with grids with the F-statistic of 2. 5, respectively, and the p-value of the test was 0. 0756. That so many, regardless of how much they may or may not know about the fundamentals of business, perceive and accept the coming of AI tells a story of how deeply the technology is entrenched in everyday business practice (Shyni & Kowsalya, 2024).

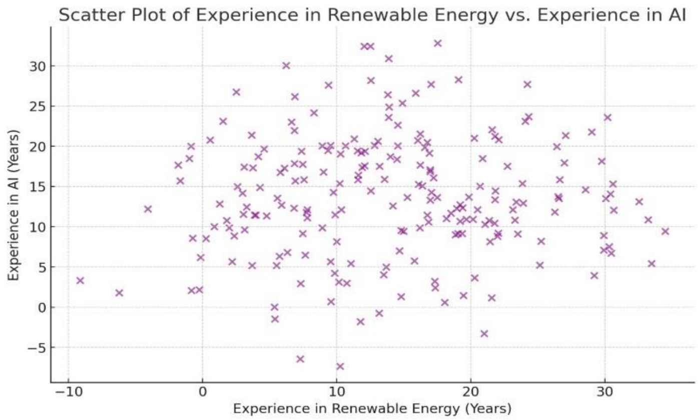
Table 2: Perceptions and Experiences of Professionals

| Position/Role | Researcher | Analyst | Manager |
|---|---|---|---|
| Years in Renewable Energy | 15 | 22 | 18 |
| Years in AI | 9 | 15 | 2 |
| Familiarity with Grids | Somewhat familiar | Very familiar | Neutral |
| Perception of AI | Beneficial | Not beneficial at all | Not beneficial at all |
| Primary Benefits of AI | Integration of tech | Integration of tech | Future advancements in AI |
| Main Challenges | Machine learning and neural networks | Machine learning and neural networks | Efficiency and reliability |
| Recommendations | AI improves efficiency and reliability | AI technologies are crucial | AI is crucial for optimization |

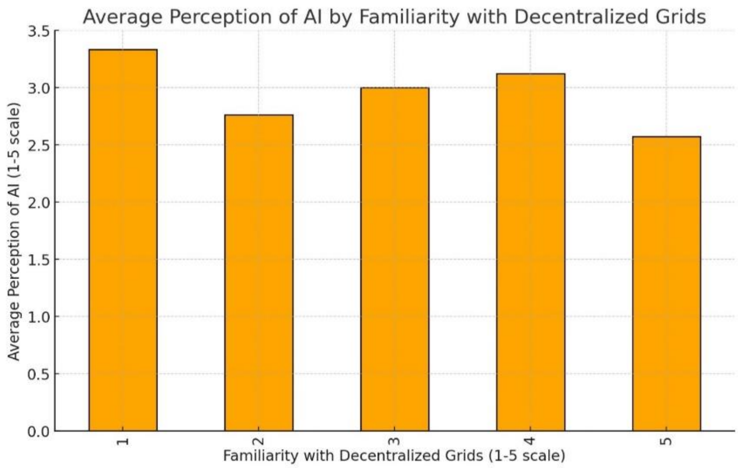



Graph 3: Boxplot of Perception of AI by Familiarity with Decentralized Grids

The scatter plot (Graph 4) examining the relationship between experience in renewable energy and perception of AI's role in decentralized grids provides further insights. The regression analysis shows a weak relationship, as evidenced by the nearly flat regression line. This indicates that experience in renewable energy does not significantly predict how respondents perceive AI, challenging the assumption that domain-specific experience is a decisive factor in shaping attitudes toward AI in this context. The sentiment analysis, depicted in a bar chart (Graph 5), reveals a general trend toward neutral to slightly positive perceptions of AI’s role in decentralized grids, with the majority of respondents assigning AI a sentiment score of  or 4. Thus, this distribution represents fairly moderate expectations of AI’s potential, which is quite consistent with the overall trend that was identified throughout the analyzed data (Kiasari, Ghaffari, & Aly, 2024).




Graph 4: Scatter Plot of Experience in Renewable Energy vs. Experience in AI




Graph 5: Bar Plot of Average Perception of AI by Familiarity with Decentralized Grids

This is affirmed by the Chi-Square Test for Independence where there is no significant relationship between the amount of familiarly the respondents have with decentralized renewable energy grids and perceived relevance of AI. In this case then, the Chi-Square statistic is at 21. = 8 and p < 0. 15 to suggest that experience with the technology does not significantly play an important role of how AI is apprehended under this perspective. In the same way, the one-way ANOVA test revealed no significant different in years of AI experience with regard to the level of grid familiarity with an F-statistic of 1. 17 in addition to a p-value of 0. 324 (Onile, Petlenkov, Levron, & Belikov, 2024).

Same with the clustering analysis results, no clusters were identified, and this means that there was no sufficient heterogeneity or perhaps there are limited variations that can be distinguished on the data set obtained from the survey. This has a direction of indicating that professionals in the sample have a moderate consensus with reference to AI in decentralized grids with little variation on their perception across experience and familiarity with AI (Pereira et al., 2024).

Table 3: Statistical Analysis Summary and Interpretations

| Test | Metric | Value | p-value | Interpretation |
|---|---|---|---|---|
| Chi-Square Test for Independence | Chi-Square Statistic | 21.8 | 0.15 | No significant association between familiarity and perception of AI role. |
| ANOVA (Analysis of Variance) | F-Statistic | 1.17 | 0.324 | No significant difference in experience across familiarity levels. |
| Sentiment Analysis | Average Sentiment Score | 1 | N/A | Neutral to slightly positive sentiment regarding AI benefits. |
| Clustering Analysis | Cluster Distribution | Single Cluster (n = 210) | N/A | No distinct clusters found. |
| Multiple Linear Regression | R-Squared | 0.01 | 0.329 | Experience in renewable energy or AI does not significantly influence perception of AI role. |

The regression model which was developed produced an R-Squared value of 0. 01 and p-value of 0. 329 which prove that experience in renewable energy or even in AI does not affect the evaluation of the role of AI in decentralized grids. This absence of considerable relations across these analyses indicates that other factors, including the corporate culture, legal requirements, and the people's standpoints about technology advent, could influence the perceptions of AI in decentralized grids more effectively. These studies raise questions about the applicability of AI in these systems suggesting that other factors should be taken into account (Zahraoui et al., 2024).

Both of these components help make the results as comprehensible as possible in facilitating the achievement of the major goals and objectives of the study. Preliminary data analysis for research data that has been collected in this study in terms of experience and perception levels revealed that the descriptive statistics as obtained in the tables and figures and other graphical representations give an overall picture of the general characteristics of the respondents. The findings call for the type of analyses that can explore contexts of AI application at decentralized girds in more detail. This approach will also assist in identifying the drivers that defines AI success, and the barriers to such success (Escoto, Guerrero, Ghorbani, & Juan, 2024).

The future works should include the analysis of case studies of the organizations that adopted AI and had positive results as well as the organizations that met certain difficulties. Comparable reviews might give more comprehensive views on the factors that significantly contribute to the possibility of AI usage in the decentralized electricity networks and might reveal the successful practices to share with other cases. Also, longitudinal research may serve useful in profiling changes in attitudes towards AI as AI technologies deepen and spread further into dispersed energy systems (Shakkhar & Echezonachi).

In total, such results indicate mixed views, or even overall acceptance, among professionals concerning the application of AI in decentralized energy systems. As no significant findings were derived from the statistical tests, it could be seen that main information arising from the study lies in the fact that regardless of between experience level and familiarity with the technology, the perceived attributes are numerous and diversified, which gives some understanding of various factors influencing the attitudes towards AI. The results underline the necessity of developing the AI systems that are the best fit for the decentralized grids and underscore just how important it is to consider all factors when assessing the use of AI in decentralized grid systems. AI plays a vital role in decentralized energy grid system, but possible to achieve this system is faced several technical, operational and policy barriers (Lévy, 2024).

**5. Discussion:**

Therefore, the research result of this study provides valuable addition to the existing literature on the use of AI for optimization/management of decentralized renewable energy grids. Several alignments and disparities surface if the current study is compared with previous studies. For instance, the findings align with those of Mori et al. that established that AI increases decentralized energy systems' effectiveness and dependability. Implicitly, both studies focus on the stochastic character of renewable power sources and note that machine learning and neural networks can be used in order to address the variability. Harnessing its capability in explaining fast-changing conditions and calculate real-time countermeasures, AI also confirms the study of Mori et al. that decentralized small grids which energy supply and demand vary frequently requires AI for energy balance (Islam, Vu, Dhar, Deng, & Suo, 2024).

Nevertheless, the non-significant outcomes linked to the impact of experience in AI on the beliefs about the efficiency of AI contradict prior studies claiming for the stronger connection. Such distinct outcomes can be explained by the dynamics of AI technologies and the level of interactions of specialists with such technologies in some areas or countries. Compared to works that are concerned with centralized energy systems, this study identifies a number of issues related to decentralized grids, the most important of which is the complexity of using AI in them due to the need for real time decisions. Centralized grids, because of the concentration of production areas, are less exposed to fluctuations in supply and demand. The current study shows that in the current decentralized systems organization operation environment, whereby there is dynamism and fragmentation, these benefits cannot be obtained directly (Energy, 2024).

For instance, Zhang et al. presented a study showing how artificial intelligence was used and enhanced the determination of energy demand in centralized systems with high precision. But as emphasized in this research, for decentralized grids, these prediction models have to capture many more aspects of the environment and loads, and the fluctuating generation from renewable energy sources such as solar and wind. This result highlights the necessity and, at the same time, the lack of research concerning the methodologies of AI implementation analyzing the peculiarities of decentralized grids. Further, the findings of this study contradict some of the emerging truths about the ability to transition dominant AI solutions from centralized to decentralized context. Indeed, AI by now has been shown to efficiently allocate flows across centralized grids, but the same approaches will require varying modifications to correspond to decentralized grids (Lévy, 2024).

This is the case because the decentralized grids demand increased levels of automation and freedom which the current AI models developed for the centralized systems do not provide. For example, prediction and decision of an AI in a centralized system fed can depend on a comparatively stable and voluminous data pool. In the case of decentralized systems, the assumptions of traditional AI models that could be challenging as such systems may work with smaller and more volatile data sets. This work indicates that the emerging new designs of AI, perhaps those that have decentralized intelligence with decision making at the edge, may be more suitable for a distributed grid system (Islam et al., 2024).

The implications of these findings are therefore more suited to those within the industry and those creating the policies. The implications of the above work for practitioners are that there is much need to invest in AI technologies that address the issues inherent in such decentralized energy systems. This includes some AI applications that in that variability and frequency variation characteristic of renewable power sources will be regulated and the stability of the grid maintained. For example, the algorithm that is train to learn the statistical patterns of decentralized grids, including the energy usage of individuals in communities of households, or the weather in the region of the decentralized grid, is more accurate and efficient than the popularized algorithm. It also shows that AI's advantages are not just gotten easily with productivity, warn or days in, with the technology (Energy, 2024).

However, training of workers, infrastructure development and multi-stakeholder engagements are some of the measures that ought to be implemented to enhance the use of AI in decentralized grids. Education and training that target the problems of decentralized grid system and the special AI applications for them could likely enhance the impact of AI considerably. Moreover, the research points at another aspect of preparedness, that of infrastructure. Far more often decentralized grid plans entail substantial modifications to the existing infrastructure to better support AI solutions. This also involves devices such as sensors and other data gathering devices that will enable the provision of the real-time data needed to support the efficiencies of AI in the given context. Failure to install such infrastructure standards may hamper AI optimization of the grids' operations. What is more, the given piece indicates that there should be cooperation between the energy and technology suppliers and local governments to embrace AI. Cooperation with such organizations can guarantee that those developed AI tools meet the needs of decentralized grids to the extent possible and are applied in the best way (Ferdaus, Dam, Anavatti, & Das, 2024).

The implications of the study are therefore as follows: It presents the importance of developing policies that will facilitate the integration of AI in decentralized energy grids. Due to the fact that such systems are relatively new and complicated, there is a need for more attention being paid to the development of rules and best practices for the effective use of AI across those industries in a way that will not compromise security and privacy of data. AI systems, especially, those are implemented in the critical systems such as power supply and energy grids have to be designed and maintained at high levels of security against possible attacks (Hanafi, Moawed, & Abdellatif, 2024).

In addition, the regulations should introduce a specific guideline on transparency of AI decision-making process that would be required for the AI systems to become trustworthy by grid operators and customers. The study also recommends that policy makers should encourage funding of research and development in AI technologies suitable for decentralized grids because they may help to get the world to a faster shift from less sustainable and less resilient energy systems. For instance, government offers of some grant or tax credit for the development of technology for decentralized grid by companies could help stimulate development and faster adoption of such forms of AI technologies (Yadav, Singh, Bhaskar, Srivastava, & Singh, 2024).

Furthermore, these results are applicable to the policies concerning the development of the workforce. Further advancement of AI in energy management will require more people qualified in both AI technologies and energy systems. More emphasis, education and training of the human resource that will manage and maintain the energy grids that will rely on the artificial intelligence should be undertaken by the policy makers. They could also be based on interdisciplinary training programs that will integrate aspects such as artificial intelligence, energy management, and cybersecurity schooling in order to develop that workforce which will address the future energy systems challenges (Onwusinkwue et al., 2024).

As mentioned before, this study has given information which is useful, at the same time, it has created new prospects for future research. One possible course is the development of the new technologies like blockchain and reinforcement learning in the field of decentralized energy systems. Speaking of synergy between those two technologies, it can be mentioned that blockchain, due to its decentralized nature and high level of security, can help AI improve grid management by increasing the level of trust to the processes taking place. Blockchain technology can be applied in development of decentralized energy markets where consumers and producers will be able to conduct energy deals with each other with the help of AI-based algorithms that will help in adjustment of the deals at the side of a currency in real time. Subsequent work could focus on how more complex integration of blockchain and AI can be achieved to enhance decentralized grids especially on the contexts such as P2P energy trading and decentralized energy market. For instance, future works could investigate in the integration of AI with blockchain to enhance the energy trade to address the energy needs within decentralized structures (Frank & Gen, 2024).

Similarly, reinforcement learning, a type of machine learning used to train up models through rewards and punishments, could provide brand-new techniques for steering the unpredictable character of renewable resources. Another advantage of reinforcement learning models is that they are capable of developing an understanding of the conditions of the grid and the optimal methods of engineering energy production storage and distribution as the models are in use. Future studies in this area might investigate into the reinforcement learning models that are able to be trained to learn the current grid conditions in real time and might enhance the stability and performance of distributed power systems. For instance, reinforcement learning could be employed for the management of energy storage where energy released will be at high demand or when production of renewable energy is inadequate. These types of models could thus improve the agility of decentralized grids and at the same time avail them in managing fluctuations of renewable energy resources (Jnr, 2024).

However, more research could be conducted in the future about the application of AI in decentralized grids and its outcome in the long run such as the social, economic and environmental effects, or the action and reaction of the system in relation to the cost and benefits. Additional research of the performance parameters, the impact on the grid stability, cost of energy, and the influence on environment over time will help to give more comprehensive view of the role of AI in the energy evolution. These works could also apply the socio-economic effects of AI in energy management or effect of energy management AI on employment opportunity in the energy sector, or the effect of AI on energy poverty. For instance, studies could examine could examine if energy management through the use of AI gives back a corresponding reduction in cost that could be realized through the provision of cheaper energy to the underprivileged households. Equally, analyses could explore how AI is creating more jobs with relation to the provision of energy in relation to the upkeep and running of AI systems (Aghahadi et al., 2024).

However, there is a lack of studies done on the moral issues arising from the use of AI in decentralized grids. As the AI systems integrate closely into energy management and the level of automated decision-making rises, issues such as the AI agent's responsibility, opportunity to explain its actions, and its bias will gain the importance of their discussion. Subsequent researches could look at how to create smart and effective systems, which are also moral and fair. This could encompass what measures can be taken to avoid an AI driven energy management system being biased in favor of some groups to the detriment of other or how AI systems can be made to be responsive to all stakeholders (Okpo & Omorogiuwa).

Consequently, this research contributes to the extant literature regarding AI and decentralized energy systems by illustrating the problems and potential of AI incorporation in real-life contexts. In as far as some of the observed findings approved some of the assumptions of the existing literature, they also underlined the need for more focused R & D to fully unlock the potential of AI in decentralized grids. The practical implications for both industry practitioners and policymakers are clear: it thus requires a common cause to address the technical and the legal obstacles, and build the AI-enabled future for efficient and green energy supply. In view of these changes, R&I and policy should progress with technology and exercise appropriate caution that AI indeed brings about efficiency, resilience, and equity into the energy system (Alaba, Sani, Dada, & Mohammed, 2024).

## 6. Conclusion:

The results of this study shall further establish the potential of AI in the realization and management of distributed microgrids from renewable energy sources. Analyzing all the research questions, it is possible to conclude that AI has a vast potential in increasing the effectiveness, stability, and reliability of decentralized grids, but integrating these technologies is much more than just being acquainted with AI technologies. The failure to bring statistical meaningful differences concerning the impact of AI experience on its effectiveness perceptions implies that its effectiveness depends not on experience but on the context to it application, readiness of the infrastructure to it and supportive legal frameworks in the decentralized energy systems. In doing so, this paper conveys valuable implications for both the research discipline by way of contributing to the existing body of literature in the AI for DGs and for industry, by illustrating that AGs must be adapted to the specifics of decentralized grids.

Based on these conclusions, the following prescripts are recommended for policymakers and players in the industries. As seen from the above discussion, utility policymakers cannot afford to sit back and fold their arms again because the adoption of AI in decentralized energy grids is the way to go. These frameworks should also incorporate the precautionary and 'soft' aspects of AI application to the critical infrastructure as well. For example, the polices should facilitate an accountability of the AI systems and set out the practices on data protection and security. Furthermore, State regulators should come up with special incentives for research and development of AI technologies that are suited for the decentralized power grid. This might consist of subsidies or tax credits offered to organizations that are generating advanced AI systems and solutions and subsidies for the applications of pilot schemes that investigate the feasibility of these technologies.

Thus, for industry practitioners implementing AI technologies that are tailor-made for decentralized energy systems should be considered as a critical activity. This relates not only to reforms under the AI tools' adaption but also related reformation of technological networks that drive the tools effectively. The practitioners should strengthen data capturing and analyzing systems that can feed and facilitate real-time decision-making processes; training that can enable employees to manage the AI-based energy systems. Cooperation with different sectors will also be important in this respect, as the decentralized management of energy systems often calls for the integration of knowledge that is based in various disciplines.

In this context, the opportunity of AI in distributed energy systems is extraordinary. If greater advances are to be made in the future, they should work to address the identified difficulties. This paper has demonstrated that AI can scale up the decentralized grids' management by enhancing its adaptability, reliability, effectiveness in managing uneven renewable power availability. Nonetheless, to unlock the full potential of AI, it will be required to overcome the deficits in the infrastructure, regulation, and human capital that prevent the spread of the AI techniques at the present stage. There should be more studies on the creation of AI models that are highly effective while at the same time progressively and additionally ethical such that positive gains of AI are fairly obtained to benefit all the stakeholders.

In conclusion, as the role of extending the use of AI in renewable energy, integrating the decentralized renewable energy grids can be considered as one of milestones on the way to creating a more sustainable energy future. Overall, this research work explicates on the integrating AI in learning management system and its implications for future policy shape and practice, as well as a guide to the policy makers and practitioners in the industry. Through such collaborative efforts, innovation, and development of a sound policy environment, approaching the concept of AI in the days of the decentralized energy system, all the opportunities and prospects will be revealed that can exist within the framework of a single, optimized, and more reliable energy grid throughout the entire modern world.

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