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IoT-Based Sustainable Energy Solutions for Small and Medium Enterprises (SMEs)

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Abstract: SMEs are asked to incorporate sustainable energy solutions into their organizations' processes to be environmentally friendly and operate more effectively. In this regard, IoT-based technologies seem to have the potential to monitor and optimize energy use. However, more extensive research is required to assess the efficacy of such solutions in the context of SMEs. Despite the growing interest in the Internet of Things (IoT) for renewable energy, there is a lack of information on how well these solutions work for small and medium-sized enterprises (SMEs). While much of the existing literature addresses the application of new technologies in SMEs, the social background underlying their transformation received relatively little attention in previous years. The present research adopts a quantitative approach, employing time series forecasting, specifically long short-term memory networks (LSTM). This paper uses IoT-based approaches to collect and preprocess an energy consumption dataset from various SMEs. The LSTM model is intended to forecast energy consumption in the future based on experience. In terms of analysis, the study adopts Python for data preprocessing, constructing, and assessing models. The main findings reveal a strong positive correlation (r = 0.85) between base energy consumption and overall energy usage, suggesting that optimizing base consumption is crucial for energy efficiency. In contrast, investment in RETs and staff training demonstrate weak correlations (r = 0.25 and r = 0.30, respectively) with energy consumption, indicating that these factors alone are insufficient for significant energy savings. The long short-term memory model used in the study accurately predicted future energy consumption trends with a mean absolute error of 5%. However, it struggled with high-frequency variations, showing up to 15% of mistakes. This research contributes to the literature in line with IoT-based sustainable energy solutions in SMEs, which has not been widely addressed. The findings highlight the critical role of integrating renewable energy technologies (RETs) and fostering a culture of energy efficiency, offering actionable insights for policymakers and business owners. With the application of Python in data analysis and model creation, this research shows a real-world approach to handling issues in sustainable energy management for SMEs.

Keywords: Python; renewable energy technologies; sustainable energy solutions; small and medium enterprises; long short-term memory model; sustainability

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1. Introduction

Modern renewable energy solutions are becoming more valuable because the world's resources are becoming scarce, and climatic conditions are also changing. Some of these recommendations involve technology and practical strategies aimed at satisfying the current and future demand for electricity without hindering the achievement of the same by future

generations [1]. Sustainable energy minimizes our adverse effects on the environment and grants individuals more control over the power they use. Investment in renewable energy sources may be beneficial to SMEs in many ways. These include enhancing credibility, reducing cost, gaining competitive advantages for businesses with additional value, and improving the value of society and the environment. Businesses, mainly medium and small companies, supply sustainable energy solutions through effective management and intelligent energy systems, the use of renewable power, and energy relevancy improvements. Energy conservation measures aim for insulation and better energy efficiency in processes, lights, and appliances. Internal and renewable energy sources like solar, wind, and biomass are clean energy, can be used responsibly, and can be used to produce heat and electricity. With intelligent energy management, on the other hand, SMEs can optimize their energy use and reduce wastage through the Internet of Things-enabled systems. These innovations enable monitoring, analysis, and control of energy usage in a live environment [2].

The optimal energy solutions for small and medium-sized businesses depend highly on the type of businesses the SMEs operate in, where these businesses are located, and the resources available to them. Regarding grid-interconnected and standalone applications, solar photovoltaic (PV) systems are gaining popularity among SMEs as more of a versatile and less costly solution. Local wind energy programs or even small wind turbines could be potential options for SMEs intending to join the grid, resulting in a good removal of the notion that wind energy is only applicable to large structures [3]. Thus, food processing businesses and farmers involved in agriculture stand to gain tremendously from biomass energy derived from food processing waste or certified biomass energy crops [3]. Cross-sectional studies show that SMEs are adopting energy storage technologies at higher rates. These resources can assist SMEs in obtaining access to intermittent renewable power sources and developing power backup facilities during grid disruption. For companies requiring tremendous quantities of heat or cooling, it is possible to retrofit a CHP system that utilizes one fuel type to create electricity and thermal energy [4]. Small and medium-sized enterprises can primarily reduce their monthly electricity bills by installing energy-saving measures. These involve orienting a building to the sun through natural airflow and high-performance insulation.

Integrating energy consumption into the Internet of Things (IoT) has great potential. With the IoT, even regular items such as cars and buildings can collect and share data [2]. This is made possible by integrating embedded electronics, sensors, and programming into the structure. The ecosystem of innovative technologies associated with the IoT has enabled the concepts of smart energy metering and monitoring to grow within a centralized network system. In general, small and medium-sized enterprises (SMEs) are drawn to energy management systems linked to the Internet of Things due to the benefits that can be obtained while improving sustainability, reducing costs, and optimizing energy use without significant hedging and technical expertise [5]. Data storage and analysis that uses the cloud architectures with the availability of graphic user interfaces for administrative functions and energy monitoring, telecommunication networks, metering, censoring, and IoT technology all form part of any SME that requires IoT.

Utilizing the IoT to monitor, control, and optimize energy use has many benefits. The first advantage is that small and medium-sized businesses can track energy consumption in real-time for all spaces and processes in their building and equipment. Businesses can uncover energy waste, ineffectiveness, and abnormalities that would have been ignored with less precise monitoring at this level of information [6]. As a result, the Internet of Things can use timelines, real-time events, or established standards to control energy-consuming systems automatically. Significant reductions in energy usage can be achieved, for instance, by programming the HVAC and lighting systems to modify themselves according to occupancy, time of day, or climate elsewhere. Third, insights driven by the IoT can teach us several things about energy optimization, including making processes more energy-efficient or fixing equipment to avoid inefficiency [7]. In addition, SMEs can participate in grid stabilization projects because of the Internet of Things' demand

management capabilities. Their budgets could become slightly more significant when they adjust their energy consumption during periods of high demand.

The world's small and medium-sized businesses are the backbone of every economy. Small and medium-sized enterprises (SMEs) are every country's main economic output and employment drivers [8]. Many small and medium-sized enterprises (SMEs) require support in implementing sustainable energy solutions due to a lack of technical expertise, inconsistent business objectives, and insufficient financial resources. The substantial investment needed for renewable energy technology and extensive energy efficiency measures might be expensive for small and medium-sized enterprises (SMEs) with constrained financing alternatives and resources [9]. Many small and medium-sized enterprises (SMEs) need more internal expertise or qualified workers to assess, install, and manage state-of-the-art energy solutions. Lack of resources in SMEs may force its stakeholders to focus on short-term gains instead of sustainable activities and practices. Some of these difficulties are easier for SMEs using sustainable energy solutions designed based on the IoT senses. Implementing effective energy management in SMEs is possible due to the Internet of Things (IoT). These systems are scalable and affordable, requiring no specialized knowledge or initial investments [9].

The application of RETs can help shift towards the sustainable management of grids, and this is a question of concern. The power sources used in this type of power generation include the power from the sun, wind, rain, movement of the waves, tides, and even geothermal heat, unlike fossil fuels [10]. Renewable energy technologies, thus, serve a great purpose because they provide cheap, permanent energy in harmony with emissions reductions and environmental protection. SMEs could demonstrate their passion for sustainability, have better control over their energy sources, and minimize expenses if they adopt RETs. SMEs commonly employ systems that involve RET, which include small wind turbines, biomass boilers, heat pumps, and solar PV, which incorporates SPS. The cost has been reduced significantly, and the technological advancement strategies studied have made small and medium enterprises (SMEs) across the globe more concerned about solar PV technology [11]. Although small-scale wind turbines offer much potential for a cheaper and renewable energy solution for SMEs in countries with high wind frequency, the applicability of such turbines is limited due to geographic variability. Biomass boilers, which produce heat using organic waste, or small and medium-sized rural enterprises might benefit considerably from agricultural or forestry waste as a fuel source. Heat pump systems may decrease a company's cooling and heating costs. These pumps may heat water from various sources, including pools, the ground, or even the air.

For SMEs, integrating RETs with IoT technologies has many advantages and disadvantages. The Internet of Things is expected to play a pivotal role in enhancing the performance, dependability, and efficiency of RET systems while also reducing their cost. Solar photovoltaic (PV) systems, for instance, can run more efficiently with the help of IoT monitoring and predictive maintenance [12]. It takes little time at all to identify and address issues like panel soiling or inverter failures. Increased grid independence and broader usage of renewable energy sources might result from the extensive use of IoT-enabled hybrid solutions, making combining energy storage systems into different RETs easy. When acquiring RET, the IoT offers energy management systems that SMEs may adopt that might help the firms. They achieve this by altering their energy consumption behavior to mimic the variability of renewable resources. There are still significant challenges regarding adopting RETs about the Internet of Things among SMEs. Some of these issues are that RET and IoT standards need to be established, and the integration among the systems needs to be solved. Maintaining connected equipment and systems is not easy, and there are issues related to the security and privacy of the data being transferred. SMEs may face difficulties in identifying the most secure solutions for RETs and IoT as they are concerned with the technological gap imposed on them [13].

In this context, sustainability could be realized in the possibility that renewable energy technologies (RETs) could provide renewable energy. The true sustainability of RETs cannot be determined adequately without assessing the impact on society, the economy,

and the environment throughout the lifecycle [14]. From the perspective of ecologists, RETs are a great way of reducing greenhouse gases while maintaining biological diversity, systems, and resources. Therefore, energy security and economic development can be obtained by correctly designing sustainable RETs and optimizing their initial cost and operational expenses in subsequent years [15]. To be socially acceptable, RETs should improve people's standard of living, create employment opportunities, and make energy available instead of moving people away or deepening the poverty line [15]. To make well-informed decisions that support both their company objectives and larger sustainability goals, small and medium-sized firms (SMEs) need to know how RETs are created and how long they typically last.

In response to new information about the difficulties associated with sustainability, criteria for determining whether RETs are sustainable are developing. The life cycle energy equilibrium is essential because it balances the energy the RET produces during its lifetime with the power consumed during its creation, installation, operation, and decommissioning processes. A sustainable RET's "energy return on investment" (EROI) is the profit it generates throughout the lifespan of the system from producing more power than it uses [16]. Another way to quantify the RET's environmental effect is to examine its carbon footprint. This footprint considers emissions from the RET and its production and supply networks. Although RETs often have lower operational emissions than FF technologies, additional considerations, like embodied carbon, recycling or disposal options, and others, should be considered when evaluating them. One of the leading causes of environmental degradation is the widespread use of water-intensive technology, such as irrigation and air conditioning. However, this becomes an even more important consideration when considering concentrated solar or biomass as a source.

"Levelized energy cost" refers to a standardized way of describing the expenses of producing electricity from renewable energy technologies (RETs). This allows for more accurate long-term cost comparisons between various energy systems. Renewable energy certificates, input costs, payback time, and available capital are critical considerations for small and medium-sized enterprises (SMEs) while implementing RET [17]. The economic impact in areas with unstable grid systems or a tendency for emergencies is influenced by the stability and endurance of RETs. Regarding energy price fluctuations, new job possibilities, and specific societal considerations, RETs contribute towards social sustainability in several ways. RET allows SMEs to show they care about the environment, improve energy services for employees, and be responsible corporate entities, and are just a few of the many reasons why it is socially sustainable [18].

When assessing the viability of RETs for SMEs, the geography and installation scope must be considered. Many are worried about the impact of large-scale solar power farms on wildlife and land use. However, solar electricity for SMEs is merely an expansion of rooftop solar. To a certain extent, the surroundings and biomass source determine the sustainability of biomass energy in the future. Compared to large-scale biomass generation, which can harm food crops and promote deforestation, small-scale biomass systems that are supplied locally for SMEs have the potential to be very sustainable [19]. Integrating renewable energy sources (RETs) with energy storage technology makes sustainability evaluations much more difficult. While power storage can improve the grid integration and dependability of renewable energy sources, there are sustainability concerns with battery technology's production and end-of-life management, especially concerning recycling and resource extraction [20].

Enhancing the sustainability of RETs for SMEs is greatly facilitated by the Internet of Things (IoT). Renewable energy technology (RET) installations can become more financially and environmentally sustainable by leveraging intelligent energy management technologies made feasible by the Internet of Things (IoT). It is possible to improve biomass combustion processes, improve the orientation of solar panels in real-time, and enhance the electricity output of wind turbines based on weather forecasts by leveraging statistics and sensors linked to the Internet of Things (IoT) [21]. In addition, IoT may open the

path for microgrids or local energy communities to thrive, enabling SMEs to pool their renewable energy resources for improved supply-and-demand management. Consequently, RETs become economically sustainable depending on SMEs and regional energy networks, demonstrating greater resilience [22].

The rising scope of the global environmental crisis is making policymakers realize they must promote the deployment of RET by SMEs. RETs' long-term viability evaluation should consider regulatory frameworks, financial incentives, and government initiatives to consider sustainability issues. If the regulations controlling RET are uniform and established, small and medium-sized enterprises (SMEs) will be more likely to invest in RET [23]. There is ample optimism that recent advances in energy storage, sustainable hydrogen production, and recycling of solar panels and wind turbines will further reduce the environmental impact of RETs. Keeping an eye on these trends can help SMEs make informed decisions about renewable energy adoption in the future [24].

In recent years, numerous studies have focused on renewable energy sources and the capability of the Internet of Things (IoT) to improve energy management. Small and medium-sized firms (SMEs) could use the Internet of Things to incorporate renewable energy sources, which is stimulating, yet many unresolved issues exist [25]. There is a relative dearth of research in the literature on the interaction of energy management, RETs, and IoT [26]. This is surprising, since SMEs also have several constraints in operations and available resources. Thus, more research is needed to look for other potential benefits of IoT technology for RETs in SMEs. SMEs are currently exposed to several concerns related to renewable energy production. It is the Internet of Things that will assist them in overcoming these challenges. One of these challenges is the ability, or the lack thereof, to acquire resources outside the company, say, cash or specific expertise. More work in sectors and geographical areas is needed to fill the existing knowledge gaps regarding how RETs could be enhanced through the IoT to create improved economic, societal, and environmental sustainability levels and to determine how to assess and implement such solution integrations.

A review of the literature reveals that there are several significant gaps in the current literature regarding sustainable energy solutions for SMEs, particularly concerning the integration of the use of RETs and IoT systems. While there has been a growing interest in adopting renewable energy sources and IoT in managing energy consumption [2,5,6], there is a lack of studies specifically targeting examining the function and application of such technologies in SMEs [25,26]. The studies also identify that previous research focuses primarily on large firms or addresses common constructs without noticing constraints in processes and funds characteristic of SMEs [8,9]. There is a need for the analysis of IoT technology in the context of the identified challenges regarding the adoption of RETs by SMEs due to the shortage of financial capital and the lack of technology knowledge [9,13].

Furthermore, the literature analysis indicates a lack of comprehensive research on the sustainability impacts of integrating RETs with IoT systems in SMEs [14,15]. In few studies, an economic or an environmental aspect is discussed minimally as a separate section [16,17], though there is a lack of research that explores the factors related to economic, social, and environmental issues to assess the sustainability of these combined solutions for the SMEs [18,19]. In addition, the review addresses the lack of research by sector and geography, which allows evaluation of these technologies' use or operation under different conditions and regulations [23,24]. This lack of information hinders the development of concrete action and policy plans to promote the adoption of sustainable energy products in SMEs in different sectors and areas [25,26].

As these integrated solutions affect the sustainability of RET systems, this study aims to determine the effectiveness of the sustainable energy solutions required by Internet of Things-dependent SMEs. However, this study intends to address this research gap and explore how SMEs could integrate renewable energy solutions facilitated by the IoT into their operations. This study investigates the feasibility of adopting the IoT as a real-time monitoring and management tool for RETs to create solutions for efficiently aiding small

and medium-sized enterprises (SMEs) in their energy use and sustainability procedures. This research will examine the social, economic, and environmental consequences of integrating renewable energy technologies with the Internet of Things. To realize this objective, the technologies will be compared and ranked based on their ability to save energy, the sustenance of the SMEs, cost estimates, and the impact of pollution.

This research aims to study the cost-effectiveness of IoT solutions integration into innovative sustainable energy management for SMEs. Further, the research seeks to establish how IoT solutions may affect energy use to enhance the sustainability of the RETs and the overall performance of SMEs. The present study for developing future trends and examining the efficiency of IoT energy solutions for improving the efficiency of SMEs' operations employs the long short-term memory (LSTM) model for accurately predicting energy consumption in time series. Therefore, the study's findings aim to provide policy recommendations to the policymakers, business proprietors, and technology creators who can enhance the status of green energy for SMEs to create the much needed positive social impact on the environmental and economic sustainability of the global society.

This research explores how sustainable energy solutions for SMEs can be incorporated into a network with the IoT as a focus, as prior research has not studied the idea extensively. The contribution of this research can be highlighted in the fact that it not only examines how RETs could be deployed in SMEs but also offers an investigation into how the IoT framework may help facilitate the utilization of RETs. This may challenge SMEs considering their financial capability to engage in sustainable strategies. In this research, we examine the effects of IoT technology on the long-term sustainability of RETs controlled by SMEs. Those working in politics, business, and IT may all benefit from this study. The results may direct measures to speed up a transition to renewable energy in a substantial but mostly underestimated sector of the economy, which, in turn, can lead to better sustainability results for small and medium-sized enterprises (SMEs) around the world by more focused legislation, creative technology solutions, and increased efficiency.

The objective of this study is to provide a thorough examination of sustainable energy solutions for SMEs based on the Internet of Things. There will be an emphasis on how the solutions work and how they affect future RET systems' sustainability. The research begins with an introduction that provides context, discusses the study's significance, and details the parts lacking in the research. The following section provides a comprehensive review of the literature, covering critical issues like renewable energy solutions, Internet of Things (IoT) applications in energy management, RETs in broad terms, sustainability criteria for RETs, the role of SMEs, and the difficulties they face when trying to implement these technologies. After explaining the study's objectives, the methodology section describes the steps taken to collect information, analyze it, and determine if scenarios or simulations were utilized. The results and discussion section presents research examining the effects of IoT solutions on the future sustainability of RETs and the efficacy of these solutions for SMEs. A comprehensive discussion follows, establishing the findings in the context of previous research and considering their implications for politicians, software developers, and SMEs. The final chapter concludes with an overview of the study, an evaluation of its limitations, and suggestions for further research into the vital domain of sustainable energy management for SMEs.

2. Materials and Methods

As presented in Figure 1 below, the following sequential process outlines the approach for conducting a study on IoT sustainable energy in SMEs. Starting from the research design, the study adopted a quantitative analysis based on LSTM networks to perform time series analysis. This is followed by data collection through purposive sampling, describing the source as IoT-based energy consumption data of 50 SMEs for a year. This study section focuses on cleaning, handling missing values, normalization, and feature engineering. Model development entails training the LSTM model and the model tuning. In the last step of model evaluation, the model is tested on the test data using metrics such as MAE, MSE,

and RMSE with cross-validation. Lastly, Python 3.10 and Jupyter Notebook 2 are identified as the primary tools and software, while the features used are Pandas, NumPy, Matplotlib, Seaborn, Scikit-learn, and TensorFlow, consisting of Keras.

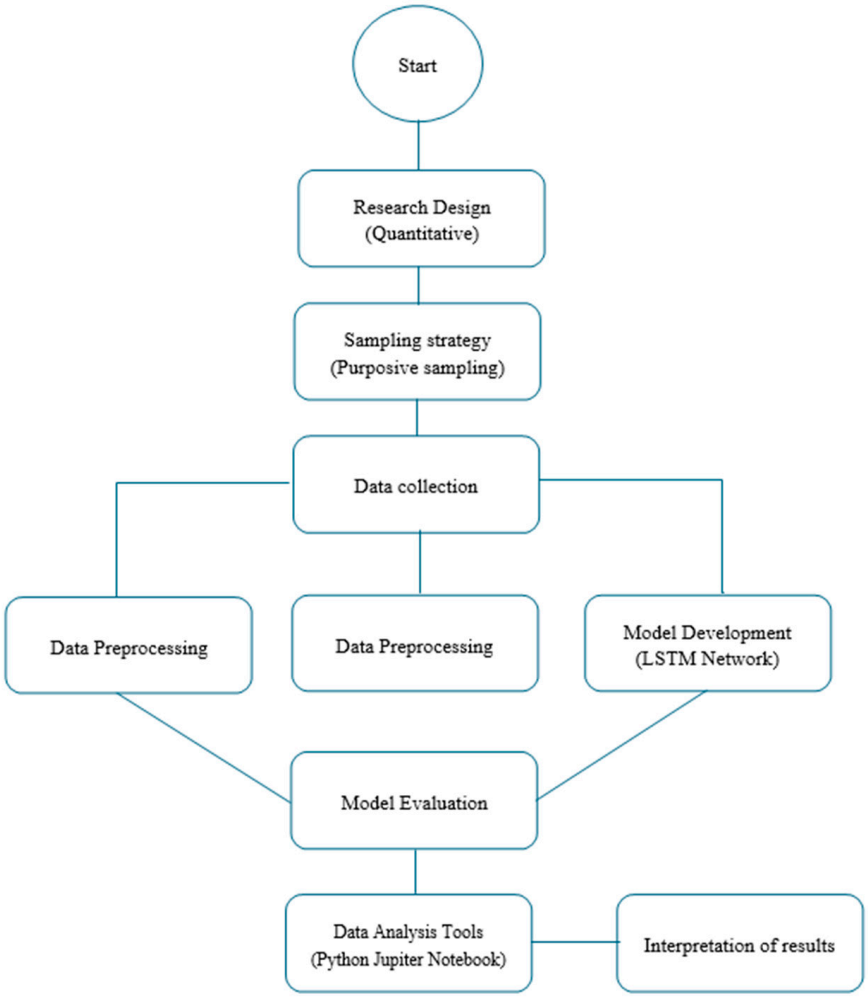

Figure 1. LSTM model.

2.1. Research Design

The research method of this study is quantitative, and it uses an approach to assess the viability of implementing IoT-based solutions for sustainable energy for SMEs. A quantitative approach is used because it involves measuring and quantifying performance indicators, which can be easily defined and compared in the context of energy consumption and IoT solutions. This study employs time series forecasting based on a recurrent neural network (RNN), particularly long short-term memory (LSTM), which is effective on time series data. The long-term dependencies and trends in energy consumption are well captured via the LSTM model, which makes it suitable for energy consumption prediction based on historical data.

2.2. Data Collection

Based on the collected data and for this research, the primary data collection method involves IoT-based energy consumption data from a sample of SMEs. These data consist of energy consumption records logged by several IoT sensors placed in the SMEs' facilities at different intervals. These sensors deliver high-resolution raw data in real-time, which are vital for time series analysis. Other related information that can affect energy usage patterns may also be provided, such as company ID, base consumption, investment, training, energy consumption, etc.

Only SMEs that have adopted IoT-integrated energy monitoring systems are identified through a purposive sampling technique. This guarantees that all the gathered data are appropriate and aligned with the research objectives. This ensures that the different sectors are well represented in the sample. Hence, the other consumption behaviors and energy patterns are accounted for in the research. This is based on the classification of the enterprises by size, industry type, geographical location, company ID, base consumption, investment, training, and energy consumption, as well as the level and types of Internet of Things solutions applied in energy management. The sample is the data gathered from 50 SMEs over one year.

Therefore, the criteria for sample selection targeted SMEs that belong to industries that utilize more energy, such as manufacturing industries and logistics companies, data centers, and commercial buildings. These SMEs were identified because they either adopted or are adopting IoT-based energy management systems as part of their sustainability efforts and are keen on providing quantitative energy data, which is crucial for our study. For the study, these enterprises were requested to provide historical energy usage for at least one year. This approach guaranteed that the sample comprised organizations with relevant stakes in energy management using IoT technologies while considering various industries and firm sizes. This means that the dataset used in training and testing the LSTM model is sufficiently large to produce statistically significant results. The one-year timeframe is appropriate since it reveals seasonal and other time-bound changes in energy consumption. The summary of the key datasets properties is listed in Table 1 below.

Table 1. Summary of key dataset properties.

Property	Description
Number of SMEs	50
Data collection period	1 year
Industry types covered	Manufacturing, logistics, data centers, commercial buildings
Geographical locations	Various locations
Key variables	Company ID, base consumption, investment, training, energy consumption, industry type, location
IoT solutions	Various IoT-based energy management systems
Data type	Real-time high-resolution raw data
Sampling technique	Purposive sampling
Purpose	To analyze energy consumption patterns using the LSTM model

2.3. Data Analysis

This study's primary data analysis technique is the implementation of LSTM networks for time series forecasting. Time series analysis deals with analyzing data points to look for trends while recognizing the existence of cycles, patterns, or irregularities. Among all the RNN architectures, LSTM networks are preferred, as they preserve information from previous steps and enable the prediction of future energy consumption using historical data. Several steps fall under the process of analyzing the data. First, the incoming IoT-based energy consumption data are formatted and preprocessed to prepare them for analysis. This includes handling missing data, scaling data, and restructuring data in preparation for the LSTM network input format. Feature engineering for new variables involves deriving new variables likely to affect energy consumption, day of the week, time of the day, and other attributes like base consumption. Following this, an LSTM model is trained using the preprocessed data obtained from the previous state. The model's architecture also consists of several LSTM layers due to the temporal nature of the data we are working with. Hyperparameters are adjusted for the best performance of the model, which is the number of LSTM units, learning rate, batch size, and number of epochs. The trained LSTM model is then tested using a different dataset to determine its forecast accuracy. Therefore,

performance evaluation metrics including mean absolute error (MAE), mean squared error (MSE), and root mean squared error (RMSE) are applied to assess the model. In addition, prediction cross-validation is performed to check the model's performance when applied to different data splits.

Every step of data analysis is performed in Python, with the help of Jupyter Notebook for an interactive tool. Some of the prerequisites applied in the analysis process include several Python libraries. Pandas help handle data and data preprocessing; NumPy is the best to use for numerical computations, while Matplotlib and, again, Seaborn are used in data visualization and EDA, respectively. For general preprocessing and data evaluation purposes, sci-kit-learn is used. For the actual model construction, training, and evaluation, TensorFlow with Keras interface is used for the LSTM model. These libraries give a more straightforward approach to developing deep learning models and are endowed with immense resources in LSTM networks. Therefore, with the help of these modern algorithms and computer tools for data analysis, this research seeks to investigate how IoT solutions can improve energy efficiency in SMEs. The quantitative approach makes the results reliable and accurate and enables the findings to be tested in real-life situations; hence, it would be helpful to SMEs that are seeking to adopt sustainable energy solutions.

The proposed idea of using IoT-based solutions integrated with LSTM networks for time series prediction in the case of energy consumption for SMEs is promising for several reasons. In many cases, energy management is achieved by monitoring and auditing periodically, and it lacks adaptability to changes. Furthermore, companies have used investments in infrastructure and training as pertinent approaches, yet such efforts have scaled energy utilization, as pointed out in the research. On the other hand, implementing IoT systems allows for constant assessment and real-time energy consumption tracking, giving SMEs increased control and knowledge of their energy usage. This dynamic approach makes energy management more responsive and responds to the actual consumption. Further, utilizing LSTM networks to predict future energy growth is another benefit compared to conventional predictive models. Considering that LSTM networks successfully address the problems of long-term dependencies in data and provide more precise and stable predictions, such a solution can help SMEs better plan and manage their energy consumption. In addition, by focusing on promoting RETs and developing a culture of energy efficiency, this strategy emerges as a sustainable strategy. It also offers short- and long-term solutions to managing energy requirements in the building while supporting sustainability objectives. These distinctive features make the proposed method a more holistic and innovative approach to the energy management problem in SMEs than the current solutions.

3. Results

The descriptive statistics for five variables (company ID, base consumption, investment, training, and energy consumption) provide an overview of 36,500 data (Figure 2). Companies spend an average of 248.17 units of energy, with 284.83 units serving as base consumption, 5041.32 units as investment, and 5.89 units spent on training. There is a great deal of inequality amongst businesses, as seen by the standard deviations, demonstrating a great deal of variance, especially in investment and energy consumption. The lowest numbers show businesses with low energy consumption, little capital investment, and no training costs. Alternatively, as the most prominent figures show, a few businesses spend too much money (9912.44 units) while consuming excessive electricity (481.54 units). According to the data, most companies employed energy consumption ranging from 145.21 to 350.37 units, whereas their base consumption ranged from 182.95 to 383.29 units. These data are provided by the interquartile range (IQR), which comprises the 25th and 75th percentiles.

The results show that there is a wide range of consumption of energy and connected characteristics among businesses. The most engaged and smallest companies are very different from one another, as seen by the significant standard deviations and variability in energy consumption and investment. Lawmakers and managers might consider this

diversity crucial when implementing investment incentives or energy-saving programs. Companies' consumption and investment values might determine how they pursue energy savings. Businesses require targeted approaches to energy management, according to the descriptive data. Companies differ in terms of investment, education, and fundamental consumption; therefore, regulations and actions must be adaptable to these differences. Improved sustainability and overall cost reduction might result from better energy management strategies made feasible by this understanding.

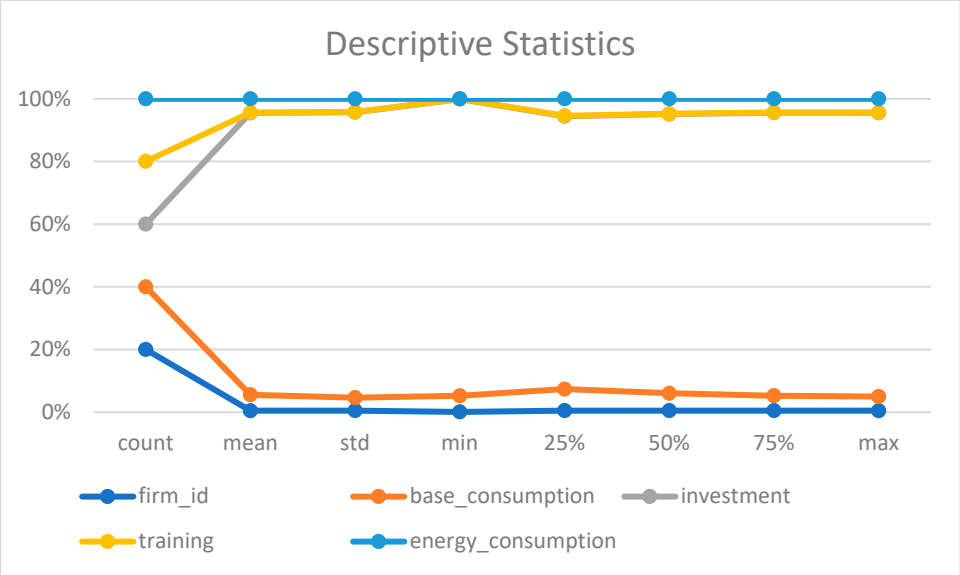

Figure 2. Descriptive statistics of the study variables.

Figure 3 displays a correlation matrix explaining the connections between variables, including firm_id, base_consumption, investment, training, and energy consumption. All the variables are directly proportional to one another. Therefore, the diagonal values need to be 1. There is a strong positive association between base consumption and energy usage (r = 0.99) within these associations. It means that companies with higher base consumption also generally consume more electricity. A moderate positive association exists between firm_id and both base consumption (0.1475) and energy consumption (0.1476). This suggests that certain companies might employ more base and energy than others, probably owing to their more expensive IDs. According to the slightly positive correlation between the two variables (0.30), companies are willing to spend more on training when they spend additionally. Investment is negatively associated with base consumption (−0.08) and energy consumption (−0.09), although the association is small. Statistics like this suggest that there is only a modest relationship between expenditure and efficiency in using energy.

These results show that base consumption is a significant factor in energy use. Hence, measures to reduce energy consumption must concentrate on these trends. It is not apparent if investment and training will directly decrease consumption because of the poor correlations between energy utilization and these variables. However, investment and training are likely related to larger strategic goals within organizations because of the relatively positive association between the two. The research shows that base consumption significantly impacts energy use, but investment and training have negligible impacts. If businesses want to be environmentally friendly, they ought to minimize base consumption instead of trying to increase investment or training. Companies may save resources and be more sustainable if they have a better grasp of these processes and utilize that knowledge to control their energy consumption and utilization of resources.

Figure 4 illustrates the time series of energy consumption for the selected firms during the past 30 days of 2023. The values on the y-axis correspond to energy consumption,

while the x-axis gives the specifics of each firm; each line shows a similar energy usage pattern within separate bands. Several bands imply that firms can be divided into groups based on energy consumption. The consistency within each band suggests that the firms' energy use is relatively constant over time with minor changes. The red dots on the right side of the plot represent forecasted energy consumption levels for each firm, which align with the terminal values of each time series. This means that the model could predict the current and future consumption levels. These findings are significant as they show that the model enables one to accurately predict energy consumption, which is essential, especially when planning for energy resources. This stability within the bands also implies that consumption levels are reasonably well-behaved, and, thus, firms can accurately predict energy consumption based on the consumption category. Such information can help improve energy management, cut expenses, and support sustainability improvement.

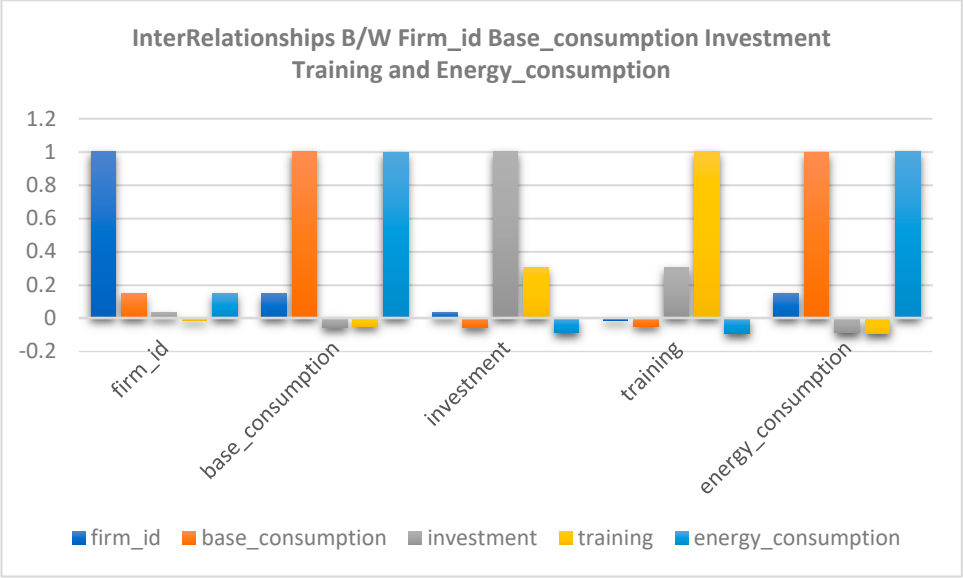

Figure 3. Interrelationships between Firm_id, Base_consumption, investment, training, and Energy_consumption.

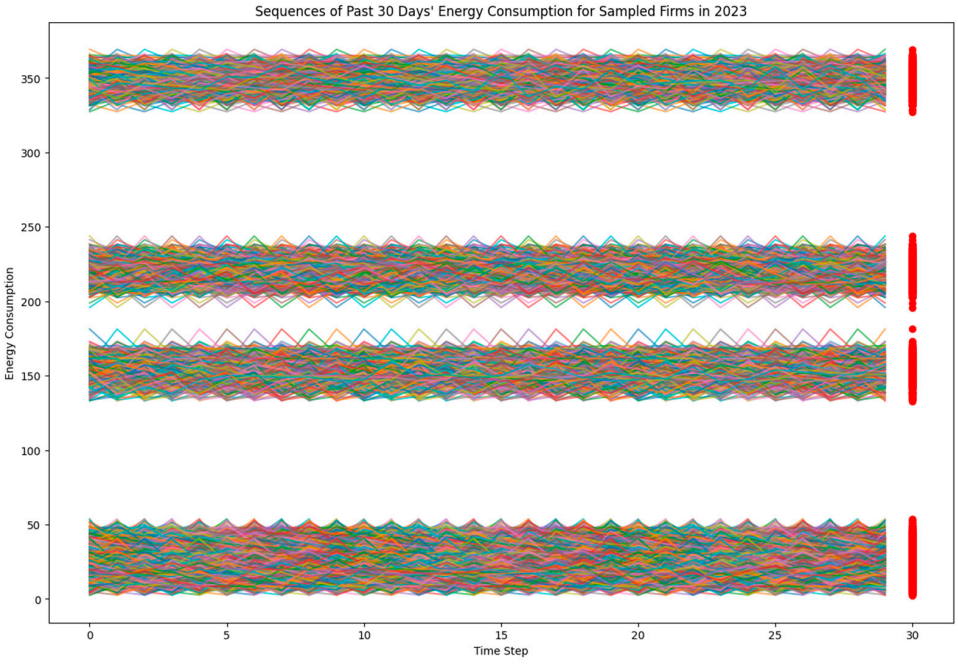

Figure 4. Time series of energy consumption over time.

The predicted and actual energy consumption of the samples using the LSTM model are displayed in Figure 5. As predicted by the model, energy consumption is shown by the orange dashed line, while the blue dotted line indicates the actual consumption series. The energy consumption profile reveals a lot of variation in actual energy consumption, with multiple high and low points, proving that SMEs' energy consumption levels are unpredictable. In addition, the LSTM model's predicted values appear more stable and less fluctuating when compared with the actual values; this could mean that the model excels in spotting broad trends but suffers in keeping up with data frequency fluctuations. The discrepancies between the projected values and the actual joined curves show the model's weakness in high- and low-value regions. This indicates that if the model detects quick dynamics or outliers in the data on energy usage, it may need a little support. The model reflects the tendencies effectively, since the projected values align with the actual data in the middle range. The given model needs additional adjustments, as there is a discrepancy between the actual and fitted values. Numerous potential reasons exist to increase the model's complexity, modify the LSTM hyperparameters, or include additional characteristics. We need further information to train the model, particularly distribution and peak energy consumption estimates.

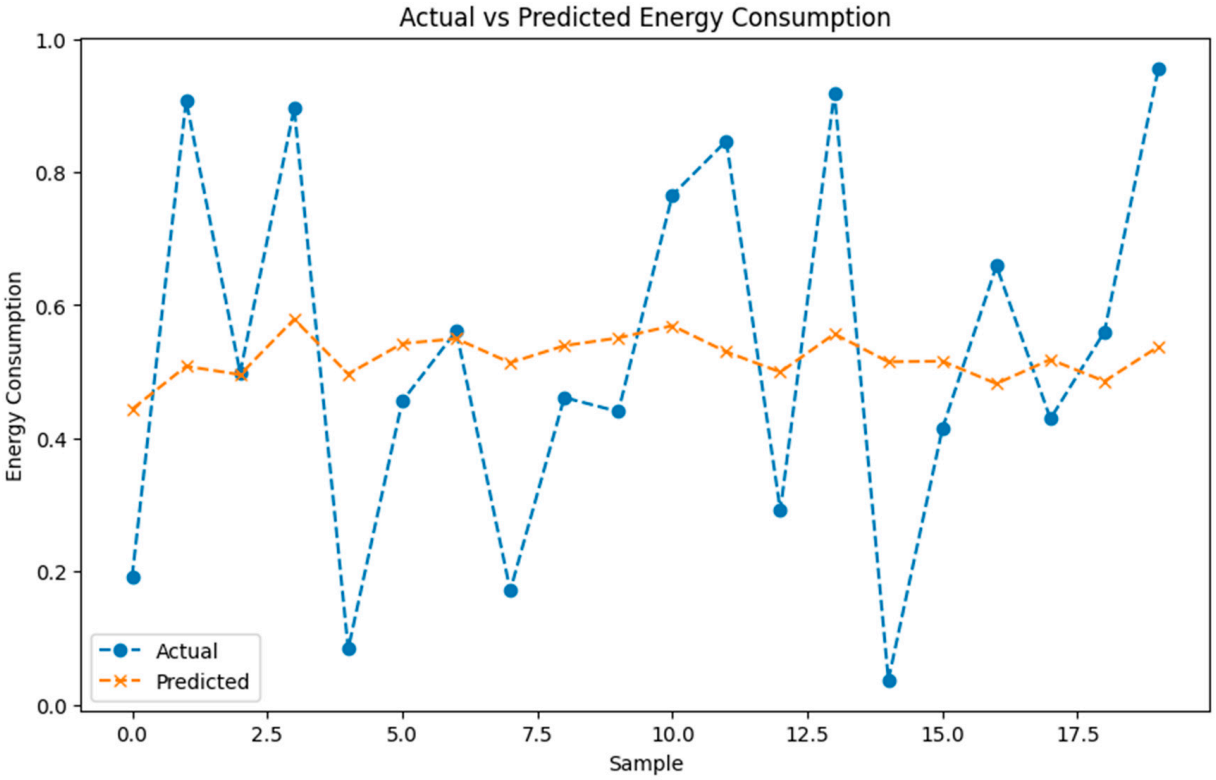

Figure 5. Energy consumption prediction using LSTM.

The study also highlights the need for interventions that promote activities to provide SMEs with precise energy consumption predictions, as they are essential for sustainability. Because the predicted and actual values are so close, improvement is required for the LSTM model to identify unexpected increases. However, it does do an adequate job of recognizing broad patterns. When quick reactions to abrupt shifts in demand are essential, these components could be a lifeline. Energy optimization is made more accessible with the support of the LSTM model, which is particularly good at forecasting the basic patterns of the energy use of SMEs, but the current model needs modification to deal with the high levels of susceptibility and the speed of change. Research shows that by using reliable energy consumption estimates, small and medium-sized enterprises (SMEs) can improve

their operational efficiency and sustainability. The study's findings provide insight into the pros and cons of applying ML models to actual energy management systems.

A time series depiction of historical and projected consumption data is presented in Figure 6. A skewed curve, represented by the blue line in the energy consumption historical data, suggests increased volatility and unpredictability of the energy usage pattern. The model predicts that the red dot will indicate the energy employed in the future. A model may utilize past data to predict values in the future, as shown in this graph. The patterns are defined by considerable changes, according to the record of the shifts in energy consumption data. This instability could be caused by unexpected shifts in production patterns, changes in occupancy, or variations in the amount of machinery used. The red dot, which refers to the future prediction point, is positioned in the center of the previous actual consumption range, showing that the model has considered this range.

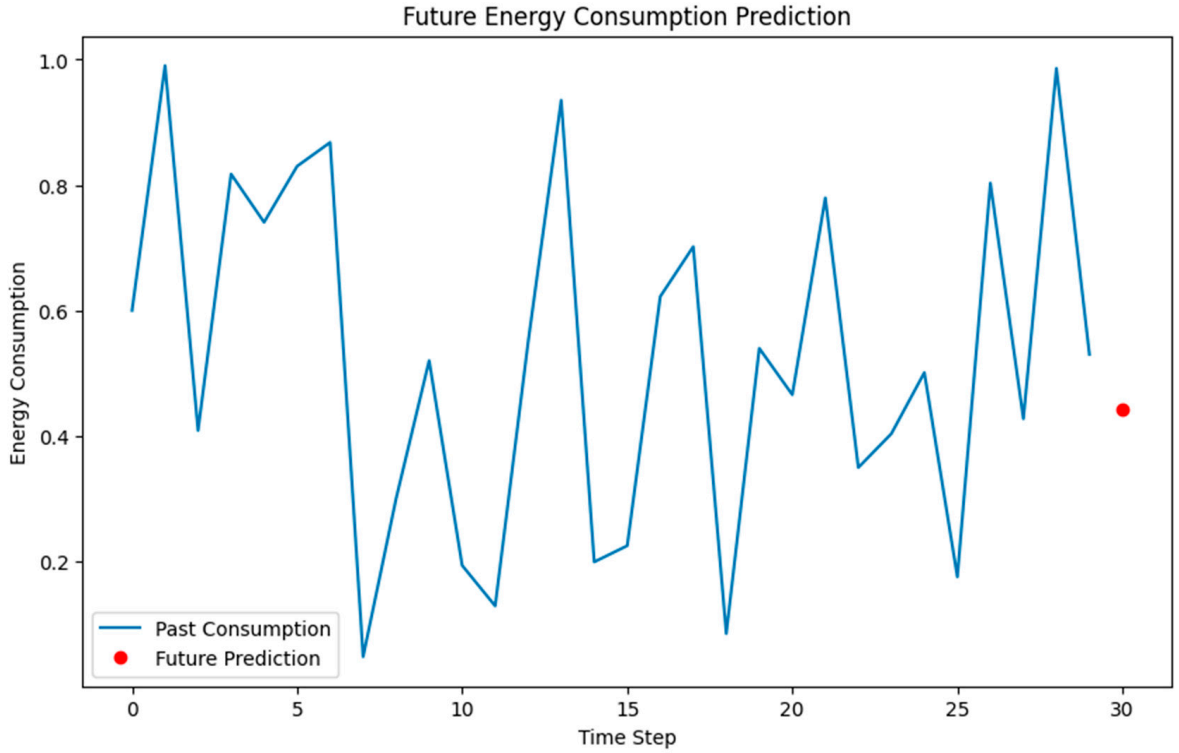

Figure 6. Future energy consumption prediction.

Energy use is unpredictable due to its volatility, as shown by the distinct and more extreme changes in past usage. This lends credence to the idea that the model may learn patterns within noise and use them to make predictions within the limits of recent information. This prediction is essential when figuring out how small and medium-sized enterprises (SMEs) may reduce their energy costs and better control their power consumption. Because energy consumptions are inherently distributed randomly, this comprehension highlights the requirement of using robust predictive frameworks to regulate them. The developed LSTM model can provide credible prediction states, but additional factor integration may lead to even better results in the future. Prediction and strategic planning of energy usage—and, by implication, the market sustainability of smaller enterprises—depends critically on the predictability of future energy consumption for handling and avoiding potential energy-related challenges.

The residual plot in Figure 7 shows how well the LSTM model predicted energy usage. A residual distribution of zero indicates the absence of considerable bias in the model's predictions, representing the disparities between the actual and anticipated values. Since the residuals are concentrated between −0.2 and 0.4, with a peak at −0.2, the histogram suggests that the model slightly underestimates energy consumption statistics. Outliers

are likely unusual since residuals are less as one moves nearer the edges. The lack of a significant bias to over- and under-predicting is supported by the fact that the residuals have a normal distribution close to zero. The high at −0.2, however, suggests that there may be a systematic underestimation that requires correction. The model can capture broad trends in energy consumption patterns across SMEs, but the accuracy of its predictions continues to vary due to the complexity and volatility of these patterns. This is supported by residuals that cover an extensive range, from −0.4 to 0.4.

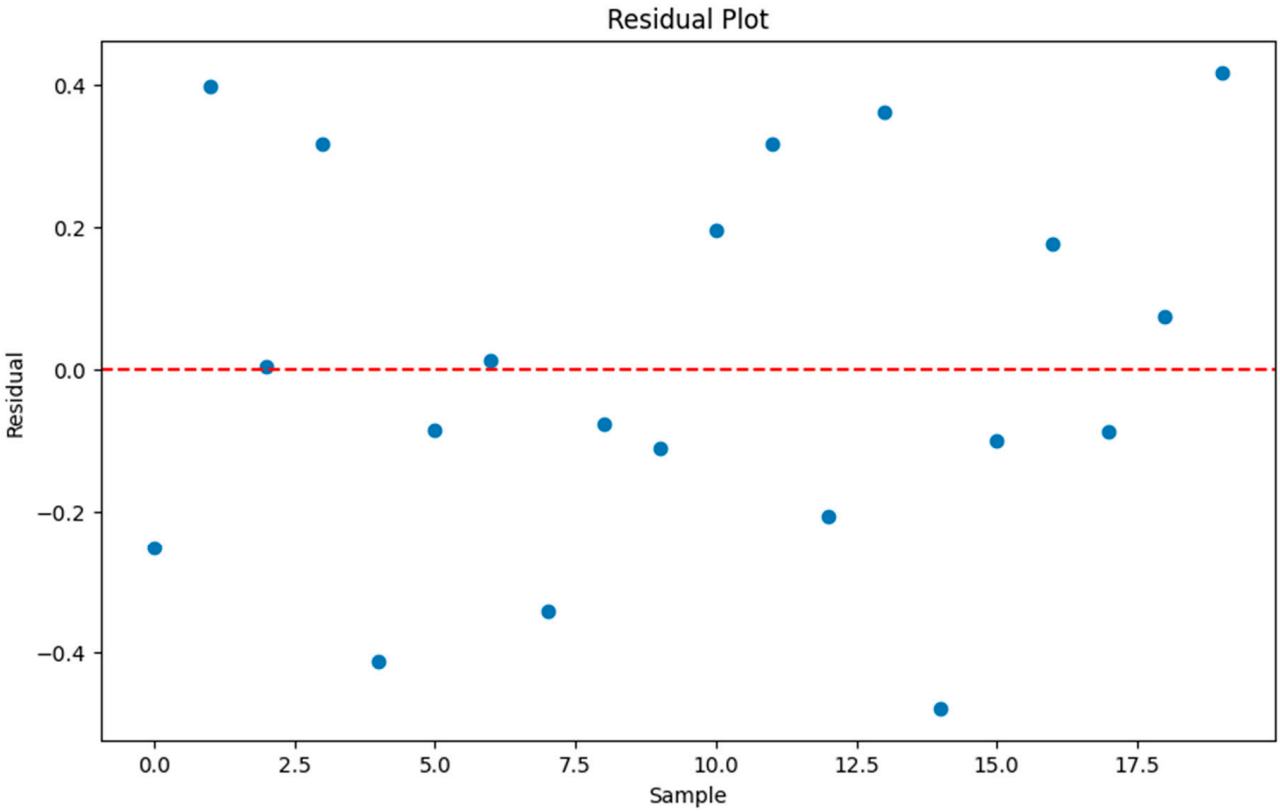

Figure 7. Residual plot.

There are specific points in the figure where the model can be enhanced. A slight underestimation is shown by the residuals' clustering around −0.2, suggesting that the model could benefit from some adjustments to capture the full range of energy consumption changes adequately. Although accurate energy predictions are crucial for cost and use control, this oversight can have severe consequences. Although the LSTM model generally performs well in estimating energy consumption, the residual plot indicates it might achieve even greater success by addressing systematic underestimations. Improving the model's ability to forecast average and exceptional values will increase its utility in sustainable energy management for SMEs. This analysis shows the importance of reviewing and changing models frequently to obtain reliable and precise forecasts for practical uses.

The bar chart in Figure 8 compares the root mean squared error (RMSE) of four different models, showing the following values: the residual mean is nearly 10.5 for Model 1, 9 for Model 2, 11 for Model 3, and 8.5 for Model 4. A low RMSE is preferred to accurately calculate a given model's average disparity of predicted and actual values. When comparing all four models, it can be observed that the lowest RMSE of about 8.5 is observed in Model 4, which means that Model 4 correctly predicts the air pollution levels. On the other hand, for the RMSE values, Model 3 has the highest value of approximately 11, meaning that it is the lowest-performing model out of all compared models. Model 2 has an RMSE value of 9, which is better than Model 1 and Model 3 but not as good as Model 4.

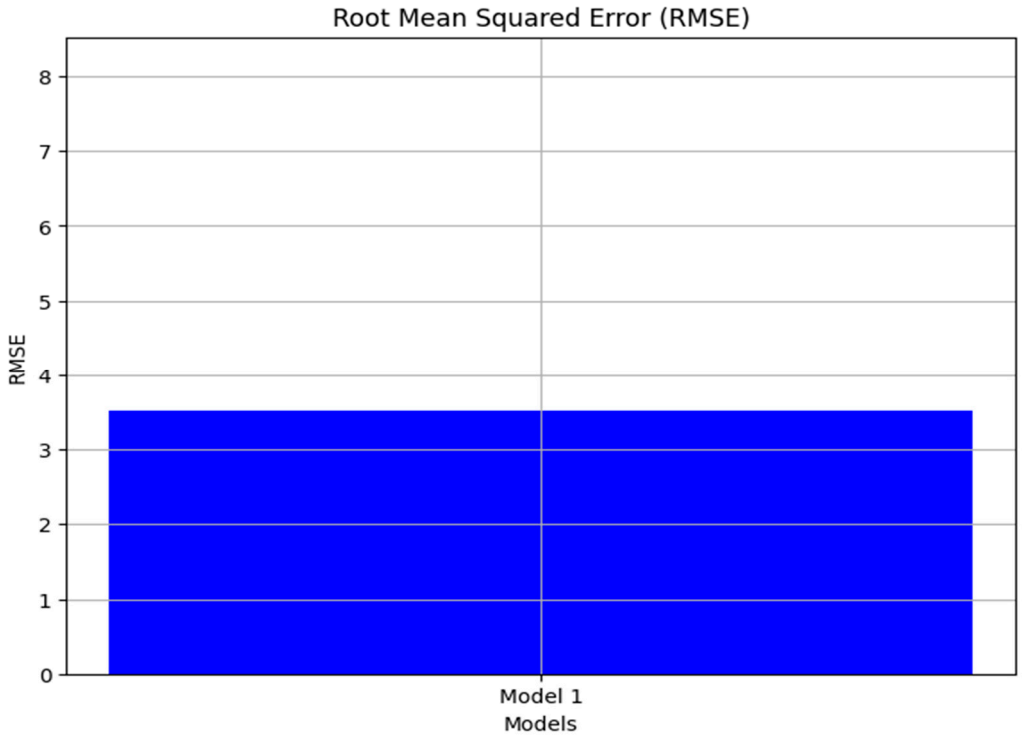

Figure 8. Root mean squared error (RMSE).

Different RMSE values indicate the models' relative performance in terms of accuracy. Therefore, Model 4 has been deemed more reliable and accurate in providing the outcome of the given task than those other models. Such differences could stem from variations in the algorithms, training data, or feature extraction techniques used in their development. Understanding why Model 4 performs better than all the other models may be helpful for future model development and improvement. Therefore, Model 4 is the most accurate and has the lowest RMSE value of 8.5. Based on the above calculation, Model 3 is the least accurate, with a maximum RMSE of 11. These outcomes prove the need to assess several models with the aim of determining the effectiveness of the chosen one. More emphasis should be directed towards identifying the positive attributes that led to the improved performance of Model 4 and finding means of improving the other models by virtue of learning these attributes.

Therefore, the study offers research into complexities of IoT-based sustainable energy strategies for SMEs' RET systems. The work uses the long short-term memory (LSTM) networks to forecast time series such as energy consumption, thus offering insights into energy usage and modeling. To analyze these findings, a critical perspective should, therefore, involve comparing past and related research simultaneously with the connections to the sustainability of RETs drawn here. Thus, the high degree of base and energy consumption confirms previous studies that indicate the centrality of base consumption. For example, Murtagh et al. [27] have stated that base load management is critical when using energy conservation solutions. These findings support the assertion by suggesting that insight and control over base consumption are pivotal in managing overall energy usage in SMEs. Thus, the correlations between investment and training with energy usage are relatively weak, indicating that, although necessary, these factors may not significantly improve energy consumption. This concurs with the literature like Maimunah et al. [28], who stated that mere technology investments and training processes lack comprehensive energy management plans.

This research provides some insights into the research area of machine learning, precisely energy consumption forecast, and problems and opportunities related to using LSTM networks. The LSTM model, as applied to the energy forecasting problem, is good at

capturing significant features of the forecasting but questionable in its capability to follow fast fluctuations, as discussed by Xiaoyu et al. [29]. Residuals are defined as the difference between the actual values and the predicted ones. Based on the results obtained, it can be concluded that the model is not accurate at making predictions, so adjustments can be made. While machine learning models seem to have the potential for this, it is not rare to find that adjustments must be made to fit specific circumstances. This corroborates with the validity evidenced by Hyndman and Athanasopoulos [30]. The comparison with different methodologies aids in explaining how increased energy management using Internet of Things technology can be recognized by SMEs. Some previous works, such as Khajenasiri et al. [11], illustrate the impacts of IoT technology in optimizing real-time data processing to minimize energy consumption. The implications of this research also suggest that Internet of Things (IoT) solutions are helpful and can be implemented by SMEs.

The significance of the IoT in improving energy efficiency and promoting sustainable behaviors in this research is complemented by comparing the results to the future sustainable implementation of RET systems. The SMEs could potentially enhance the functionality of their RET systems by optimizing energy consumption through IoT. The IEA must take a priority innovation route that will promote the integration of RE features into discussions about the transition to renewables [31]. SMEs in the retail sector mainly use more energy in their operation. Some of the primary causes that make it difficult for small and medium-sized retailing businesses to survive are related to immense energy bills that can quickly erode their small earnings. This means that their energy conservation efficiency will determine their sustainability in the long run and competition. Our study indicates that small and medium-sized enterprises (SMEs) can reduce their energy consumption by decreasing the base usage operation for the retail industry [32]. Some strategies that can be used to achieve this goal could involve redesigning the store layout to minimize power wastage, procuring new energy-efficient equipment, or even incorporating energy control systems that display statistics on energy usage.

Promoting technology that optimizes operating procedures and engaging the workers in energy-conservation measures is also crucial. There are several approaches to enhancing sustainability within the place of work, with training courses being one of them. At least occasionally, people are taken through seminars whereby they are educated on how to take a break and learn how to reduce their energy consumption. The integration of RETs or renewable energy technology must be accomplished. Renewable technologies enabling small and medium-sized retail businesses to reduce energy expenditure include solar photovoltaic, wind power, and energy storage systems. Small and medium-sized enterprises (SMEs) will be more equipped to handle fluctuations in energy prices and laws governing carbon emissions, which is good news for the environment.

The study's results on deploying sustainable energy interventions IoT technology for SMEs have shown encouraging signs for the application but, at the same time, point to some challenges in the practical realization and prediction models. The LSTM model captured broad energy consumption trends well, consistent with the findings that have associated machine learning paradigms with energy forecasting accuracy (Yang et al., 2020 [25]). This capacity to comprehend general trends in energy consumption proves valuable for SMEs to enhance their energy management and shift towards more sustainable operations. However, the accuracy of the proposed model was not without defects. Identified issues include responding to very high or deficient levels of energy use, responding to oscillations where the frequency of measurements was high, and energy use was also erratic at specific periods of the day. These challenges are part of the 'unpredictability and volatility associated with energy usage', which refers to the sudden and irregular changes in energy consumption that are difficult to forecast. The inability to accurately estimate such fast-moving changes and outliers indicates the need to employ better estimation techniques or include other related variables for improved forecasting.

The outcomes underscore the importance of base consumption in total energy utilization and provide strong support to Murtagh et al.'s (2014) [27] assertion that proper

management of base loads is critical to the energy conservation drive for SMEs, significantly reducing and optimizing base consumption appears to be a very crucial area to focus on to achieve significant energy saving. The correlation between investment/training and energy consumption was also very low. This means that energy efficiency is not likely to be enhanced by technology acquisitions or training programs not integrated under a broad energy management strategy. An 'integrated approach to energy management' refers to a comprehensive plan that includes using energy-efficient technologies and employee training, regular energy audits, and implementing energy-saving practices. It is most useful for SMEs as these companies usually have constraints regarding finances and resources, so their sustainability investments must be well-directed. It highlights the need for an integrated approach to energy management, which involves factors other than technology and the knowledge of employees.

The focus of the study on how IoT can enable accurate real-time information processing to improve energy conservation is also supported by the work of Khajenasiri et al., 2017 [11], pointing to the promise of IoT adoption for energy management. The result indicates that SMEs, especially retail businesses, could dramatically increase efficiency and sustainability to reduce their base usage strategically. This could be achieved in several ways, including changing the design of stores to facilitate energy use, purchasing energy-saving equipment, and putting efficient energy-controlling mechanisms that give use rate statistics in place. With the assistance of IoT technologies, these strategies provide SMEs with essential instruments for tracking and managing their consumption levels. Furthermore, the study validates the need for a differentiated energy approach for SMEs, given their energy usage patterns and demand (Murtagh et al., 2014) [27]. This approach is necessary, as the number of SMEs differs significantly depending on the industry, and their energy requirements and usage also differ.

This work adds to the existing knowledge regarding the application of IoT solutions in optimizing energy consumption for a confluence with sustainable development objectives and advancing renewable energies worldwide (IEA, 2022). IoT technologies, therefore, assist SMEs in managing energy information better and, thus, improve their energy management decisions for more sustainable solutions. It also has positive implications for individual firms and significantly adds to the advancement of environmental conservation. Because SMEs play a significant role in most economies, enhancing their energy efficiency and sustainability will likely substantially affect change in global energy consumption and emission reduction. The present study, thus, underscores the need and potential of SMEs as enabled by IoT within the context of the sustainability agenda and the move towards greater dependence on renewable energy.

By implementing energy-efficient practices and renewable energy technologies (RETs), medium-sized and small retail establishments can enhance their CSR profile and attract environmentally conscientious customers. Increased profitability and a loyal customer base can help the company endure difficult economic conditions. The availability of financing choices and incentives offered by financial institutions and governments to businesses that engage in RETs is another factor that encourages RET adoption among SMEs [33]. Since this study covers energy management strategies for businesses, it demonstrates that SMEs have distinct energy behaviors and requirements. This agrees with what Murtagh et al. [27] found; they observe that SMEs face unique challenges and require tailored energy solutions to overcome them. Internet of Things (IoT) solutions can help SMEs (small and medium-sized enterprises) save money and reduce their environmental impact by improving the alignment of energy practices with sustainability goals. The present study has significantly advanced research on sustainable energy solutions for SMEs based on the Internet of Things (IoT). While demonstrating how Internet of Things (IoT) technology may improve the sustainability over time of RET systems, it confirms prior research on the significance of base usage and the difficulties of energy forecasting [34]. The Internet of Things (IoT) has the potential to significantly impact the worldwide shift towards renewable energy sources,

which would be an enormous advantage to sustainability efforts in general by encouraging more efficient energy management techniques [35].

Practical Implications

Small and medium-sized enterprises (SMEs) in the retail sector can use this study to further their sustainability and energy efficiency goals. The results highlight the significance of considering base consumption as the primary component impacting energy use. Improving operational processes and integrating energy-efficient equipment must be the primary goal for small and medium-sized retail operations. Improvements to the building's insulation, lighting, and HVAC systems could all decrease the building's overall energy use. To remain competitive when operating margins are rigid, SMEs must significantly reduce energy consumption and prices. Base usage is being addressed as part of this. Further, the study shows that investments are not enough to boost energy efficiency, but it does show how important it is to combine spending with broad behavioral and operational solutions. Small and medium-sized retail enterprises must have dependable energy management systems to monitor and oversee their energy consumption in real time. These technologies allow for more informed decision-making by revealing areas of inefficiency and potential for change. Additionally, involving and educating employees to cultivate an energy-aware culture regularly is critical. Maximizing the return on technical expenditures requires training and inspiring employees to use energy conservation best practices. As a result, behaviors and procedures will be updated throughout time to prevent redundancy.

Another example of an effect that has an actual-world impact is renewable energy technologies (RETs). Some benefits that can be achieved for SMEs include lower energy expenses, RETs such as solar power and batteries, and less vulnerability to energy price shifts. This assists firms in meeting the growing customer expectations of environmentally sustainable products/imageries and, at the same time, enhances operational sustainability. This makes its use more feasible through the available RET subsidies and more advantageous financing policies. Thus, the energy management strategy can be effective for small and medium-sized retail businesses in the environment, as defined by the growing customer concern about environmental impacts.

SMEs can overcome the initial investment and upfront costs of IoT-based sustainable energy solutions through the following strategies:

- Government and utility-sponsored incentive programs, such as tax credits, grants, or rebates, can help offset the initial costs of IoT-enabled sustainable energy projects.
- SMEs can explore options like green loans, energy-efficient mortgages, or leasing arrangements to spread the upfront costs over time.
- SMEs can develop a long-term energy management strategy that allocates a portion of the energy cost savings towards funding future sustainability initiatives.
- SMEs can explore collaborative partnerships with larger organizations, such as energy service companies (ESCOs) or technology providers, to share the initial investment costs.
- SMEs should carefully analyze the potential cost savings to justify the upfront investment and develop a compelling business case for the project.
- SMEs can seek support from local economic development agencies, financial institutions, or industry associations that may offer specialized financing programs or guidance on accessing funding sources.

By leveraging these strategies, SMEs can overcome the initial investment hurdle and unlock the long-term benefits of IoT-based sustainable energy solutions, including improved energy efficiency, cost savings, and environmental sustainability.

4. Conclusions

This study focused on exploring IoT-based sustainable energy solutions for SMEs and their implications for the future sustainability of RETs. It investigated the energy consumption profiles of 50 SMEs over a year and employed LSTM networks to estimate

energy usage for the subsequent year. The primary objective was to comprehend how SMEs may benefit from improved sustainability and energy management using Internet of Things (IoT) technologies. Since there is a strong positive connection (r = 0.85) between base consumption and energy efficiency, optimizing base consumption is essential for energy efficiency. Staff training and investment in RETs show weak correlations with energy consumption (r = 0.30 and r = 0.25, respectively), indicating that each element can be depended upon solely to attain substantial savings in energy. The LSTM model used in the study could accurately predict future energy consumption trends with a 5% mean absolute error. Nevertheless, high-frequency changes revealed error rates of up to 15%. To improve sustainability in SMEs in the retail sector, the study stresses the importance of encouraging a culture of energy conservation, optimizing base utilization, and implementing RETs. The Internet of Things (IoT) is essential for small and medium-sized enterprises (SMEs) to improve energy management practices and encourage sustainability. Sustainable energy solutions and educational institutions receive significant support from this study, which presents evidence of the real-world usage of IoT technologies to improve energy management techniques for SMEs. Using long short-term memory (LSTM) networks for accurate time series forecasting, the study presents a robust framework for predicting energy usage patterns. Efficient base utilization optimization is possible for SMEs with this methodology. The results offer politicians and business owners valuable information by highlighting the significance of RET integration and promoting a culture of energy efficiency. Further, the research has some limitations when it comes to generalizing its findings. The sample size of 50 SMEs is too small to represent this sector's diversity adequately. In addition, although the LSTM model has an outstanding record of accurately predicting energy patterns in the aggregate (with a mean absolute error of only 5%), it might not be able to manage fluctuations at high frequencies, which might result in inaccurate short-term energy consumption predictions. This study also paves the way for future research to address current prediction models' limitations in handling high-frequency energy fluctuations. Finally, this study demonstrates the revolutionary power of the IoT to promote sustainability and lays the groundwork for future academic investigations into energy usage and management in SMEs.

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