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Article

# The design and implementation of Intelligent-Electricity Consumption and Billing Information System (IEBCIS)

**Bukohwo Michael Esiefarienrhe*, Itumeleng Michael Maine**

Computer Science and Information Systems Dept., North-West University, Mafikeng 2790, South Africa
*** Corresponding author:** Bukohwo Michael Esiefarienrhe, Michael.Esiefarienrhe@nwu.ac.za

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**Abstract:** The increasing demand for electricity and the need to reduce carbon emissions have made optimizing energy usage and promoting sustainability critical in the modern economy. This research paper explores the design and implementation of an Intelligent-Electricity Consumption and Billing Information System (IEBCIS), focusing on its role in addressing electricity sustainability challenges. Using the Design Science Research (DSR) methodology, the system's architecture collects, analyses, and visualizes electricity usage data, providing users with valuable insights into their consumption patterns. The research involved developing and validating the IEBCIS prototype, with results demonstrating enhanced real-time monitoring, load shedding schedules, and billing information. These results were validated through user testing and feedback, contributing to the scientific knowledge of intelligent energy management systems. The contributions of this research include the development of a framework for intelligent energy management and the integration of data-driven insights to optimize electricity consumption, reduce costs, and promote sustainable energy use. This research was conducted over a time scope of two years (24 months) and entails design, development, pilot test implementation and validation phases.

**Keywords:** IEBCIS; prepaid smart meters; electricity consumption; electricity dashboard; electricity consumption monitoring

## 1. Introduction

As global energy demands continue to rise, coupled with the imperative to reduce carbon emissions and mitigate climate change, the need for innovative solutions to optimize electricity consumption and billing processes has become paramount. Energy saving and emission reduction are vital for sustainable energy management, reducing waste and emissions, ICT and Business Intelligence (BI) enhance this by providing real-time data and insights, enabling precise tracking, optimization, and sustainable resource use (De Wet and Koekemoer, 2016; Hosseini et al., 2017; Muntean, 2018; Porras et al., 2017; Wang and Wright, 2020). The issue of electricity crises, particularly in countries like South Africa, has become increasingly prevalent. The country has experienced frequent load shedding, leading to disruptions in economic activities affecting millions of households. This crisis has been exacerbated by aging infrastructure, insufficient investment in new power generation capacity, and challenges in the energy sector's governance (Jing et al., 2022; Salmon et al., 2016). The absence of an advanced intelligent electricity dashboard prevents effective energy usage monitoring and management, hindering public engagement and awareness in electricity-saving initiatives, which ultimately causes higher electricity bills and wasteful consumption practices. Hence, without access to real-time consumption data and pricing information, citizens cannot participate in demand response programs or other energy-saving initiatives, missing opportunities to reduce costs and contribute to grid stability (Ndaba, 2021). Moreover, the lack of a dashboard limits citizens' awareness of energy-saving practices and technologies, hindering efforts to improve energy efficiency and sustainability (Ndaba, 2021; Porras et al., 2017). Addressing these issues is crucial, as they not only impact the reliability of electricity supply but also have significant economic and social implications (Jing et al., 2022; Muntean, 2018; Wang and Wright, 2020). By implementing energy-saving measures and reducing emissions, countries can enhance energy security, mitigate the effects of climate change, and promote sustainable development (Porras et al., 2017; Wang and Wright, 2020). This study presents an intelligent-electricity consumption and billing information system (IEBCIS) which is a pivotal advancement in the realm of energy management, particularly in the context of addressing the pressing challenges of electricity sustainability (Hosseini et al., 2017; Porras et al., 2017). Implementing a dashboard for citizen interaction is crucial for several reasons. It provides users with the ability to monitor their electricity consumption through visualizations (Jing et al., 2022), access an accurate billing system, report faults and submit complaints, use an educational portal on electricity, retrieve load-shedding schedules, and access other essential functionalities. This is particularly important in countries like South Africa, where electricity shortages can lead to risky behaviors such as illegal connections and overloading of electrical circuits (Salmon et al., 2016). Thus, by allowing citizens to monitor their electricity consumption in real-time, the dashboard promotes transparency and accountability in the billing process, reducing the likelihood of billing errors and disputes (Ndaba, 2021; Salmon et al., 2016). By regularly tracking electricity usage data, coordinators can identify trends, patterns, and anomalies that may indicate issues with the system or opportunities for improvement (Salmon et al., 2016). Additionally, good system maintenance helps prevent malfunctions or failures that could disrupt electricity services or lead to inaccuracies in billing (Ndaba, 2021; Shahbaz et al., 2021). Overall, these practices help electricity coordinators and administrators effectively manage IEBCIS, ensuring its reliability and accuracy in providing examination references for decision-making. A smart meter is an advanced digital device that records electricity usage in real-time and communicates this data to both consumers and utility providers, enabling more efficient energy management (Radenković et al., 2018), examples of them are shown in **Figure 1**. Thus, when combined with a smart grid, smart meters become integral components of a larger, interconnected energy system designed for optimal energy distribution, monitoring, and control (Aguilar-Fernández et al., 2015; Ndaba, 2021; Radenković et al., 2018; Shahbaz et al., 2021). Several studies have investigated and emphasized the importance of leveraging advanced technologies and usage of smart meters to enhance energy management practices, using various approaches such as BI, internet of things (IoT) and cloud computing, data mining, artificial intelligence (AI), machine learning, wireless sensor networking, Zigbee and radio frequencies technologies amongst other approaches. For instance, article (Ndaba, 2021) highlighted the potential of smart metering systems in enabling more granular and real-time monitoring of electricity consumption, thus empowering consumers to make informed decisions regarding their energy usage. The interconnected research from Studies (Aguilar-Fernández et al., 2015; Alladi and Vadari, 2011; Ceci and Razzaq, 2023; Fan et al., 2022; Khan et al.,

2023) underscores the need for sustainability-focused energy management and the role of advanced technology and stakeholder engagement in achieving this goal. Study (Alladi and Vadari, 2011) emphasizes stakeholder engagement as a critical factor in project sustainability, particularly within energy projects, as engaging stakeholders early and effectively addresses risks and builds long-term trust essential for sustainable outcomes. The article by Ceci and Razzaq, (2023) highlights the environmental implications of energy consumption in G10 countries, advocating for information and communication technology (ICT), and renewable energy as tools to reduce material footprints (MF) and environmental impact. However, it cautions about ICT's own ecological costs and calls for policies that support sustainable ICT-driven initiatives, particularly in emerging economies. The article by Fan et al. (2022) complements these themes by addressing seasonal power imbalances in residential areas, proposing a predictive model that uses data mining and machine learning (Particle Swarm Optimization-K-means and Support Vector Machine) to improve power demand forecasting and grid efficiency. Similarly, the work of Khan et al. (2023) introduces a hybrid AI model (Convolutional Long Short-Term Memory and Bi-directional Gated Recurrent Unit) to enhance prediction accuracy for both energy consumption and generation in net zero energy buildings (NZEBs). This model's precision and real-time application potential bolster smart grid management, aligning with the sustainability goals emphasized in studies (Alladi and Vadari, 2011; Ceci and Razzaq, 2023). Building upon these foundational studies, the IEBCIS seeks to integrate cutting-edge technologies such as intelligent dashboards, advanced data visualization techniques, and sophisticated analytics tools to revolutionize electricity consumption and billing management. By providing users with real-time insights into their electricity usage patterns, the IEBCIS empowers them to make informed decisions that can lead to substantial energy savings and reduced carbon footprint (Aguilar-Fernández et al., 2015; Salmon et al., 2016; Shahbaz et al., 2021). Thus, this study adopted various methodologies detailed in Venable et al. (2017), which discusses design science research (DSR) methodologies, emphasizing their importance in creating effective solutions and artifacts to improve human realities. Their paper outlines several DSR methodologies, including systems development research methodology (SDRM), design science research methodology (DSRM), action design research (ADR), and participatory action design research (PADR), each offering distinct processes and frameworks for conducting research. The evolution of these methodologies is highlighted, showcasing a shift from IT-centric designs to more client-engaged approaches that emphasize flexibility and local needs. The major component that facilitates this study is the use of modern smart meter data. Smart meters have emerged as a fundamental technology in the quest for sustainable electricity management globally. Introduced to address the limitations of traditional meters (old electricity meters), smart meters are now extensively used in many countries due to their ability to provide real-time, accurate, and detailed information about electricity consumption (Ndaba, 2021; Radenković et al., 2018). Unlike traditional meters, which require manual readings and provide limited information, smart meters offer continuous insights that help both utilities and consumers monitor and manage energy usage more effectively, optimize consumption patterns, and enhance billing accuracy (Fan et al., 2022). This real-time data allows for more accurate billing, eliminates the need for estimated bills, and enables consumers to track their electricity usage more effectively. One of the key advantages of smart meters is their ability to store and transmit data. Smart meters are equipped with advanced communication technologies, including Zigbee, wireless fidelity (Wi-Fi), radio, and cellular amongst other, which enable effective communication between utility providers and consumers (Aguilar-Fernández et al., 2015; Salmon et al., 2016; Shahbaz et al., 2021). This two-way communication allows utilities to remotely monitor and manage electricity consumption, identify potential issues such as power outages or equipment failures, and implement demand-response programs to reduce peak loads (Khan et al., 2023). For consumers, smart meters provide access to detailed information about their electricity usage, helping them make informed decisions about energy consumption and potentially save money on their electricity bills. In addition to the smart meter data storage and communication capabilities, smart meters also play a crucial role in promoting energy efficiency and sustainability (Aguilar-Fernández et al., 2015; Salmon et al., 2016). For example, providing consumers with real-time information about their electricity usage, smart meters encourage them to adopt more energy-efficient behaviors and technologies. User interaction is a critical component of smart grid technology, enabling a dynamic exchange of information between the grid and end-users (Aguilar-Fernández et al., 2015; Salmon et al., 2016) which also supports the integration of distributed energy resources (DER), such as solar panels and wind turbines, facilitating localized energy generation and reducing reliance on centralized power plants (Fan et al., 2022). This interaction allows users to actively participate in managing their energy consumption, leading to more efficient and sustainable energy usage. One key aspect of user interaction is the collection of power information from various devices and appliances within a user's premises (Ndaba, 2021). This data collection enables the provision of real-time electricity pricing and consumption information to users (Ndaba, 2021). Additionally, user interaction involves the implementation of control mechanisms for managing the load on the user's internal power devices (Ndaba, 2021; Salmon et al., 2016). By enabling users to control their energy usage based on real-time pricing and consumption data, user interaction promotes energy conservation and sustainability (Hosseini et al., 2017; Porras et al., 2017). Moreover, user interaction plays a vital role in demand response programs, where users can adjust their energy consumption in response to grid conditions, contributing to grid stability during peak demand periods. By providing users with real-time information about their energy usage and the availability of renewable energy, user interaction encourages the adoption of renewable energy technologies (Porras et al., 2017). This integration of renewables not only reduces reliance on fossil fuels but also contributes to a more sustainable and environmentally friendly energy system (Hosseini et al., 2017). By enabling users to monitor their energy consumption and make informed decisions regarding their consumption patterns, user interaction promotes a more conscious approach to energy utilization. This behavioral shift can subsequently contribute to a reduction in overall energy consumption and a decrease in greenhouse gas emissions, thereby enhancing environmental sustainability (Hosseini et al., 2017; Radenković et al., 2018). Italy was the first country to implement a widespread smart meter system, commencing in the early 2000s (Shahbaz et al., 2021). Subsequently, other European nations, including Sweden, Denmark, and Spain, began adopting smart meters in the mid-2000s (Fan et al., 2022). In South Africa, the rollout of smart meters commenced in 2009 with the objective of improving electricity efficiency and mitigating losses within the grid (Aguilar-Fernández et al., 2015). However, this initiative encountered several challenges, including funding constraints and technical issues, resulting in delays in the implementation process.

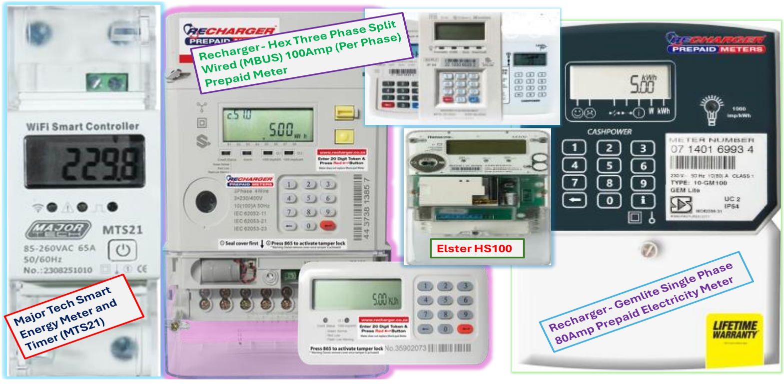


**Figure 1.** Different types of prepaid electricity smart meters.

Source: Authors' work.

Currently, one of the most advanced countries in terms of smart electricity and meter systems is Norway (Fan et al., 2022). Norway has achieved a high level of smart meter penetration, with nearly 100% of households having smart meters installed (Fan et al., 2022). This high level of penetration is due to Norway's early adoption of smart metering technology, as well as government support and incentives for smart meter deployment. Additionally, Norway's strong focus on renewable energy and sustainability has driven the adoption of smart meters as part of a broader strategy to reduce energy consumption and carbon emissions (Fan et al., 2022; Radenković et al., 2018). Moreover, several countries are leading the way in advancing smart electricity and meter systems, for instance Finland, Estonia, Denmark amongst other countries has achieved a remarkable rollout milestone of smart meters and is now pursuing a second phase to further enhance its advanced energy infrastructure, capturing millions of metering values from a vast network of devices. Collectively, these nations illustrate the global trend towards integrating smart technologies in energy management, enhancing efficiency and consumer engagement, while also adapting to local challenges and specific energy needs. This study addresses a critical gap in bidirectional high-speed communication and intelligent communication between the supply and demand sides of the electricity grid. This gap is primarily rooted in the limitations of existing infrastructure and communication technologies, which hinder real-time data exchange and feedback mechanisms. Thus, proposes innovative solutions to enhance communication technologies, potentially integrating advanced communication protocols and data analytics to facilitate a more interactive and responsive energy management system. Through leveraging emerging technologies such as IoT devices, machine learning algorithms, and cloud computing, the study aims to create a robust framework that not only improves the efficiency of electricity consumption but also enhances customer engagement through real-time monitoring and feedback. In terms of scientific contributions, study advances the field by introducing a novel framework that emphasizes the integration of intelligent communication mechanisms within electricity consumption and billing systems. It fills existing gaps by providing empirical evidence on how enhanced communication can lead to improved operational efficiency, reduced energy wastage, and greater consumer awareness. This original approach builds on existing work by extending the concept of smart metering beyond traditional billing systems to a comprehensive solution that incorporates user behavior analytics and predictive modeling. Moreover, address the sustainability aspect by exploring how improved communication can facilitate demand-side management, thereby contributing to environmental sustainability and optimizing energy resource utilization. This innovative perspective not only enhances the theoretical understanding of smart electricity systems but also provides practical implications for policymakers and utility providers seeking to modernize their infrastructure. Many countries face challenges in upgrading their communication networks to support the requirements of smart grid systems, such as real-time data exchange and remote-control capabilities. This gap hinders the implementation of advanced grid management techniques, including demand response and real-time pricing, which relies on seamless communication between the grid and end-users (Ndaba, 2021; Radenković et al., 2018). Addressing this gap requires prioritizing research and investment in communication infrastructure, including the adoption of standardized protocols and the development of new technologies to enable more efficient and reliable communication in smart grid systems (Alladi and Vadari, 2011). This study builds upon a foundation of research in intelligent energy management, sustainability, and smart grid technology. Existing studies have widely explored various dimensions of energy management systems, such as real-time energy tracking, demand response systems, and predictive analytics to reduce peak demand (Adegboye et al., 2013). Furthermore, the theoretical foundation of this study draws from both systems engineering and energy informatics, applying design science principles to embed intelligence directly into the billing and consumption monitoring process. The approach enables not only more precise billing based on real-time data but also dynamic consumption alerts and insights for end-users, which have been less emphasized in prior work. In terms of theoretical advancement, IEBCIS builds on the concept of intelligent metering but diverges from earlier research by incorporating a more user-centered design which fosters proactive engagement in energy conservation, directly aligning with environmental and economic sustainability goals. With greater insight, studies on smart metering technologies and energy billing systems highlight various innovative approaches to enhance metering accuracy, improve user experience, and promote efficient energy management in diverse contexts. In their work, Matthews et al. (2018) presented a novel smart meter design specifically developed to address Nigeria's unique energy metering challenges. It introduces remote configuration capabilities and offers flexible billing options (both prepaid and post-paid), allowing communication via SMS for smoother interaction between consumers and utility providers. This approach aligns closely with with the work of Aljumaah et al. (2022), which described a smart energy prepaid billing system leveraging wireless sensor networks (WSNs) with Zigbee technology and RFID. By facilitating wireless data collection on consumer kilowatt-hour (KWh) consumption and providing balance information directly, it bypasses the need for telecommunication or internet connectivity, ensuring reliability in energy monitoring and billing. Adding a robust layer of operational security and efficiency, The article by Zhao et al. (2021) outlines a three-tier intelligent meter reading system architecture, integrating data processing, presentation, and storage. This structure includes modules that manage data security, task management, and line data analysis, which provides a seamless and secure operational experience for users. The article by Patil et al. (2017) builds upon this security theme, presenting an intelligent energy meter (IEM) designed to combat power theft and enhance overall power quality. This system incorporates Arduino, global system for mobile communication (GSM), and Raspberry Pi components, validated through experimental testing to showcase its practical utility and accuracy. Together, these studies provide valuable insights into modernizing smart metering systems, each contributing unique technological features to support accurate billing, enhance communication, and improve security in energy management across various regions. Consequently, the work of Aljumaah et al. (2022) discusses a smart metering system specifically designed for Iraq's electricity grid, integrating Zigbee, Bluetooth, and GSM to achieve seamless two-way communication between consumers and suppliers. By testing this system in real-world conditions in Karbala, the study demonstrates how the device can track energy usage metrics such as voltage, current, and power factor. Data is periodically sent to a centralized data concentrator unit (DCU) using long-range GSM technology, chosen for its low interference, improving overall data accuracy and reliability. Complementing this, Suryadevara et al. (2014) explores a flexible, low-cost smart system for monitoring and controlling household electrical devices to reduce energy costs, making efficient energy usage more accessible. The work of Mahmood et al. (2008) builds on this approach with an automatic meter reading (AMR) system designed for improved power system control and timely data collection, which aids operational decision-making, reduces power outages, and minimizes losses in power management. Meanwhile, articles Aboelmaged et al. (2017) and Manikandan et al. (2023) introduce IoT-based systems that add user convenience through mobile applications and real-time monitoring of electricity usage. The article by Manikandan et al. (2023) specifically emphasizes reducing human error and payment delays in billing by integrating an Arduino-based IoT digital meter, while Sahani et al. (2017) further elaborates on the application of IoT, incorporating remote power disconnection and emergency control features for enhanced energy management. The Internet of Things (IoT) is a networked system enabling digital devices to communicate and exchange real-time data over the internet or specialized networks without human intervention (Aboelmaged et al., 2017; Manikandan et al., 2023; Sahani et al., 2017). Additionally, Patil and Limkar (2016) introduce a prototype system that uses machine-to-machine (M2M) communication and smart meters for real-time data collection, where consumption data is visually represented on a web platform for user accessibility, automating billing to increase efficiency. The work of Preethi and Harish (2016) describes a smart meter system with theft detection capabilities, leveraging Zigbee and GSM to transmit data and alert users of potential theft, while offering prepaid and postpaid billing flexibility. The article by Raji & Oladosu, (2024) focuses on Nigeria's shift from manual to electronic prepaid meters, highlighting how traditional billing faced issues like delayed readings and consumer confusion. The research of Phapale et al. (2024) expands the functionality of smart meters with an IoT-based system that prioritizes solar energy over the grid in

Bangladesh. It uses a microcontroller and mobile app to monitor energy usage, handle billing, and provide alerts for safety issues like gas leaks, aligning sustainable energy goals while also enhancing grid reliability and consumer empowerment. Furthermore, Al-khafaji et al. (2024) describe a smart meter for India utilizing an Arduino microcontroller and GSM technology, where AMR and real-time short message services (SMS) updates allow users and providers to manage power loads and billing, effectively reducing theft and operational costs. Article by Tripathi et al. (2024) details a wireless system using radio frequency identification (RFID) prepaid cards and machine learning for energy monitoring and theft detection. This system's use of wireless sensor networks (WSNs) and centralized data storage enables a reliable, internet-independent solution for efficient billing. The article by Abisheak et al. (2024) introduces an IoT-based system with continuous monitoring and alerts that optimize user consumption decisions. Together, these solutions represent a significant shift towards data-driven, user-centric, and automated energy management.

This study aims to design and implement IEBCIS that manages electricity usage effectively, visualizes consumption data, and optimizes billing processes. Key research objectives include creating a robust, user-centered platform for real-time electricity monitoring, designing an interactive dashboard to enable consumers to track their consumption patterns, and automating billing processes to enhance accuracy. The system supports both prepaid and postpaid models, integrates Business Intelligence (BI) tools to facilitate data-driven decision-making, and incorporates authentication mechanisms to detect energy theft and anomalies, thereby promoting secure, efficient energy management. The IEBCIS framework comprises four main features: (1) importing electricity consumption data; (2) generating billing statements; (3) visualizing electricity usage and providing a complaint portal; and (4) offering a knowledge repository portal for user education. Scalable and adaptable, this system aligns with evolving sustainability goals and can integrate with future energy management technologies. The paper is organized as follows: section 2 covers research material and methods, section 3 presents the results and discussion, section 3 presents the architecture and design planning of the IEBCIS, the final section provides conclusion and future work on electricity sustainability.

## 2. Material and methods

The time scope of this research spanned a six-month period, during which data was collected and analyzed to support the development and implementation of IEBCIS. The initial stages of the study involved a two-month phase dedicated to gathering baseline data on current electricity consumption, billing practices, and user interaction trends within the system. Following this, a three-month period was allocated to system design, prototyping, and iterative testing of IEBCIS to ensure functionality and adaptability within real-world scenarios. Finally, the last month was reserved for validating the system's efficiency, with targeted testing and feedback collection to evaluate user engagement, accuracy in billing automation, and monitoring capabilities. This timeline allowed for thorough examination and refinement of each phase, ensuring a comprehensive approach to addressing the study's objectives within a realistic timeframe. This study uses primary data. The data used to test the system, that is the data compiled in an excel file for electricity consumption and billing. Then the same data is then used to draw different graphs to help the users visualize their electricity consumption. The table compiled for the electricity consumption include date, time, consumption power per gour and relatively estimated bill, the total power consumption. Other data collected includes the use of questionnaires (Microsoft forms), interviews and system usage observations. The questionaries compiled for the user and electricity supplier were based on the research question, research objectives, system functionalities, gaps in the system to the traditional system, recommendations, etc. Consequently, the data collected regarding the system usage either by electricity customers and providers were gather based on system ease of use, security, etc. In this paper, we adopted the Design Science Research Methodology (DSRM) to guide the design and development of the IEBCIS [16]. DSRM is particularly well-suited for studies aiming to create innovative solutions to practical problems, as it provides a structured process for the design, development, and evaluation of technological artifacts. This methodology allows for the iterative refinement of the system based on feedback and evaluation at various stages. The comparison of the DSRM process used in this research with other traditional research methodologies is presented in **Table 1** below. Consequently, the steps particularly taken for design science methodology in the development of IEBCIS are presented in **Table 2** below.

**Table 1.** Comparison of DSR, DSRM to traditional research methodology.

| Aspects | Design Science Research Methodology (DSRM) | Design Science Research (DSR) | Traditional Research Methodologies |
|---|---|---|---|
| Purpose and Focus | Structured to create and evaluate artifacts that solve identified, practical problems systematically | Emphasis on artifact creation and problem-solving through iterative design and testing | Focused on explaining, predicting, or understanding phenomena |
| Process and Approach | Follows a structured framework: identify problems, define objectives, design artifacts, demonstrate, evaluate, and communicate | Iterative and solution-oriented; involves design, testing, and refinement | Linear, hypothesis-driven; follows stages of defining questions, data collection, analysis, and conclusion |
| Primary Output | An artifact that is rigorously evaluated for utility and effectiveness in addressing real-world issues | Practical artifacts (e.g., models, systems) evaluated for utility and effectiveness | Theoretical insights or explanations, often generalized to broader contexts |
| Evaluation Methods | Uses both formative and summative assessments, focusing on artifact utility, relevance, and rigor | Mixed methods, with focus on real-world application and artifact efficacy | Quantitative (statistical analysis) or qualitative (interpretive) methods, aiming for validity and reliability |
| Contribution | Practical contributions with a systematic approach to problem-solving, often adding to applied knowledge | Solution-focused, often resulting in innovations or improvements in practice | Primarily theoretical knowledge, contributing to understanding or general knowledge |
| Data Collection | Emphasizes methods suitable for artifact evaluation, such as case studies, experiments, or simulations | Mixed methods (quantitative and qualitative) to evaluate the designed artifact | Typically uses a single dominant approach (either quantitative or qualitative) depending on the paradigm |

Source: Adapted from Venable et al., 2017.

**Table 2.** Design Science Research Methodology (DSRM) process for the development of IEBCIS.

| Research Steps | Concerns | Output to Next Step | Entry Point? |
|---|---|---|---|
| Identify Problem and Motivation | Issues with electricity consumption inefficiency and billing accuracy. | Clear definition of electricity management challenges. | Understanding electricity inefficiencies and billing issues. |

| | | | |
|---|---|---|---|
| Define Objectives of a Solution | Develop a smart system to monitor, analyse, and optimize electricity usage. | Objectives for IEBCIS design to improve electricity management and user awareness. | Energy sustainability, cost reduction, real-time monitoring. |
| Design & Development | Architecture, components, and dashboard functionality design for the IEBCIS. | A functional prototype of the system including data visualization and smart metering features. | Technology requirements (smart meters, data analytics). |
| Demonstration | Demonstrating how IEBCIS can track electricity usage and generate billing information. | System tested with real data to ensure functionality and usability. | Test cases with electricity consumption and user data. |
| Evaluation | Analyse system performance in real-world scenarios for effectiveness and accuracy. | Evaluation of system efficiency, cost savings, and user satisfaction. | Feedback from users on system performance and reliability. |
| Communication | Share results with stakeholders, providing insights into system performance and future improvements. | Final report detailing system benefits and recommendations for further development. | Stakeholder engagement and publication of research. |

Source: Venable et al., 2017.

As indicated, the study applies DSRM to address inefficiencies, errors, and lack of real-time data in traditional electricity billing systems. Through an iterative process, DSRM allowed us to identify the problem, set targeted objectives, and create a responsive web-based platform that meets the needs of both electricity consumers and administrators. The developed platform enhances billing accuracy, security, and user engagement by providing real-time data access, monitoring, and visualization. Our primary research instruments included the dashboard itself, user feedback mechanisms, testing simulations, and system performance metrics, which were used to evaluate usability, security, and adaptability. The research process involved a simulated user base, representing various consumer categories and administrative roles, to test the system's functionality across different scenarios, replicating real-world diversity. This structured approach involved defining objectives focused on a secure and adaptable system, designing the dashboard with data visualization, authentication tools, and a feedback portal. Following initial demonstrations, the platform underwent iterative improvements based on user feedback and performance metrics, ensuring it met rigorous usability and security standards. While this simulated environment enabled effective testing, it introduced limitations, such as the inability to capture all potential variations in actual user behavior or high-traffic conditions. Addressing these limitations, future research should deploy the system in a live environment to gather comprehensive data from real users, thus enhancing the platform's utility across broader energy and utility management contexts. This iterative, feedback-driven approach not only resolves practical billing challenges but also establishes a foundation for future research into real-time data solutions in utility management.

The diagram in **Figure 2** gives a visualization of the security for log in described in the database structure. It illustrates the entities (objects or concepts) in our system or database, their attributes (characteristics or properties), and the relationships between these entities.

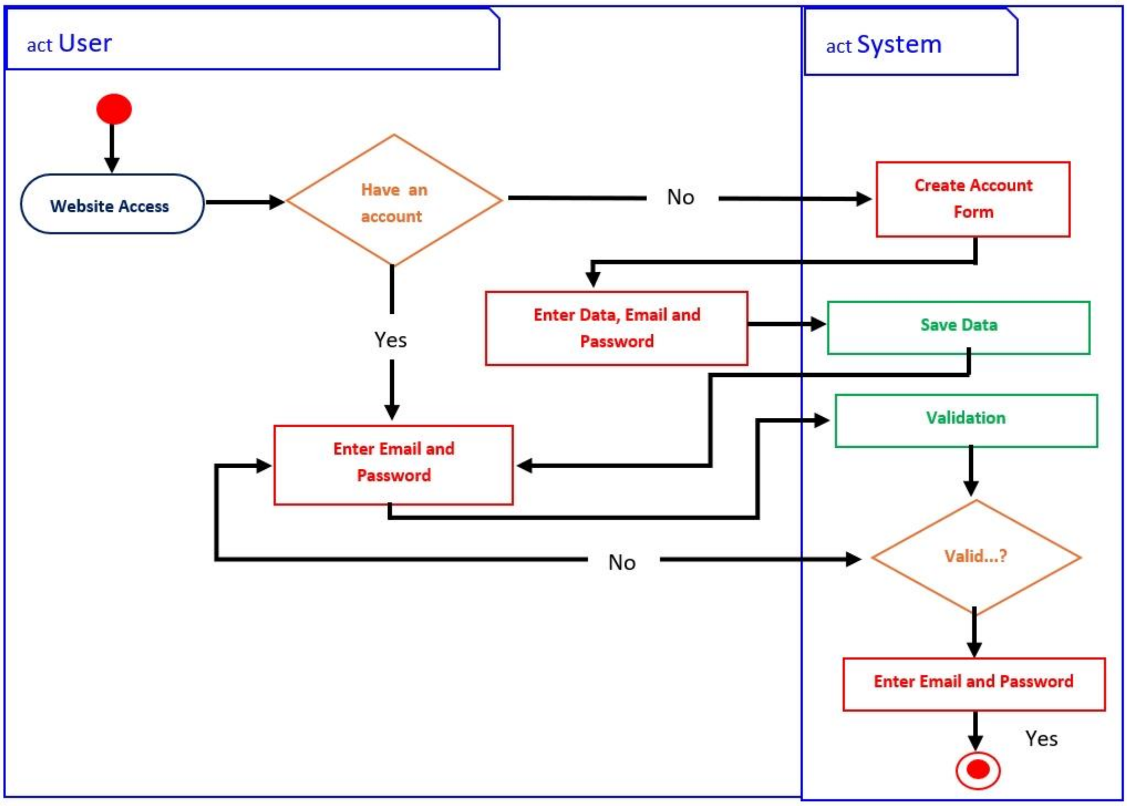


**Figure 2.** Entity-Relationship Diagram (ERD) showing login security.

Source: Authors' work.

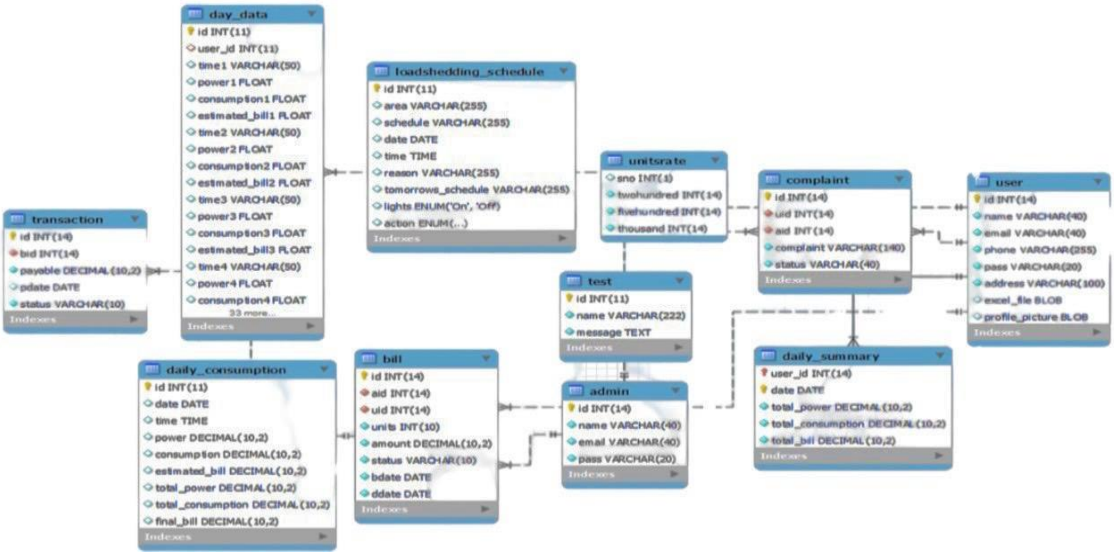


**Figure 3.** Entity relation diagram for user and admin.

Source: Authors' work.

The diagram in **Figure 3** shows the relationship between entities in the system and enable us to model and organize data effectively, reflecting the actual electricity management processes and ensuring robustness in our system. Furthermore, **Figure 4** depicts the Use Case Diagram, illustrating the interaction between a system and its external factors, such as users and administrators. This diagram outlines the system's functionality from the perspective of these actors, emphasizing how they interact with the system to achieve specific goals based on their level of access and capabilities.

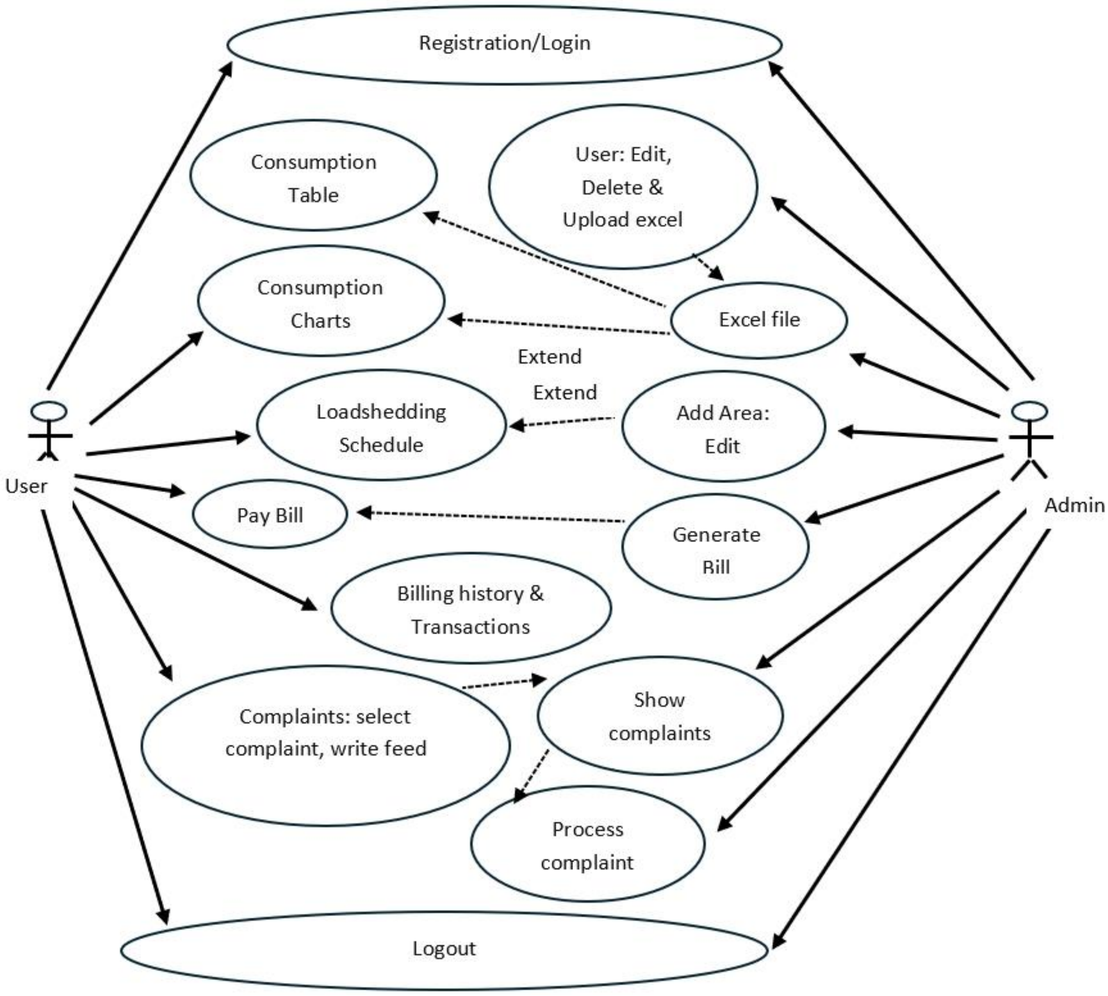


**Figure 4.** Use case diagram.

Source: Authors' work.

Thus, every two hours, a point is marked on the graph to show the user their exact electricity consumption for the preceding two hours. These points are then connected to one another to form a solid line, providing a clear understanding of the consumption pattern over time. Additionally, the bar graph is generated directly based on the user's electricity billing. It shows the detailed bill generated based on the user's electricity consumption every two hours.

**Figure 5** illustrates the structured operation of the user and admin login system through a graphical representation or activity diagram. The process begins with the initiation of the login process, indicated by a rounded rectangle, where the user or admin seeks access to the website's front page. The next step, represented by a decision point in the form of a diamond shape, is where the user or admin inputs their login details, such as their email address and password, if they have created their account before. If they do not have accounts, they proceed to the sign-up form to input their data, such as names, contact details, email addresses, and create their login password. After users have created and saved their details, they input their email addresses and passwords, and the system checks the validity of the provided credentials, as indicated by the blue rectangular box. The data is directly stored in the database, which is phpMyAdmin (XAMPP control panel) hosted locally in the system for development purposes. In case of invalid credentials (the "No" path), the system prompts the user to re-enter the correct email and password. This loop continues until the correct credentials are provided. If the credentials are correct (the "Yes" path), the system confirms the accuracy of the data from the database, grants access, updates session data, and directs the user to the appropriate dashboard or website content. Once the user or admin has successfully logged in, they can access various tabs, options, and data within the site based on their interests. The diagram serves as a visual representation of how our login system works, aiding in the implementation and testing of the login functionality to ensure data security and prevent unauthorized access.

## 3. Results and discussion

In addressing the primary aim of this research, we focused on developing IEBCIS not just as an artifact but as a solution to enhance the entire electricity billing and consumption management system. This approach aligns with Design Science Research (DSR) principles, which emphasize the importance of solving real-world problems through innovative solutions. To clarify the methodology employed during the testing phases, we established a structured approach involving several key steps. Initially, we conducted user testing sessions where participants interacted with the system, allowing us to gather qualitative feedback on usability and experience. The test incorporated quantitative metrics such as task completion rates and error frequencies to evaluate system performance. Additionally, security assessments were conducted to identify vulnerabilities, ensuring the integrity and reliability of the system. The results confirmed the effectiveness of IEBCIS in improving user experience and energy consumption management, as it addressed specific inefficiencies found in traditional billing systems. These findings are essential to demonstrate how the system answers the research questions (RQs) posed in this study. By implementing this rigorous testing methodology, we ensured that the outcomes of our research could be generalized and applied to broader contexts within the field of energy management, paving the way for further developments in real-time data solutions. This section presents key findings and discusses how the system addresses the research questions (RQs) posed in this study:

i. How does IEBCIS improve electricity monitoring and billing accuracy?
ii. What challenges does IEBCIS face in regions with electricity crises like South Africa?
iii. How does real-time data in IEBCIS influence consumer energy-saving behavior?
iv. What does security measures ensure the protection of consumer data in IEBCIS?

The answers to these research questions reveal IEBCIS's ability to significantly contribute to energy management solutions by providing accurate monitoring, addressing region-specific challenges, influencing consumer behavior through real-time data, and ensuring stringent data protection. Below is a detailed breakdown of the system's performance and features.

*(a) System performance and user accessibility*

The IEBCIS architecture was designed to be highly accessible across a variety of devices, including smartphones, tablets, and desktop computers, regardless of the operating system. This flexibility was integral to making the system more inclusive and widely available. During testing, the system handled multiple concurrent users without any significant decline in performance.

*(b) Admin portal capabilities*

The admin portal was designed to provide enhanced control and functionality for administrators. It allows them to manage user data, generate electricity bills, monitor load-shedding schedules, and handle user complaints. The portal's reporting capabilities enabled administrators to quickly access key data, improving operational efficiency. The feedback system, which allows users to submit anonymous suggestions, was instrumental in gathering user feedback for system improvements. This feedback loop ensured that the system could evolve based on actual user needs, contributing to the overall success of IEBCIS.

*(c) Electricity consumption and billing analysis*

One of the key features of IEBCIS is its ability to monitor electricity consumption and generate precise bills. The system utilizes real-time data collected from smart meters to calculate energy charges, any outstanding interest, and fixed monthly fees. The formulas presented in Equations (1)–(3), along with the data from **Table 2**, are used to compute the electricity usage and billing amounts. Based on these calculations, electricity consumption is visualized over time for different users, with various graphs generated to show how the system enables users to track their consumption patterns.

$$y = x \tag{1}$$

$$p = xh + i \tag{2}$$

$$f = p + m \tag{3}$$

*where:*

*y*—Current meter reading (Meter reading reported from last month's bill)

*x*—Total kWh used since last reading

*p*—Total energy charge

*h*—Charge per kWh

*i*—Outstanding interest (20%)

*f*—Final bill

*m*—Fixed monthly fees

*(d) Login security and access control*

Security was a key focus in the development of IEBCIS, particularly in relation to login and access control. The system implements robust security protocols, including the storage of user credentials in a secure local database (phpMyAdmin) to prevent unauthorized access. During rigorous testing, no security breaches were identified, demonstrating the system's resilience. Additionally, the system's functionality to loop back after incorrect login details further strengthens security, ensuring users can only access the platform after entering the correct credentials. The process for user and admin login is visually represented in the activity diagram in

**Figure 5**. This secure environment is vital for safeguarding sensitive user and billing information, which in turn helps establish trust between users and the service provider.

*(e) System limitations and areas for improvement*

Although IEBCIS achieved its objectives, there were some limitations that need addressing. The reliance on an internet connection poses challenges in areas with unstable network infrastructure, particularly in regions facing electricity crises like South Africa. A future version of the system could include offline functionality to ensure continuous access even during connectivity issues.

*(f) Discussion on system's impact*

IEBCIS has had a measurable impact on both user behavior and electricity management. By offering users detailed, real-time insights into their electricity consumption, the system encourages them to adopt more energy-conscious behaviors. The system's interactive features provide a seamless experience for both users and administrators. Administrators benefit from enhanced control and real-time reporting, while users gain transparent billing and secure access to their electricity data. Security measures, such as protected login systems, play a significant role in ensuring the protection of consumer data.

The IEBCIS system was successful in optimizing the user experience, providing accurate electricity billing, and promoting responsible energy consumption. While some challenges remain, such as internet connectivity and manual processes, the system's strengths in accessibility, transparency, and security make it a valuable tool for improving electricity management in the long term.

## 4. The architecture and design planning of the IEBCIS

The architecture of Intelligent-Electricity Consumption and Billing Information System (IEBCIS) plays a crucial role in effective energy management by facilitating data collection, analysis, and real-time monitoring. It supports the implementation of advanced features like demand response and energy forecasting, which help optimize energy usage and reduce costs. The system's architecture, as illustrated in **Figure 5**, comprises various components that work together to maximize its operational efficiency. For instance, the prepaid smart meter records a range of data, including electricity consumption, prepaid credit balance, meter readings, payment transactions, tariff information, load profile data, meter status, and communication logs. Data collection and processing are conducted in a real-time, with periodic updates to ensure accuracy. Specifically, data is collected continuously, with processing occurring at set intervals to facilitate timely analysis. The primary focus is on storing both historical data historical and current electricity consumption data, which is initially stored in an Excel file format. This data is then cleansed and structured according to a relational database schema, which is vital for efficient querying and reporting. The data is stored in a locally hosted XAMPP environment, utilizing a MySQL database to manage and structure the electricity consumption and billing data efficiently. This data is structured according to the database structure before being imported into the IEBCIS dashboard interface for visualization and analysis. The system features functionality allowing customers or users to upload Excel files themselves after requesting them from their electricity support agent. Alternatively, they can request the agent to upload and update their electricity data on their behalf. The uploaded file is stored directly into the database. Additionally, the electricity support agent or admin must implement security measures to protect customer data. This includes hashing login passwords, implementing adequate authentication measures, and ensuring the security of user electricity billing and consumption data. It is also important to monitor and secure all payment activities.

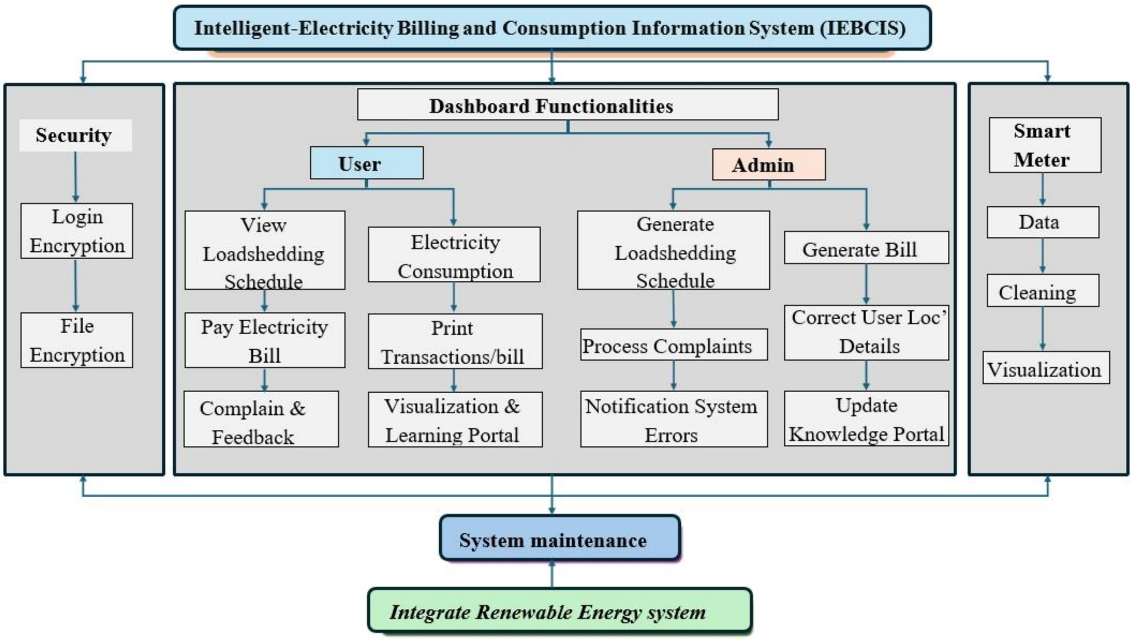


**Figure 5.** The IEBCIS Architecture.

Own source.

Consequently, the electricity support agents will need to continually test the system functionalities to ensure proper operation without errors. They should also regularly upgrade the system to enhance performance and flexibility based on their research findings and user feedback. Upon uploading the updated electricity data file, users should be able to view generated graphs based on the uploaded data through the user dashboard interface, which can be accessed by login into their accounts. This feature enables users to make informed decisions and adjustments to save costs effectively (Jing et al., 2022; Shahbaz et al., 2021). The electricity agents must ensure that every graph generated within the system is based on the data provided and is as accurate as possible. Additionally, they should provide user-friendly interfaces and clear instructions to help users navigate the system easily and understand the data presented in the graphs. **Figure 3** illustrates the functional features developed in the IEBCIS system. The service functions include uploading real-time electricity consumption, billing data and visualizing this information through various graphs, including bar charts for monthly usage and pie charts for usage distribution by appliances. This visualization aids in gaining insights into consumption patterns and enables informed decision-making to reduce electricity usage, helping users understand the impact of their habits on their overall bill. However, the system does not show user the consumption of each individual electrical appliance, which prevents users from understanding how each device impacts their total bill, limiting their ability to make targeted adjustments for cost savings. The load shedding functionality provides users with updated schedules of load shedding in their respective areas, which are maintained and updated by electricity professionals or agents. Users can view these schedules but cannot edit them. Additionally, the reporting functionality allows users to report issues and complaints directly to their electricity provider, facilitating prompt assistance. The knowledge repository feature assists users in understanding measures they can take to protect themselves from electrical hazards, save electricity, and make informed decisions. On the admin portal, electricity agents can view all user accounts created but cannot access their login passwords, ensuring security. Admins can also access all billing histories, generate user electricity bills, and view unpaid bills for transparency.

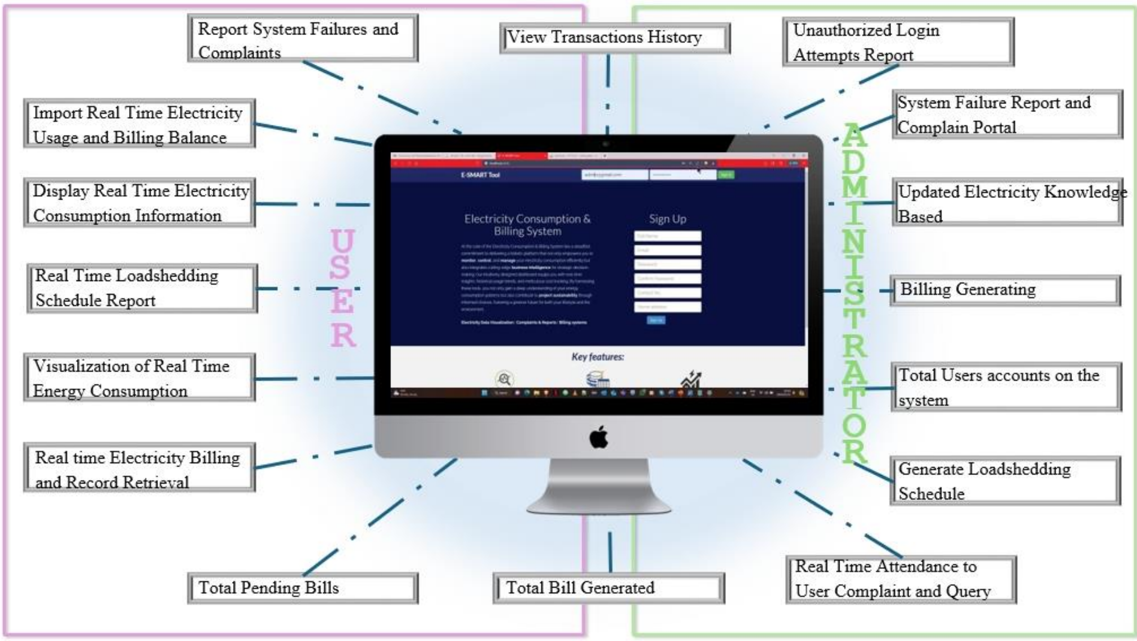


**Figure 6.** Design capabilities of IEBCIS system.
Own source.

The entire functionalities of the systems including various modules accessible found on the software are shown in **Figure 6**. They can also monitor user complaints, recommendations, and queries, addressing them promptly. Additionally, admins receive a report showing the number of unauthorized access attempts to the system, aiding in security improvements. **Figure 7** displays the front page of the website, where users can sign up or create their account to access the dashboard. The front page showcases key features of the dashboard, accessible after user login. Furthermore, the admin uses the same front page to access the administration portal. However, the user and admin dashboard portals differ significantly in terms of access control, security measures, performance, development and maintenance requirements, customizations, and auditability.

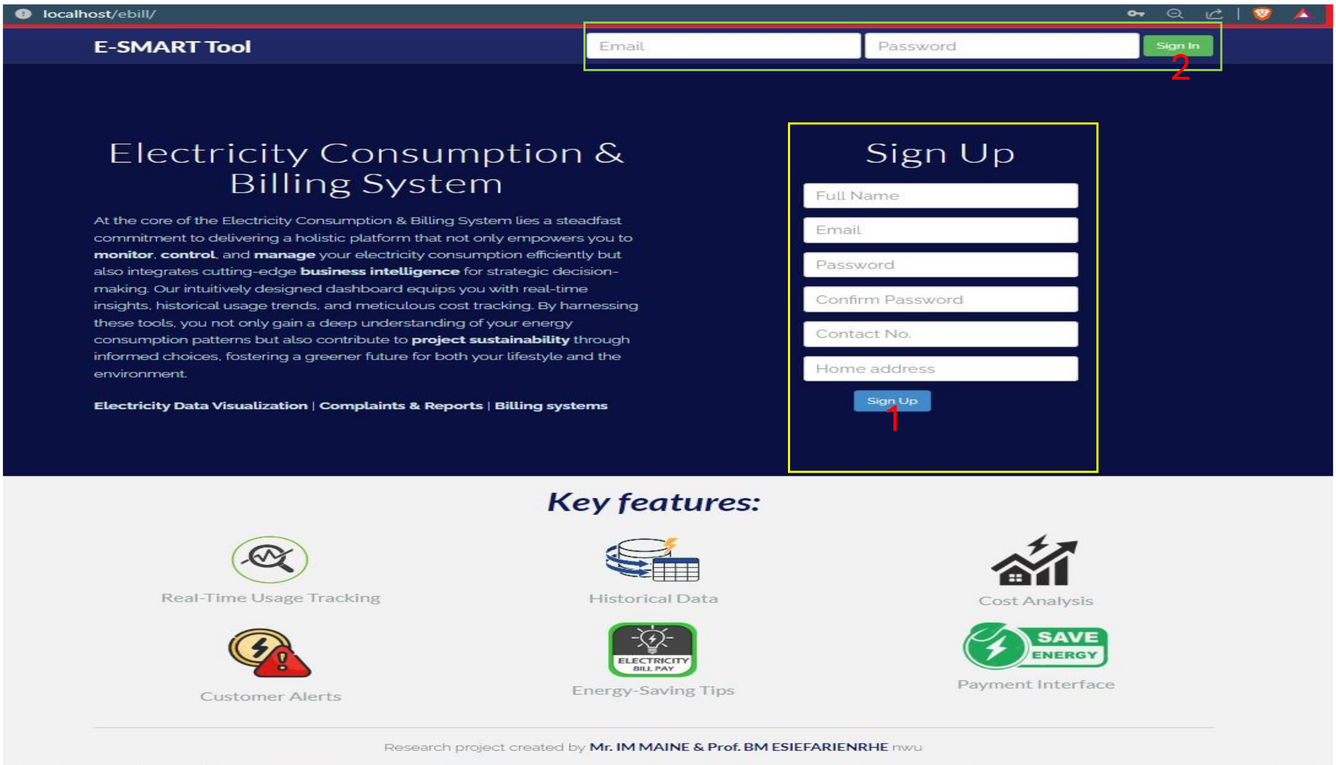


**Figure 7.** E-Smart tool login page.

Own source.

## 4.1. User and admin portals

Usability tests were conducted with users during the prototype development to ensure that the system's features met user needs effectively. These tests focused on evaluating the ease of navigation, accessibility of key features like data visualization, and overall user satisfaction. Feedback gathered from these sessions helped refine the user interface and enhance usability, ensuring that the final design was intuitive and met the intended functionality. The admin dashboard portal, depicted in **Figure 8 contains the system functionalities as viewed from the software and** offers more functionalities compared to the user dashboard portal shown in **Figure 9 which contains functions related to loadshedding**. Key features of both figures 8 and 9 include real-time report generation on electricity usage and billing history, along with a "Late Users" module that tracks both successful and failed login attempts, highlighting the system's robust capabilities to manage and monitor unauthorized access attempts effectively. Upon logging in, admins can view the number of users who have created accounts, total pending bills, total transaction amounts, number of bills generated, number of unprocessed complaints, and various attempts to log in to the admin portal. Additionally, admins have access to many more additional options. The admin dashboard includes a tab labeled "Customers", which displays a table containing user details such as names, email addresses, mobile numbers, and addresses. Administrators can edit, delete, and upload an electricity consumption Excel spreadsheet for each user. The data in the Excel spreadsheet comes from their different smart meters, which will be used to plot various charts and graphs in the user dashboard portal after they have logged in. The "Billings" tab in the admin portal contains billing history and an option to generate new bills for users. Administrators can generate electricity units for customers, view pending bills, and see bills processed by users. The "Complaints" tab displays a table of user complaints and includes an action column where admin can process (or close) the ticket or complaint after it has been attended to. Additionally, there is a button labelled "Show Anonymous Table", when clicked by the admin, displays a modal fade table containing anonymous messages or feedback from various users regarding portal improvement or other issues. The admin has the privilege to delete the feedback if they choose to do so. The "Loadshedding" tab consists of a table with various areas associated with their load shedding stage number, load shedding time, reason for load shedding, tomorrow's schedule (if available), a "lights" column indicating whether the load shedding is currently taking place (On) or not (Off), and an action column as shown in **Figure 10**. The action column allows administrators to edit the entire row of the area and load shedding schedule and includes a delete button to remove the area and its load shedding schedule. The table and its connectivity are clearly depicted in **Figure 3** and **Figure 4**. When users access their dashboard portal, as shown in **Figure 10**, they will see the information edited by the admin but displayed differently for user-specific needs. Upon logging in, users can view the number of their paid and pending bills, as well as the number of unprocessed complaints. They have the option to display their electricity consumption table (which does not show consumptions for individual electrical appliances), load shedding schedules, and electricity consumption charts. The electricity consumption table and charts are drawn based on the overall electricity consumption Excel spreadsheet uploaded by the user to their portal's database. Similarly, the load shedding schedule table, generated per area, is retrieved from the database as created by the admin in their dashboard portal. The "Consumption" button on the left navigation (Hamburger menu) displays additional graphs and charts related to electricity consumption. However, users are required to request the Excel sheet containing the data from the admin via email if they wish to upload and run the Excel generator algorithm themselves. The generated table will appear below the charts. The "Billing" tab contains billing history where users can view their pending and processed bills. The "Due" option shows users their electricity unit allocation by the admin, payable amount, initial bill date, due date, and includes a pay button for users to take action. The "Transactions" tab includes all historical billing and pending transactions. Users can simply click the print button to save or print this data.

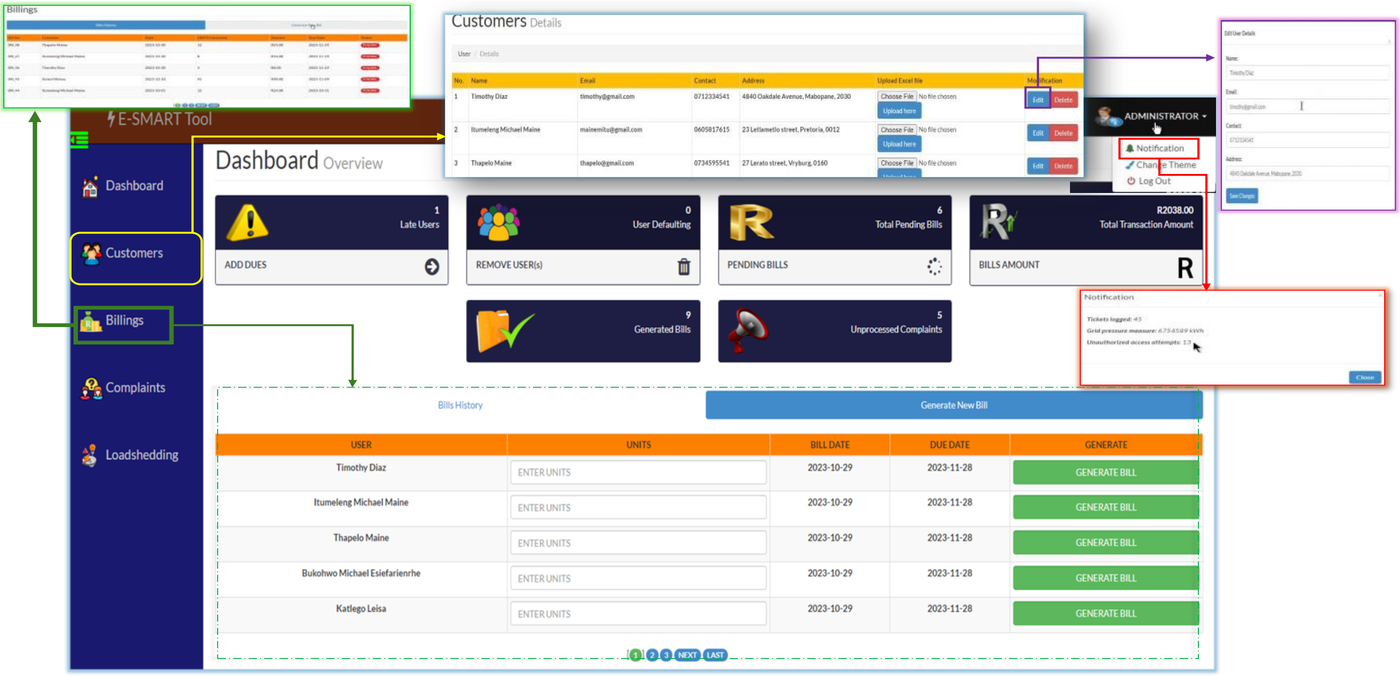


**Figure 8.** Admin dashboard portal.

Own source.

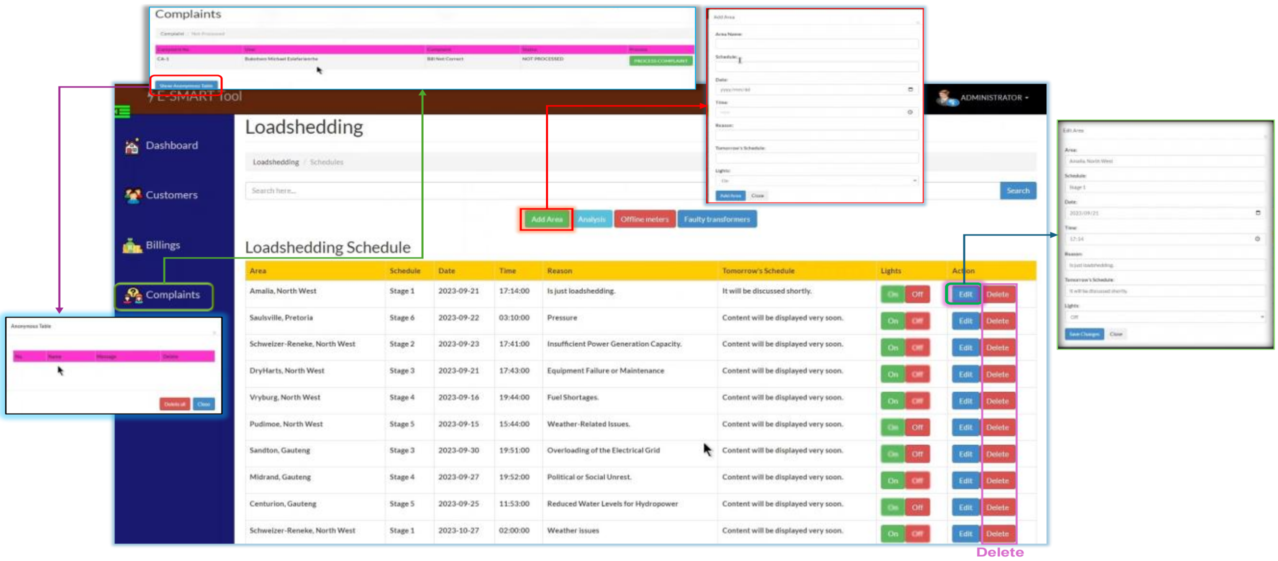


**Figure 9.** Admin loadshedding portal.

Own source.

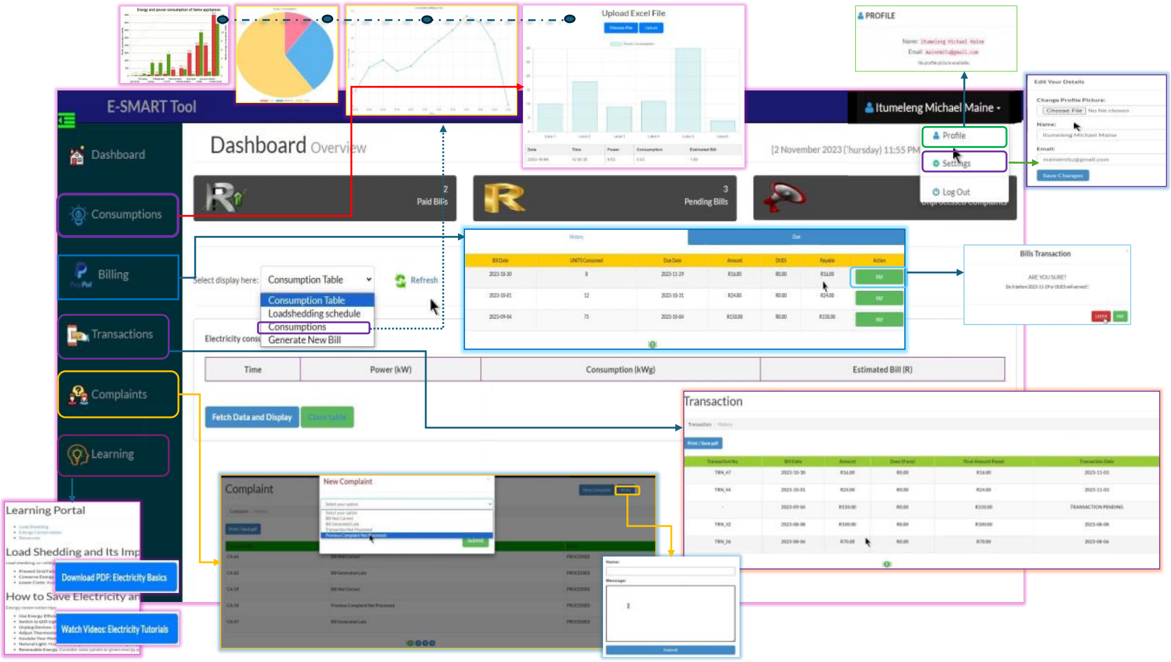


**Figure 10.** User dashboard portal.

Own source.

In addition, the "Complaints" tab in the user dashboard portal displays users' historical complaints and their status. Users can choose to log a new complaint to the administrator by clicking a button, or they can click the "write" button to compose a message, choosing whether to identify themselves or send the message anonymously. Lastly, the "Learning" tab contains various resources for users to learn more about electricity, including videos, PDFs, and reading materials available on the dashboard. In case a customer fails to settle their monthly electricity payments, a 20 percent interest will be added to their outstanding balance. However, if the customer does not have any outstanding balance, no interest will be added. Users can write a message to the admin requesting the Excel spreadsheet to be sent to them via email. This way, they can upload the file themselves in their consumption tab portal and generate the table and graphs independently.

## 4.2. Electricity usage visualization

**Figure 11** illustrates a screen displaying electricity usage graphs. These graphs are generated from the electricity consumption Excel file uploaded by the admin to the user's account.


**Figure 11.** Display of real time electricity consumption.

Own source.

The graphs depicting electricity usage are generated using mathematical models that consider variables such as electricity cost per kilowatt-hour, which varies among countries, as shown in **Table 3**. A comparative analysis of costs across regions like South Africa, the United Kingdom, Belgium, and the Cayman Islands highlights the regional influences on the economic aspects of electricity consumption. **Table 3** shows that electricity cost can varying significantly between countries hence the need to effective management principles should be applied. It allows them to understand and analyze the global diversity in electricity pricing, emphasizing its potential impact on the final billing amount and the broader implications for energy management strategies. In **Figure 11**, the electricity usage patterns are visualized through a variety of graphical formats that give users clear insights into their consumption. The pie chart illustrates power consumption within two-hour blocks (e.g., 12:00–2:00, 2:00–4:00, etc.), allowing users to observe energy usage distribution throughout the day. Meanwhile, the line graph presents hourly electricity usage trends (e.g., 1:00, 2:00, 3:00, and so forth), offering a detailed view of energy demand patterns at each hour. Additionally, a bar chart displays estimated bills over each two-hour interval (e.g., 12:00–2:00, 2:00–4:00), showing users how costs accrue across various times of day. These visualizations rely on parameters such as total kilowatt-hours used per interval, cost per unit of electricity, and peak/off-peak rates, providing users with a detailed, data-driven look at their energy consumption and cost impact throughout different periods. These graphical representations offer users with clear understanding of the relationship between their power usage and billing. By examining the pie chart, users can identify peak usage times and explore ways to enhance energy efficiency during those periods. The line graph provides insights into hourly consumption trends, empowering users to adjust their habits for cost savings. Additionally, the bar chart not only presents estimated billing amounts but also helps users recognize patterns in their billing cycles, enabling them to take proactive measures in managing and controlling electricity expenses.

**Table 3.** Electricity cost (p/kWh) by country and currency.

| Countries | Cost per kWh | Currency | Cost in Rands |
|---|---|---|---|
| South Africa | 1.16 | ZAR | **R 1.16** |
| Zimbabwe | 1.08 | Zim Dollar | R 0.05 |
| China | 0.530 | Renminbi | R 1.30 |
| United Kingdom | 0.1440 | Pound Sterling | R 3.14 |
| Kenya | 23.480 | Shilling | R 3.64 |
| Jamaica | 41.828 | Jamaican Dollar | R 4.65 |
| Brazil | 0.784 | Brazilian Real | R 2.43 |
| Argentina | 5.850 | Pesos | R 1.32 |
| Fiji | 0.1634 | Fijian Dollar | R 1.29 |
| Chile | 71.43 | Chilean Pesos | R 1.55 |
| New Zealand | 0.1688 | New Zealand Dollar | R 1.93 |
| Canada | 0.174 | Canadian Dollar | R 2.23 |
| Samoa | 0.79 | Tala | R 5.07 |
| Germany | 0.3043 | Euro | R 6.17 |
| Russia | 5.03 | Russian Ruble | R 1.14 |

Source: Based on reference (Prepaid, 2024).

## 4.3. Analyzing electricity usage and billing

Analyzing electricity usage patterns is a core functionality of the Intelligent-Electricity Consumption and Billing Information System (IEBCIS), providing valuable insights for users and administrators. The system utilizes advanced analytics capabilities to examine real-time electricity usage data. This analysis helps in identifying trends, patterns, and anomalies in electricity consumption, offering users a deeper understanding of their energy usage behavior. The data is compiled in the form there are structured in prepaid smart meter system. This process involves removing unnecessary columns of data from the excel spreadsheet, retaining only the relevant information for users and aggregating the data according to the customer database tables. This structured data is then used for analysis and visualization, enabling users and administrators to make informed decisions regarding energy consumption optimization. After the file is uploaded by the administrator into the dashboard, the system applies integrated equations based on the electricity cost shown in **Table 3**, according to the user's country cost.

## 4.4. Enhancing public awareness and engagement

Enhancing public awareness and engagement in energy consumption is equally a crucial aspect of the Intelligent-Electricity Consumption and Billing Information System (IEBCIS), contributing to sustainable energy usage practices. The system employs various strategies to achieve this goal. Firstly, it provides users with detailed information on their electricity consumption patterns through visualizations and analytics. By presenting data in an easily understandable format, such as charts and graphs, users can gain insights into their energy usage behavior. This transparency enables users to make informed decisions about their consumption habits and identify areas where energy-saving measures can be implemented. Additionally, the system offers tips and recommendations on energy-saving practices, further educating users on how to reduce their electricity consumption. The inclusion of educative videos and PDFs in the Intelligent-Electricity Consumption and Billing Information System (IEBCIS) significantly enhances its ability to promote public awareness and engagement in energy consumption. These educational resources serve as valuable tools for users to deepen their understanding of energy-saving practices and the importance of efficient electricity usage. The videos provide visual demonstrations of energy-saving techniques, making complex concepts more accessible and engaging for users. Similarly, the PDF documents offer in-depth explanations and guidelines on energy conservation, empowering users with knowledge to make informed decisions about their energy consumption habits. By incorporating these educational resources, the IEBCIS not only educates users but also encourages them to actively participate in energy-saving initiatives, ultimately leading to a more sustainable energy future. Furthermore, the IEBCIS promotes public engagement in energy-saving practices through interactive features and incentives. The system includes a feedback mechanism that allows users to provide suggestions, report issues, and engage in discussions about energy conservation. This fosters a sense of community involvement and encourages users to actively participate in energy-saving initiatives. Moreover, the system may offer rewards or incentives for users who demonstrate exemplary energy-saving behaviors. This gamification aspect can motivate users to adopt more sustainable practices and contribute to a collective effort towards reducing energy consumption.

## 5. Conclusion and future work

The Intelligent Electricity Billing and Consumption Information System (IEBCIS) embodies a transformative approach to electricity management, integrating sustainability principles and smart technologies to address the pressing global issues of rising energy demand, resource scarcity, and environmental impact. Unlike traditional systems reliant on manual meter readings and limited data insights, IEBCIS leverages real-time data analysis and historical usage tracking to provide users with actionable insights, fostering energy efficiency and sustainable practices. Distinguishing itself from existing solutions, IEBCIS offers an intuitive interface, educational resources, and customized recommendations, positioning it as a pivotal tool for both individual and societal energy conservation efforts. The primary objective of developing the IEBCIS as an effective, user-centric system for managing electricity consumption and fostering sustainable practices has been successfully achieved. Thus, the research has yielded valuable scientific contributions to the field, particularly in advancing knowledge on sustainable electricity management through intelligent systems. This framework incorporates data security measures, including encryption and access control, to ensure the confidentiality and integrity of user information. Its design emphasizes usability, scalability, resilience, and inclusivity, promoting broad accessibility and adaptability across various settings. Future iterations may incorporate machine learning to predict usage patterns, enhancing user engagement through proactive insights. Additionally, integrating real-time pricing information and demand response options will empower users to adjust consumption based on costs and availability, thereby increasing efficiency and cost-effectiveness. IEBCIS contributes to global sustainability goals by encouraging responsible energy use and reducing waste, thereby supporting climate change mitigation efforts. Future advancements may further include expanding IEBCIS to support renewable energy forecasting, extending multi-regional grid management capabilities, and enhancing visualization features for better user engagement. By adopting such innovations, IEBCIS aims to evolve into a comprehensive solution, enabling informed decision-making and contributing to a sustainable energy ecosystem.

**Author contributions:** Conceptualization, BME; methodology, BME and IMM; writing—IMM; preparation, IMM; writing—review and editing, BME and IMM; visualization, BME; supervision, BME; project administration, BME; funding acquisition, BME. All authors have read and agreed to the published version of the manuscript.

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