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Framework for Intelligent-Electricity Billing and Consumption Information System (IEBCIS)

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Abstract

The increasing demand for energy, coupled with the depletion of natural resources and environmental concerns, necessitates the adoption of sustainable energy practices. The use of electricity sustainability principles and smart meters data integration into energy systems plays a crucial role aiding electricity users make informed decisions about their energy consumption, driving sustainable energy practices and improving environmental stewardship. Despite efforts at electricity innovations, challenges persist in improving existing electricity frameworks, particularly in enhancing security and privacy measures, optimizing energy efficiency, improving user engagement and awareness, and addressing sustainability, scalability, interoperability, reliability and mounting environmental concerns and global warming issues. The integration of the principles of electricity sustainability and smart meter data into the development of a framework for Intelligent-Electricity Billing and Consumption Information System (IEBCIS) is crucial and an optimized approach to tackle these issues moving forward. Therefore, this paper presents IEBCIS framework that incorporated key aspects of electricity sustainability, interoperability, scalability, usability, reliability, security and privacy in the design of its framework. The Action Design Research (ADR) methodology using the pragmatism research philosophy was used to develop software prototypes to elucidate requirements for testing the framework. The result from the prototype showed significant potential to transform electricity billing and consumption practices by empowering users to make informed decisions about their energy usage, driving sustainable energy practices and improving environmental stewardship. Using the prototype, electricity consumers were able to access their smart data, query their electricity bills, simulate various electricity reduction best practices and view their total energy proposed savings in rands (South Africa currency). Ultimately, the IEBCIS framework achieved its aim of contributing to a more efficient and sustainable energy ecosystem, aligning with the global imperative for sustainable energy practices.

Keywords: IEBCIS; smart meters; energy sustainability; electricity consumption; electricity visualization.

1. INTRODUCTION

As the global community confronts the challenges of sustainability and energy efficiency, the Intelligent-Electricity Billing and Consumption Information System

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(IEBCIS) emerges as a promising solution. Consequently, smart meters play a crucial role in the proposed IEBCIS framework, significantly enhancing its functionality and effectiveness. These advanced meters enable real-time monitoring and measurement of electricity consumption, providing granular data that forms the foundation of the system's intelligence [1]. Smart meters facilitate the collection of detailed consumption data at regular intervals, allowing for the analysis of consumption patterns, peak usage times, and potential energy-saving opportunities [2]. Such data is instrumental in generating personalized energy management recommendations for users, empowering them to make informed decisions about their energy usage. One of the key challenges in the energy sector is the need to reduce energy waste and optimize consumption [2, 3]. By leveraging business intelligence (BI) in smart meters, an IEBCIS framework can provide real-time insights into energy usage patterns, helping consumers identify areas where energy efficiency can be improved. This approach is crucial in the context of climate change, as reducing energy waste can significantly reduce carbon emissions and contribute to global efforts to combat climate change. Additionally, the transparency and accuracy of billing provided by BI in smart meters are crucial in addressing issues of billing fairness and trust between consumers and utilities [1-4]. This is particularly important in regions where poverty is a concern, as accurate billing can help ensure that consumers are not unfairly burdened with high energy cost.

The rising concerns with traditional electricity management is rooted in the urgent need for sustainable energy practices and efficient electricity consumption management. Globally, the energy sector is confronted with challenges such as escalating energy demand, finite natural resources, and mounting environmental concerns [4]. In response, there is an increasing emphasis on adopting smart technologies, including smart meters, to optimize energy usage and enhance sustainability. Traditional electricity billing and consumption practices are often archaic and inefficient, relying on manual meter reading and offering limited insights into consumption patterns [2, 4]. This can result in billing inaccuracies, inefficient resource management, and higher costs for consumers. Moreover, the absence of real-time data and insights impedes efforts to promote sustainable energy practices and diminish environmental impact [5].

The aim of this research is to develop a framework that addresses electricity visualization challenges by providing real-time data on electricity consumption, empowering users to track their energy usage, identify inefficiencies, and make informed decisions to optimize their energy usage. Additionally, IEBCIS underscores compatibility, security, and privacy measures, ensuring a user-centric and sustainable approach. The aim of this research will be achieved using the following research questions: How can a framework for sustainable electricity be developed that integrates smart meter data for real-time monitoring and

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measurement of electricity consumption and how can the developed framework be evaluated for performance and as a proof of concept.

The rest of the sections are organized as follows: sub-section 2 gives a brief review of related literature, section 3 gives the methods used, section 4 discusses the results, section 5 concludes the research and gives future work.

2. RELATED LITERATURE STUDIES

The energy sector plays a critical role in driving economic growth and achieving sustainable development goals [6]. However, it faces the challenge of meeting increasing demands while striving for improved energy efficiency [3]. Figure 1 shows how the articles where selected to cover the reviews used in this paper. Smart grid technologies have emerged as crucial in optimizing energy efficiency, but their deployment poses challenges in addressing evolving consumer needs. The electric power systems worldwide are experiencing a notable shift driven by the growing digitization and integration of advanced technologies [1, 4]. This includes the utilization of wide-area monitoring systems (WAMS) and the integration of various renewable energy sources like solar and wind power. These developments introduce complex control procedures within the power systems [4]. Ensuring the reliability and stability of the electric power delivery infrastructure is critical due to the potential adverse impacts of disruptions on the economy, society, and environment. The authors in [7] highlighted the importance of comprehensive stakeholder engagement in project management to ensure successful project outcomes and sustainability. It emphasized that engaging stakeholders throughout all phases of a project is crucial to addressing unclear requirements and preventing project delays.

The approach outlines the need to consider the materiality, completeness, and responsiveness of stakeholder concerns, ensuring that relevant issues are identified and addressed effectively. This proactive engagement reduces risks, fosters collaboration, and enhances both the quality of deliverables and stakeholder trust, contributing to long-term project and organizational success. The authors in [8] examined the growing frequency and causes of power outages across the U.S. from 2015 to 2022, emphasizing severe weather events driven by climate change, human error, and system vulnerabilities as key drivers. It introduces a data visualization dashboard to analyze patterns and regional vulnerabilities, aiding decision-making for enhanced grid reliability and mitigating future outages. While the study provided valuable insights into managing power system resilience, its focus on the U.S. and reliance on historical data may limit its applicability to other regions or rapidly evolving technological contexts. In addition, [9] addresses the challenges of balancing energy consumption and generation in net zero energy buildings (NZEB), where mismatches arose due to consumer behavior and weather variations. The authors proposed a hybrid AI-based model, using ConvLSTM and

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BDGRU, to accurately forecast energy usage and generation. The model significantly reduced forecasting errors and offers a more precise system for managing energy in smart grids. However, the study focused on AI models for short-term predictions limiting its ability to address long-term power grid challenges, and its performance is influenced by data quality and environmental factors. Also, [10] presents a robust approach to addressing power loss in Tehran's electricity distribution network. By combining decision-making techniques such as DEMATEL and VIKOR, it effectively prioritized technical and non-technical factors influencing power losses. The integration of expert opinions via questionnaires added depth to the analysis, ensuring that the selected criteria are well-informed.

The structured methodology, utilizing both quantitative and qualitative data, enhances the research's credibility. Importantly, the study's real-world focus on improving operational efficiency makes it applicable for other regions with similar challenges in their power distribution systems. Consequently, study [11] investigates the impact of real-time energy dashboards on energy-saving behaviors among building occupants at four community college campuses in Illinois. Through a 6-week behavior change campaign, the study found significant energy savings (7–10% in electricity and 50% in natural gas) but minimal changes in occupant attitudes or behaviors. The intervention did, however, lead to improved facility management as building facility managers were able to detect and address system faults, enhancing energy efficiency. The study contributes to understanding the effectiveness of energy dashboards, suggesting that while they are beneficial for facility management, their impact on occupant behavior may be limited. Study [12], presents a design for a smart energy dashboard utilizing IoT to enable real-time remote control of electrical devices through mobile devices. The system is designed to address energy inefficiency caused by a lack of awareness and discipline in electricity use.

The proposed solution uses an ESP8266 MCU node, which connects to a Firebase cloud and controls electronic devices via a mobile application, allowing for automatic or remote operation. The system achieved high performance in usability (90.3%), functionality (85.8%), and reliability (90%), with efficient CPU and memory usage. The study concludes that the IoT-based smart energy dashboard is effective in controlling electrical devices remotely, improving energy management. Moreover, study [13] presents the NILM (Nonintrusive Load Monitoring) dashboard, a machine intelligence platform designed for real-time diagnostics of electromechanical systems using NILM data. This dashboard enables the monitoring of multiple loads downstream from a centralized point by disaggregating the operation of individual loads through signal processing, providing visual indicators of load activity and fault conditions. By networking various NILM devices, it offers a comprehensive view of loads on different electrical branches. The system's architecture is designed to handle large volumes

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of raw electrical data efficiently, offering real-time monitoring and diagnostics in an accessible format. Demonstrated on U.S. Coast Guard cutters, the NILM dashboard incorporates advanced algorithms and user-friendly interfaces to enhance energy management and prevent equipment malfunctions, addressing both technical challenges and user needs effectively.

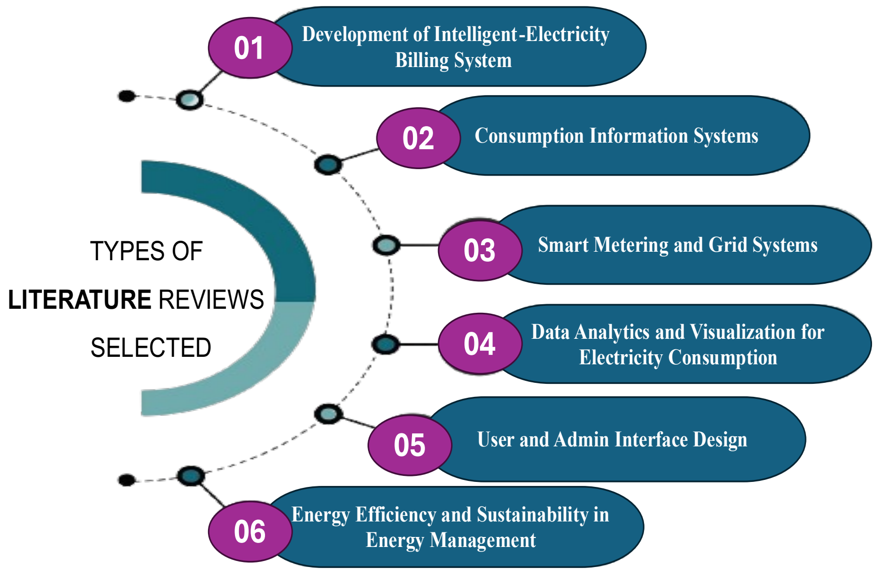

Figure 1. Types of IEBCIS related Literature Studies Reviewed.

Energy efficiency has emerged as a pivotal factor in the advancement of modern societies. The substantial energy consumption levels prevalent today have raised significant concerns, prompting all sectors to actively participate in reducing energy consumption and enhancing overall efficiency and productivity [2, 3]. The sustainability of a country's economy is directly linked to its energy dependence, necessitating the utilization of all available mechanisms to identify wastage and identify opportunities for energy conservation [1]. The prompt availability of operational data plays a critical role in identifying quality issues, bottlenecks, and process inefficiencies at an early stage [4]. Thus, [14] presented E²Home, a web-based application aimed at enhancing home energy efficiency by combining electricity consumption data with contextual information, such as the residents' locations. Using data fusion and visualization techniques, E²Home enables users to view their energy usage alongside their movement patterns, allowing them to make more informed decisions to reduce wasteful consumption. Built on the FuseViz framework, the application integrates electricity data from utility sources and location data from Android devices, visualizing them through interactive charts.

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3. METHODS

In developing the IEBCIS framework, this study utilizes the action design research (ADR) which is a research methodology that combines action research (AR) with design science research (DSR) resulting in a collaborative approach that is aimed at combining practical with theoretical knowledge to solving problems. The pragmatic research philosophy was adopted as we were more focused on the usefulness of our research outcome in solving electricity sustainability, interoperability, scalability, usability, reliability, security and privacy issues. The methodology is structured into four key stages: Problem Formulation; Building, Intervention and Evaluation (BIE); Reflection and Learning; and Formalization of Learning, as outlined in table 1**.** The aim is to address inefficiencies in current billing systems while enhancing sustainability and improving user engagement.

Table 1: Action Design Research (ADR) Framework for the Development of IEBCIS [16]

Stage	Activities	Principles
1. Problem Formulation	a) Identify research opportunities in IEBCIS inefficiencies. Various electricity billing models were studied from literature. Various electricity consumers and electricity staff of Eskom were consulted to investigate the present electricity billing systems and models used. Various literature on electricity billing systems were scooped and studied to identify research gaps and the contribution of authors over the past 10 years on electricity billing models and innovations. A systematic study was carried out to articulate these views and perspective on electricity consumption, billing and sustainability. These inquiries and exercises including clear problem formulation of sustainable electricity strategies were published (see [17]).	1) Practice-Inspired Research: Focus on real-world issues. 2) Theory-Ingrained Artifact: Link to theoretical frameworks.
2. Building, Intervention and Evaluation (BIE)	a. Set knowledge targets for efficiency and engagement. b. Customize design methodologies for user-centered development. CASE tools were used to diagrammatize the proposed solution, and a prototype	3) Reciprocal Shaping: Stakeholders feedback from review of the framework in prototype form was integrated into the system as an improvement.

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Stage	Activities	Principles
	was quickly developed for all stakeholders to criticize as a requirement elicitation strategy for the functional requirement while security, sustainability plan and visualization patterns were all agreed upon as part of the non-functional system requirement. c. Execute iterative design cycles based on user feedback. d. Determine need for additional design cycles.	4) Mutually Influential Roles: All framework as segmented as role based. Meaning, similar tasks were grouped as roles and roles were assigned to users such that they can collaborate in task execution 5) Authentic Evaluation: Framework was made available to stakeholders for evaluation and feedback was incorporated in the final product.
3. Reflection and Learning	- Reflect on design impact on user experience. - Evaluate adherence to design principles. - Analyze results against efficiency and engagement goals.	6) Guided Emergence: Use reflections to guide development.
4. Formalization of Learning	- Abstract insights into concepts for IEBCIS improvement. - Share findings with practitioners through publications. - Define design principles based on outcomes. - Relate findings to energy management theories. - Disseminate results through reports and articles.	7) Generalized Outcomes: Apply findings to similar issues.

At the Problem Formulation stage (as shown in Table 1), the research opportunity is identified by evaluating gaps in IEBCIS, especially regarding technology integration, user experience, and sustainability. Initial research questions were formulated to drive the development of a comprehensive framework. A review of the existing literature helps in uncovering research gaps in IEBCIS, while stakeholder involvement secures long-term commitment and defines roles clearly. Moving to the Building, Intervention, and Evaluation (BIE) stage, the focus shifted to incorporating various features as an entity, enhancing user engagement through a smart meter-based dashboard and improving operational efficiency. Design and development proceeded in iterative cycles, incorporating feedback from stakeholders and testing the system's performance using the framework prototype developed as an elicitation tool for stakeholders to criticize. These cycles ensure

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that the system evolves and responds to emerging needs, while evaluations are conducted to assess the effectiveness of each iteration. Moreover, in the Reflection and Learning phase, the research reflects on the design decisions made, ensuring they adhere to established principles. This stage also involves evaluating the system's performance based on pre-set goals, such as improving user experience and grid reliability. Insights from these reflections guide adjustments and refinements in the framework design. Finally, in the formalization of the learning stage, findings from the study are abstracted into broader concepts applicable to similar problems. Results are shared with stakeholders, and the design principles established during the research process are formalized and disseminated. These findings contribute to the body of knowledge in energy management and smart grid systems, with a focus on sustainability, usability, and technological integration. Methodology used in this study ensures that the research addresses practical challenges in electricity billing and consumption while contributing to both theory and practice. By applying the ADR frameworks, the study was able to develop a robust framework that is sustainable, scalable, user-friendly, optimizes electricity consumption and supports informed decision-making. These attributes

4. RESULTS AND DISCUSSION

The information in Figure 2 illustrates the three major goals for sustainable electricity development focusing on efficiency, grid reliability and resilience, data visualization and analysis. Efficiency is depicted as a foundational element of the framework, highlighting its fundamental importance. In terms of energy-saving features and user satisfaction, the performance of IEBCIS compares favorably to other electricity billing frameworks. Traditional systems often lack real-time data analytics and personalized feedback, while IEBCIS leverages smart meters and dashboards to provide detailed energy-saving recommendations (in the learning portal). This improves user satisfaction through better resource management and more accurate billing practices. Efficiency in electricity consumption is a critical aspect of sustainable energy development, encompassing several key strategies aimed at reducing waste and optimizing usage. The framework improves energy efficiency by providing real-time consumption data, personalized energy-saving recommendations, and smart meter monitoring. This helps users optimize their energy usage, while utilities can manage demand and enhance energy distribution, contributing to overall sustainability.

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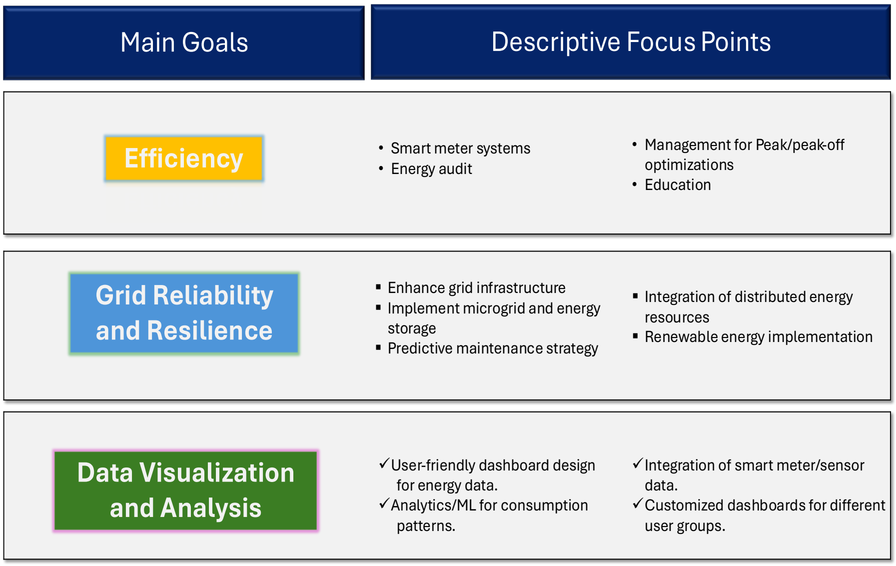

Figure 2. Integrated Framework Goals for IEBCIS development.

Smart meters, for instance, play a pivotal role in this endeavor by providing real-time data on consumption patterns and providing a wealth of data leveraged to enhance sustainability, improve operational efficiency, and reduce costs [4]. Research by [4], demonstrated that smart meter data enables more accurate monitoring of energy consumption patterns, leading to better resource management and reduced wastage. Additionally, smart meters facilitated the implementation of demand-side management strategies, allowing for the optimization of energy use during peak and off-peak hours. By leveraging smart meters, consumers and utilities companies (UC) can identify areas of inefficiency and take proactive measures to improve overall energy efficiency [8].

Smart meter's ability to store historical data supports long-term trend analysis, ensuring accurate billing, and recording load shedding information, essential for user preparedness [4, 8]. Additionally, smart meters offer insights into time-of-use patterns and users' behaviors, facilitating personalized energy-saving recommendations and contributing to sustainability goals [4]. Some of smart meters providing data on the environmental impact of electricity consumption, such as the carbon footprint, empowers users to make environmentally conscious decisions, [10] enhancing user experience and sustainability efforts, demonstrating commitment to efficient resource management and customer satisfaction while aligning with industry trends and best practices in energy management. Energy audits are another essential component of the efficiency goal, offering a comprehensive assessment of energy usage within a given environment [10, 11]. These audits help identify areas where energy is wasted or used inefficiently,

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providing valuable insights for implementing energy-saving measures. By conducting energy audits, stakeholders can pinpoint specific areas for improvement, such as upgrading to more energy-efficient appliances or improving insulation to reduce heating and cooling costs [7].

Furthermore, energy audits can help raise awareness about energy-saving practices among consumers and encourage the adoption of more sustainable habits. Demand-side management (DSM) strategies are crucial for optimizing energy use and reducing overall consumption. DSM involves implementing various measures to shift or reduce energy demand during peak periods, when electricity prices are typically higher. This can include incentivizing consumers to use energy-intensive appliances during off-peak hours, implementing time-of-use pricing, or deploying technologies that allow for more efficient energy use. By effectively managing demand, UC can reduce the need for costly infrastructure upgrades and ensure a more stable and sustainable electricity grid [9-11]. Overall, these strategies under the efficiency goal are instrumental in promoting sustainable energy consumption practices and reducing the environmental impact of electricity generation. Another major aspect is grid reliability and resilience which is very crucial to ensuring a stable electricity supply, particularly in the face of increasing environmental challenges and the growing complexity of the energy landscape [14].

Enhancing grid infrastructure is a foundational step in improving reliability, involving the modernization and reinforcement of transmission and distribution networks. This includes upgrading aging infrastructure, integrating advanced grid technologies, and implementing smart grid solutions. By enhancing grid infrastructure, UC can reduce the frequency and duration of power outages, improve system flexibility, and enhance overall grid performance [7, 14]. Implementing microgrids and energy storage solutions is another key strategy for enhancing grid reliability and resilience [9, 17]. Microgrids are localized energy systems that can operate independently or in conjunction with the main grid, providing backup power during grid outages.

Energy storage systems, such as batteries, can store excess energy generated from renewable sources and release it when needed, ensuring a more stable and reliable electricity supply [10]. By deploying microgrids and energy storage solutions, utilities can improve grid resilience, reduce dependency on centralized power sources, and enhance energy security. Predictive maintenance strategies play a crucial role in ensuring the reliability and resilience of the grid by identifying potential issues before they escalate [9, 12]. By leveraging data analytics and predictive maintenance tools, UC can monitor the health of grid assets in real-time, detect anomalies, and schedule maintenance activities proactively. This proactive approach to maintenance helps reduce downtime, minimize the risk of equipment failures, and optimize the performance of grid infrastructure. By integrating predictive maintenance strategies into grid operations, UC can improve overall grid

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reliability and resilience, leading to a more stable and efficient electricity supply [8]. Lastly, we have the most important aspect which is data visualization and analysis that plays a pivotal role in optimizing energy consumption and improving decision-making in the electricity sector. User-friendly dashboard design for energy data is essential for providing consumers and stakeholders with clear and accessible information about their energy usage [7].

These dashboards present energy consumption data in a visually appealing and easy-to-understand format, enabling users to monitor their usage patterns, identify inefficiencies, and make informed decisions to reduce energy consumption. By designing user-friendly dashboards, UC can empower consumers to take control of their energy usage and contribute to overall energy efficiency efforts. The dashboard serves as a crucial interface for users, enabling them to interpret complex data in a user-friendly manner. By integrating smart meter data into the dashboard, users can track their energy consumption patterns, identify inefficiencies, and make informed decisions to optimize their energy usage [10]. Customized dashboards for different user groups are essential for tailoring information to meet the specific needs and preferences of different stakeholders [7]. For example, consumers may require simple, easy-to-understand dashboards that provide basic information about their energy usage and cost. Moreover, the UC managers may need more detailed dashboards that provide in-depth analytics and insights into grid performance and efficiency [11]. By customizing dashboards for different user groups, UC can ensure that stakeholders have access to the information they need to make informed decisions and drive energy efficiency initiatives forward.

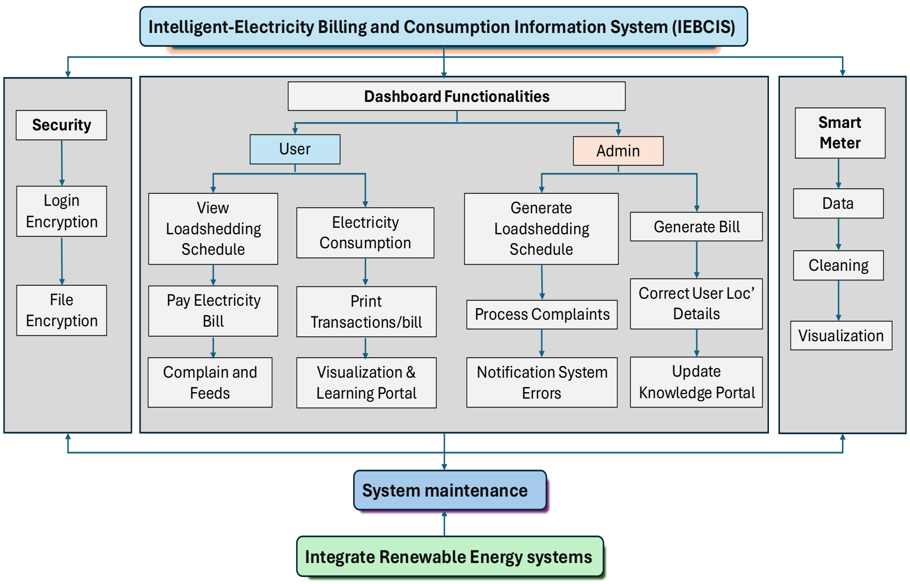

Figure 3. The Main Framework for IEBCIS in this Study

The IEBCIS framework as shown in figure 3 implements robust measures to protect sensitive user information and maintain the integrity of the platform. Data encryption is employed during transmission and storage to safeguard against unauthorized access, a practice supported by [4, 15]. Privacy is a top priority in the framework, with stringent measures in place to protect user data as there are multiple authentications required to access any system functionality.

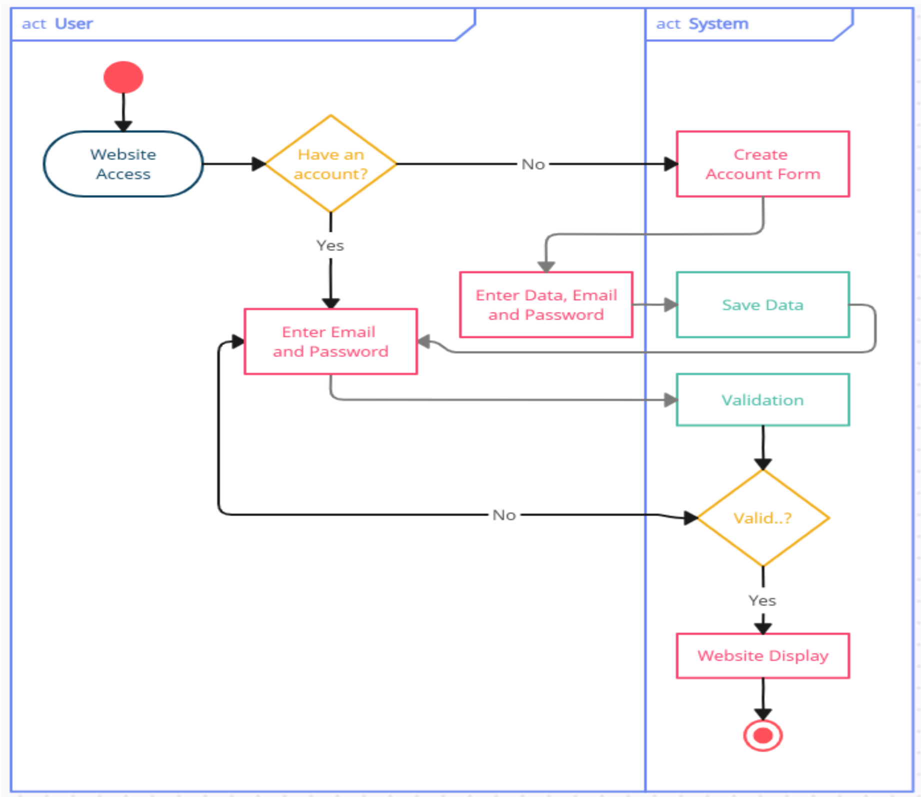

Figure 4. Activity Diagram for User and Admin Login

Data anonymization techniques are applied to protect user identities, especially when users submit complaints or feedback [4]. Users have control over their electricity consumption data, by allowing them to request such data for upload into the system to generate personalized consumption graphs. Additionally, access controls and authentication processes are in place to ensure that only authorized individuals can interact with the platform, minimizing the risk of data breaches and unauthorized access as shown in figure 4. These compatibility, security, and privacy measures collectively ensure that users can access and use the platform effortlessly, that their data remains secure and protected, and that their privacy is respected and upheld throughout their interactions with the system. This comprehensive

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approach aligns with best practices in energy management systems, as highlighted by [3] and ensures that the platform meets the highest standards of usability, security, and privacy. By prioritizing these aspects, the framework enhances user trust and satisfaction, ultimately contributing to the adoption and success of sustainable energy practices. The system architecture in figure 5, outlines the route and shows different portal for end users and administrators and their interactions with the webserver and the database which are locally hosted.

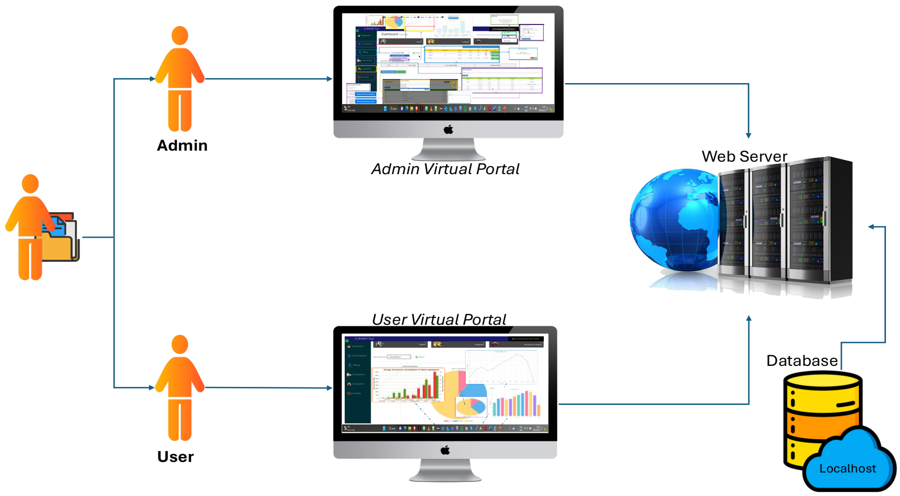

Figure 5. System Architecture Representation for the IEBCIS.

Studies have shown that effective data management is essential for the success of similar platforms, as it enables the platform to deliver reliable and timely information to users [15]. By implementing best practices in data management, such as data cleansing, normalization, and encryption, the framework provides users with a secure and reliable platform for managing their electricity consumption. The metering unit is the core component responsible for measuring and recording electricity consumption, while the communication module enables data transmission to the UC and receives remote commands or updates. Smart meters also include a processor and memory unit for data processing, storage, and firmware updates. Smart meters require a power supply, often powered by the electricity they measure, with backup batteries for continuous operation during power outages. Data accumulation and storage capabilities allow smart meters to store consumption data at regular intervals for transmission to the UC for billing and analysis purposes. Metering hardware constitutes the core components of the framework responsible for accurately measuring electricity consumption, comprising several critical elements; current transformers (CTs) and voltage transformers (VTs) are fundamental in metering electricity, with CTs measuring current and VTs measuring voltage, crucial for calculating power consumption

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accurately. CTs act as sensors measuring current flow through a conductor, while VTs measure voltage levels, enabling real-time power consumption determination. The register, integrated within the smart meter, maintains a cumulative record of energy consumption, continually adding up usage over time and typically displaying data in kilowatt-hours (kWh), essential for accurate billing and load management. At the heart of the smart meter is the processor unit responsible for data processing and communication. It calculates real-time power consumption, manages data storage, and ensures seamless data transmission to UC or other authorized entities, handling the meter's core functions efficiently. Communication hardware in a smart meter enables it to transmit data to utility companies and other relevant entities, comprising several key components [2, 4]. The modem or communication module allows smart meters to establish communication links using various technologies like cellular networks, powerline communication, radio frequency, or wired connections, serving as the gateway for transmitting data accurately and in a timely manner. The antenna or transceiver component enables wireless communication between the smart meter and external devices, including data concentrators and central servers, ensuring seamless and reliable data transmission, supporting the integration of the smart meter into the larger grid management system. Smart meters typically use flash memory as non-volatile memory to store historical consumption data. This memory type retains data even when the meter is not powered, ensuring that historical consumption records and other critical configuration information remain intact. Temperature sensors, for example, continuously monitor the meter's operating environment. Temperature data is valuable for assessing the meter's health and performance, as temperature fluctuations can indicate issues or potential maintenance needs. This information is crucial for ensuring the meter operates optimally and maintains its accuracy.

4.1. Design Principles for the IEBCIS Framework.

Several key design principles were considered to ensure its effectiveness and viability in the design of IEBCIS framework as shown in figure 6. Firstly, interoperability is paramount, ensuring that the framework can seamlessly integrate with existing infrastructure and technologies. This facilitates compatibility between different systems and promotes collaboration among stakeholders. Secondly, scalability is essential to accommodate future growth and expansion. The framework should be flexible enough to adapt to changing needs and requirements, allowing for the addition of new features and functionalities over time. Thirdly, usability was crucial to ensure that the framework is accessible and intuitive for users. A user-friendly interface and clear documentation are essential for promoting adoption and minimizing user errors. Fourthly, reliability and resilience are fundamental aspects of the framework, ensuring continuous operation and minimal downtime. Robust backup and failover mechanisms was incorporated to mitigate the risk of system failures or disruptions. Consequently, sustainability was the guiding principle in the design of the framework, promoting

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energy efficiency, resource conservation, and environmental stewardship. Lastly, security and privacy are critical considerations in the design of the framework. Strong encryption, authentication, and access control mechanisms was incorporated to protect sensitive data and prevent unauthorized access. Compliance with data protection regulations and standards is essential to safeguard user privacy and ensure trust in the system. By adhering to these design principles, the IEBCIS framework has effectively address the challenges and complexities of modern energy management while promoting sustainability and resilience.

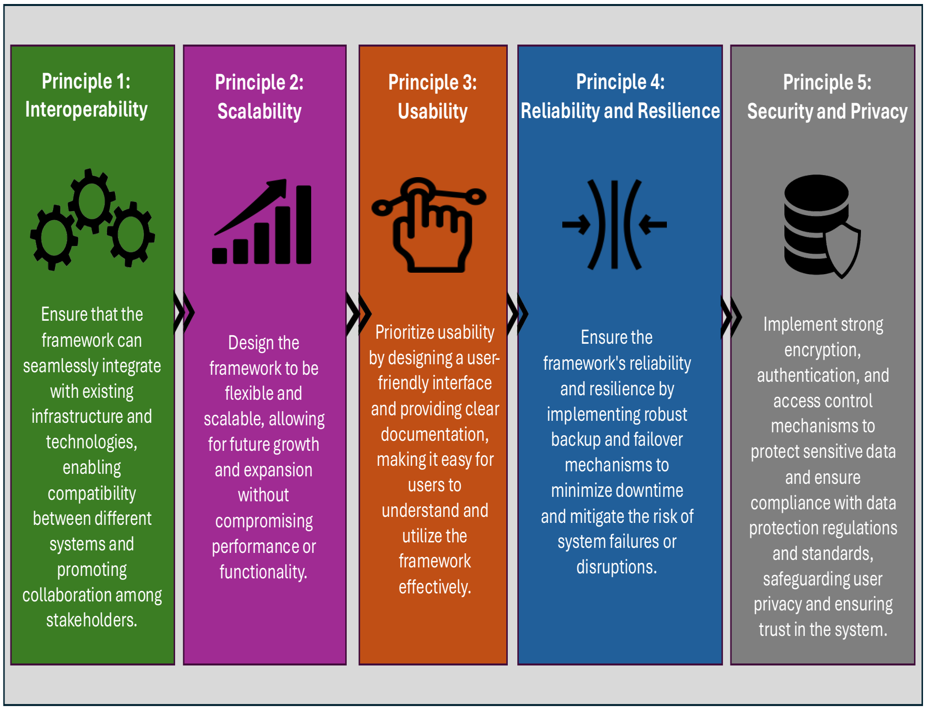

Figure 6. Five Design Principles for the Intelligent Electricity Framework.

4.2 The Electricity Framework Description

In developing the IEBCIS framework, our approach was rooted in the goal of creating a sustainable and efficient system for electricity billing and consumption information. We outlined a comprehensive framework for intelligent-electricity billing systems and its three building blocks descriptions as shows in figure 7. This building blocks enable the integration of machine learning algorithms to predict future electricity consumption patterns, leading to a reduction in billing errors and improved customer satisfaction when using system.

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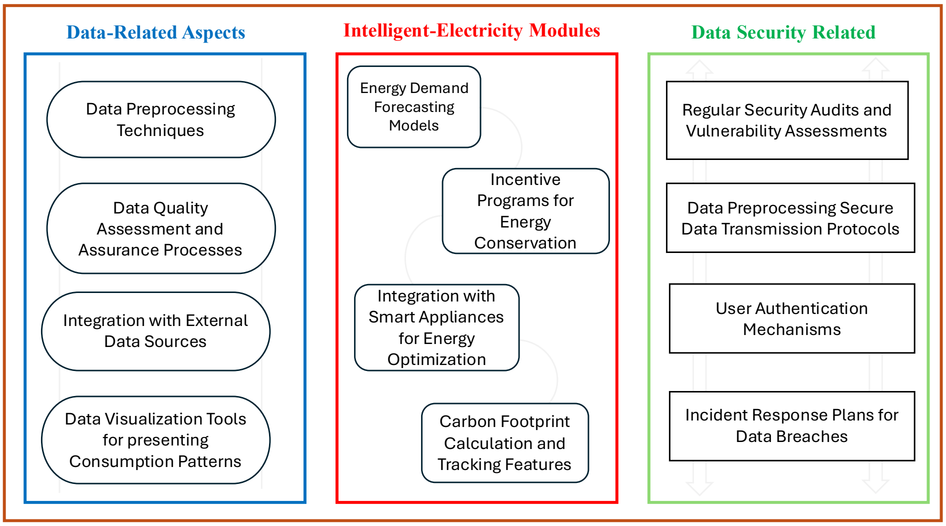

Figure 7. Three Building Blocks Descriptions of IEBCIS framework

a) Data-Related Aspects

The data-related aspect of our framework focuses on the collection, management, and analysis of electricity consumption data. We implement advanced data analytics techniques, including clustering and regression, to analyze consumption patterns and identify opportunities for optimization. By leveraging big data technologies, such as data mining, we can process large datasets efficiently and extract valuable insights that inform decision-making [4]. Additionally, we prioritize data quality and integrity, ensuring that the data used in our analysis is accurate and reliable.

b) Intelligent-Electricity Modules

The modules in the IEBCIS framework are aimed at promoting energy efficiency and renewable energy integration within the framework. We incorporate modules that allow users to monitor their energy consumption in real-time and receive personalized recommendations for reducing energy usage. Additionally, we integrate renewable energy sources, such as solar and wind power, into the framework to reduce reliance on traditional energy sources and minimize carbon emissions. By promoting sustainable practices, our framework contributes to a greener and more environmentally friendly energy ecosystem.

c) Data Security Related

Data security is a critical aspect of IEBCIS framework, given the sensitive nature of electricity consumption data. We implement robust data protection measures, including encryption, access control, and secure data storage to ensure the confidentiality and integrity of the data. Additionally, we adhere to strict data

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privacy regulations and standards to protect user information from unauthorized access or disclosure. By prioritizing data security, IEBCIS framework build trust and confidence among users and stakeholders in the electricity industry.

5. CONCLUSION AND FUTURE WORK

The IEBCIS framework represents a transformative approach to electricity billing and consumption management, driven by the imperative of sustainable energy practices. The global energy sector faces significant challenges, including escalating energy demand, finite natural resources, and mounting environmental concerns. In response, smart technologies, including smart meters, are increasingly adopted to optimize energy usage and enhance sustainability. The IEBCIS framework we developed in this study integrated principles of electricity sustainability and smart meter data that addresses the challenges of sustainable energy consumption and usage visualization. Traditional electricity billing and consumption practices are often archaic and inefficient, relying on manual meter reading and offering limited insights into consumption patterns. Prerequisites for addressing sustainable IEBCIS include a robust smart meter infrastructure, effective data management and analysis, user engagement and education, identifying inefficiencies, regulatory and policy frameworks, privacy and security measures. Design principles for our framework emphasize interoperability, scalability, usability, reliability and resilience, sustainability, equity and inclusivity, and security and privacy. The data-related aspects focus on the collection, management, and analysis of electricity consumption data, while the intelligent-electricity modules promote energy efficiency and renewable energy integration.

By providing real-time data insights, enhanced billing fairness, and tools for optimizing electricity consumption, IEBCIS empowers users and utilities to make more informed decisions, directly contributing to energy efficiency and cost savings. On a broader scale, this system aligns with global sustainability goals by promoting responsible energy usage and reducing waste, thus helping mitigate the impact of climate change. Furthermore, the IEBCIS framework has the potential to be applied in various sectors beyond residential electricity, including industrial and commercial energy management, where energy efficiency and cost control are equally crucial. The literature review highlights significant insights from previous studies, and the research design outlined in this study focuses on investigating the utilization of smart meter systems in the context of project sustainability. By conducting a systematic literature review, we identified research gaps in IEBCIS, developed a novel framework integrating project sustainability and business intelligence, and proposed methods to evaluate the developed framework. Data security measures, including encryption, access control, and secure data storage, are implemented to ensure the confidentiality and integrity of the data. Therefore, the development and implementation of IEBCIS have the potential to promote sustainable energy practices and enhance environmental stewardship. By

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integrating principles of electricity sustainability and smart meter data, IEBCIS can empower users to make informed decisions about their energy usage, leading to a more efficient and sustainable energy ecosystem.

In future, we will implement the framework using Object-oriented tools and integrate deep learning algorithms to enhance remote unstructured and non-textual data capture. Consequently, future research directions will also include integration renewable energy forecasting and expanding IEBCIS requirement to handle multi-region electricity grid, improving data visualization features and integrating the system with smart home devices.

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