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A Conceptual Framework for the Adoption of IoT in the Energy Sector: Technology-Organization-Environment Framework Approach

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Abstract- The major role played by Internet of Things (IoT) in the energy sector cannot be overemphasized. Its application encompasses the development of smart grid, development of electric buildings and integration of grid and renewable energy such as wind turbines, solar panels, hydropower systems, and photovoltaic cells. However, amidst of all these prospects lie some pressing challenges facing the application of IoT technology in the energy sector. This work studied on the recent prospects of IoT in the energy sector and its challenge. Recent works related to the study have it that the most pressing challenges facing the application of IoT in the energy sector are the adoption and the security issues. It is on this light that the work has proposed a conceptual framework using the Technology-organization-environment framework for a sustainable application of IoT in the energy sector in future. Some recommendations for leveraging IoT in the energy industry are also stated in the work.

Keywords: IoT, prospects of IoT in energy sector, challenges of IoT in energy sector, Technology-organization-environment framework, energy sources, future of IoT in energy sector.

I. Introduction

The energy sector in Africa faces unique challenges and opportunities. Many countries such as in sub-Saharan Africa have limited access to electricity, with significant portion of the population relying on traditional and inefficient energy sources such as biomass and kerosene. However, there is great potential for renewable energy sources such as solar, wind hydroelectric power. [1]. There has been a growing rate of awareness in terms of climate emergency and how energy production and consumption influence it. The search for renewable or non-renewable energy sources has an impact on the environment. Owing to the unreliable nature of renewable energy sources, harnessing renewable energy is noted to be challenging. One of the major challenges in the energy sector in Africa is the lack of infrastructure, especially in the areas. Building and expanding energy grid can be costly and logistically challenging. [2]. The relationship between energy and economic growth is complex and multifaceted. Energy is a critical input for economic activities and is essential for driving industrial production, transportation, and powering homes and businesses. As a result, access to reliable and affordable energy sources is often seen as a key for economic development and growth. Historically, countries with abundant and affordable energy sources have experienced higher rates of economic growth in recent times. This is because energy-intensive industries, such as manufacturing and construction, require significant amounts of energy to operate efficiently. Additionally, access to modern energy services, such as electricity, enables the development of various sectors, including healthcare, education and communication, which further contribute to economic growth. However, the relationship between energy consumption and economic growth is not linear. [3]. As economies develop and become more efficient in the usage of energy, they can achieve higher levels of output with less energy consumption. Technological advancements, improved energy management practices, and shifts towards cleaner and more sustainable energy sources can influence the energy-growth relationship.[4]. The role of IoT technology in the energy sector cannot be overemphasized. Internet of Things (IoT) is a new paradigm in the area of smart energy system. [5].

When applied to renewable energy, IoT has the potential to greatly impact the renewable energy sector. [6]. The IoT is defined as the emerging computing technology and a network of intelligence that bridges various devices and systems located in remote locations together by means of cloud portal. [7]. IoT has also been defined as the network consisting of physical devices embedded with electronics, software, sensors and network connectivity which enables the devices to collect as well as exchange data. [8]. In Africa, IoT is rapidly gaining momentum in South Africa, Ghana, Kenya and a host of others in various industries such as transportation, energy, education, agriculture, healthcare and climate. One of the major drivers of IoT is the increasing availability of affordable internet and mobile connectivity which is enabling most people to access the internet and has in turn created a growing market for IoT devices and services. Another driver is the increasing availability of cloud computing and data storage which has made it easier for collection and analysis of data from IoT devices. [9]. Africa's lack of infrastructure, high cost of hardware and limited technology background are all issues recently experienced in the course of IoT deployment in the energy sector. [10]. According to a guide to Industry 4.0 in the US 2019, the global Internet of Things (IoT) within the manufacturing industry is currently valued at $10.45 billion. Research conducted by International Energy Agency (IEA) and European Wind Energy Association (EWEA) predicted that renewable energy sources such as solar, wind, water may account for a major proportion of the global electricity supply by 2050. [11]. The IoT technology functions as a bridge between the physical and the digital world, enabling speedy, decentralized and real-time feedback. While the advantages of IoT technology in enhancing industrial and household operations are substantial, it holds significant importance in the South African scenario due to its impact on energy optimization. Given the energy crisis in South Africa, energy management has become a pressing concern. The method of energy conservation has become the next sought alternative. The persistent blackouts have forced South Africans to explore alternative energy sources, leading to acceleration in the solar energy market, which is projected to increase by 23.31 tera watt-hour units from 2021 to 2026 with a CAGR of 29.74%. South Africa is boasting the largest per capital backup generators in Africa, with revenue forecasts exceeding US$159,000 by 2030. [12].

II. Prospects of IoT Application in energy sector

The IoT has significant and promising prospects in the energy sector. In the energy industry, IoT can be leveraged to improve efficiency, optimize operations and enhance sustainability in the following ways:

A. Implementation of Smart Grid

One key applications of IoT in the energy sector is Smart Grid technology. By integrating IoT devices into power grid infrastructure, utilities can monitor and manage energy consumption in real-time. This enables better load balancing, demand response, and efficient distribution of electricity. IoT can also help in the detection of fault, allowing for faster response and quicker restoration of power. By using IoT in power grid, conventional grid's efficiency, capacity, reliability, sustainability, scalability and stability can be enhanced. Using the IoT in smart grids resolves the numerous problems faced by current smart grids. [13]. IoT-enabled smart grid technology provides an impressive network between the public and machines through all types of information sensing devices such as Radio Frequency Identification devices, infrared sensors, global positioning system, smart security systems, laser scanning and many others. IoT covers all domains in smart grid infrastructure such as generation, transmission and distribution of electricity and so on. The main of IoT is in the distribution part. The smart meter plays a vital role in the IoT-enabled smart grid system. [14]. The future power infrastructure that will support sustainability development is critical. A well-functioning smart grid can help reduce carbon emissions from energy sources, accelerate efficiency in energy conversion and end-user processes and promote environmentally friendly mobility. [15]. The IoT is an important tool for implementing smart grids. Various technologies of IoT are supporting in the smart grid and by using these technologies, the smart grid improves its processing alert, self-healing, recovery from disaster, and reliability. By combining IoT with smart grid, implementation of smart terminals, sensors, meters and other information and communication can be motivated. The IoT in the smart grid deals with state monitoring of devices, data gathering, entire smart grid control and safety and security purposes. [16]. IoT and Smart grids offer a new horizon in terms of power generation and distribution that can help consumers use their electricity in a more sustainable manner. [17]. The power grid is critical for converting energy from energy sources to all activities necessary for economic development. One major solution in the field of the integration of Smart grid and IoT is in the use of IEC 61850, which is an international standard defining communication protocol for intelligent electronic devices at electrical substations. [18]. The acceptance of IoT technology in the implementation and management of smart grid is still in the infancy stage, and numerous issues related to privacy and security remains unsolved. The management of huge volume of data generated remains a key problem for privacy in smart grids because of IoT technology adoption. Many challenges such as customer domain, information and communication domain and grid domain may be encountered during deployment of IoT technology. [19]. Figure 1 shows smart grids distinct applications in all domains of the IoT.

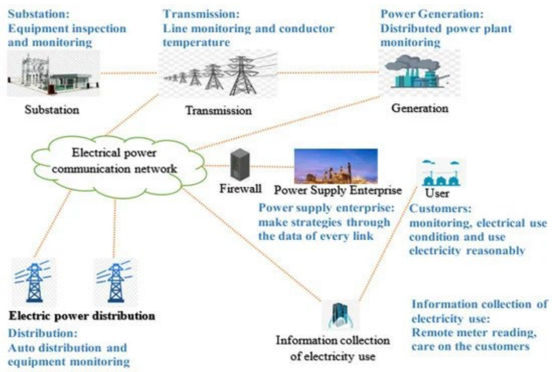

Figure 1: Smart Grids distinct applications in all domains of the IoT. [20].

B. Energy Management in Buildings

IoT can play a significant role in energy management in buildings. Smart meters, sensors can collect data on energy usage, temperature, and occupancy, enabling better control and optimization of energy consumption. This can lead to energy savings, reduced costs and improved sustainability. [21]. Buildings are responsible for a large portion of increased global electricity consumption. Buildings consume 40% of the total energy in the world and contribute to global CO_2 emissions in the same proportion. [22]. The field of energy management includes the aspect of energy use, where the energy consumption factors are considered. The IoT field is represented by three stages that are related to the field of energy management: Data capture, communication/processing, and interface. The data capture stage is responsible for obtaining energy consumption data. The captured data are used in the communication/processing stage during the process of data analysis and building consumption evaluation. The results of the processing are registered in the database and made available in the interface stage for virtualization on the internet through systems and web applications. In the final stage, communication/processing, programming languages, data storage, analysis and presentation forms are defined. [23]. Figure 2 depicts the conceptual framework of electrical energy management in buildings based on the IoT.

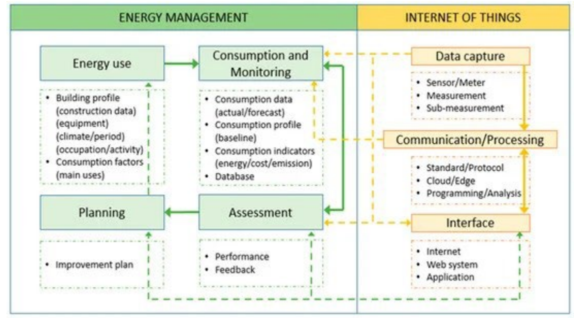

Figure 2: Conceptual framework of electrical energy management in buildings based on the IoT. [24].

C Integration of Renewable Energy Sources and Grid

IoT can facilitate the integration of renewable energy sources into the grid. By using IoT devices to monitor and control solar panels, wind turbines and photovoltaic cells, the energy generated from these energy sources can be efficiently managed and integrated into the overall energy system. [25]. Wind turbines and solar panels are among the various sources of renewable energy that are being utilized. However, the technological challenges associated with these systems are still significant to integrate the various renewable energy forms into the electricity grid infrastructure. Renewable energy sources integration into the grid are noted to be challenging owing to the decentralized manner in which they are usually installed. [26]. Smart grid is a technology that enables utilities to communicate with their customers effectively, help producers boost their efficiency and reliability, provide customers with better electricity quality and lower energy costs integrate renewable energy sources into the electricity grid, and improve the security of the grid. The IoT can provide help to the customers by enabling them to monitor and control various aspects of their overall energy systems. [27]. With the growing adoption of renewable energy sources like solar panels, hydropower systems, wind turbines and photovoltaic cells, a smart grid facilitates the integration of these power sources into the grid. It enables better monitoring and forecasting of renewable energy generation, improves grid stability and supports the efficient management of electricity flows between various sources and consumers. One of the key prospects of using IoT in smart grid system is the ability to enhance grid reliability and resiliency. IoT-enabled sensors and monitoring devices can collect and analyze real-time data on power generation, transmission, and distribution, allowing utilities to identify potential issues quickly. Efficiency is another crucial aspect that IoT brings to smart grid systems. By deploying IoT-enabled smart meters and sensors, utilities and consumers gain granular visibility into energy consumption patterns. Integrating renewable energy sources is a critical challenge modern power grid, and IoT plays a vital role in achieving this goal. IoT-enables efficient integration of distributed energy sources into the grid. This integration enhances the effective utilization of renewable energy sources, reduces reliance on fossil fuels, and supports the transition to a greener and more sustainable energy transition. [28]. Figure 3 below shows IoT applications in smart grid.

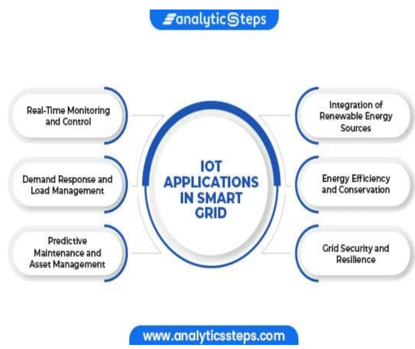

Figure 3: IoT Application in Smart Grid. [29].

III. CHALLENGES OF IOT APPLICATION IN ENERGY SECTOR

While the application of IoT in energy sector brings various prospects, its application also comes with some fair share of challenges. [30]. The two most pressing challenges of IoT applications in energy include.

A IoT Adoption in Energy

The application of IoT in the energy sector has been has been of great importance in recent years in areas such as smart grid, renewable energy, energy management systems for buildings and facilities. Technology offers numerous opportunities for energy industries, enabling them to optimize operations, improve efficiency and enhance sustainability. Amidst these numerous advantages of IoT utilization in energy, exist some crucial challenges that need urgent concern. [31]. Factors such as social and mass media influence, lack of information, compatibility and connectivity challenges, lack of standardization, high cost, distrust, and high expectation contribute to the reluctance of energy-efficient IoT adoption. [32]. The low rate of IoT adoption in energy can be based on the following constraints:

a) Legal Infrastructure

The energy sector is often dependent on legacy infrastructure that may not be compatible with IoT technologies. Upgrading existing systems in order to support IoT can be costly and time-consuming. [33].

b) Costs

A major challenge of IoT adoption in energy is the upfront costs during implementation of IoT solutions in the energy sector which includes the installation of sensors, communication network, and data management systems. The return on the investment may not be immediately apparent, hence making it challenging for some organizations to justify the expense. [34].

c) Lack of Standard

The absence of universally accepted standards for IoT devices and protocol can hinder interoperability and compatibility between different systems. This lack of standardization makes it difficult for organizations to integrate IoT solutions seamlessly. [35].

d) Lack of Knowledge

One of the adoption challenges of IoT in energy is knowledge gap. Implementing and managing IoT solutions requires specialized skills and expertise. Many energy industries may not have the necessary knowledge and experience to effectively deploy and maintain the IoT systems. Most times, the usage of IoT devices in the energy sector is not widespread; there exist a gap in the understanding of IoT overall functionalities in the energy sector. [36].

e) Data Management and Analytics

IoT devices generate huge amount of data, and effectively managing and analyzing these data can be challenging as there is a lack of IoT platforms for channeling such huge data to. [37].

f) Technology and Society

Emerging technologies such as IoT yield various benefits by helping to manage and reduce energy consumption. On the other hand, they may introduce unforeseen environmental risks. There is need to understand the interactions between technology adoption and societal impact. [38].

B Security and Data Integrity

The IoT technology has become increasingly relevant in a variety of industries. With the accelerating number of connected devices and amount of sensitive information being transmitted, IoT security has become paramount. There are concerns regarding cybersecurity and data privacy. [39]. As more devices are connected to the internet, the potential for cyber-attacks and unauthorized access to sensitive data increases. [40].

IV. CONCEPTUAL FRAMEWORK

Technology-Organization-Environment (TOE) Framework

This work proposed a conceptual framework whose core constructs were adopted from the technology-organization-environment theoretical framework proposed by [41] consisting of Technology Adoption as the dependent construct and technological context, organizational context and environmental context as the independent constructs which were found to be suitable for the study in Figure 4. Thus, these three elements influence the way an energy industry sees the need for, searches for, and adopts the IoT new technology. TOE framework can be used to understand the different factors that contribute to water scarcity and to develop strategies for addressing the risk factors: statistical (technology); climate change (environment) and uncertainty (organization). The study of [42] used the TOE framework to empirically analyze the determinants of the innovation decision for Vietnamese manufacturing firms. [43] focused on the factors that influence the cloud computing adoption for the establishment of three layer hierarchical frameworks based on Toe framework. [44] developed an information system for SMEs as well as investigated the factors that influenced the decision of SMEs to adopt information technology using the TOE framework. Many standard models have utilized the TOE framework to measure and understand students' and academics' perspective on technology adoption in learning in higher institutions. Furthermore, [45] builds on the ToE framework and on the previous studies of enterprise mobility to propose a comprehensive research model to analyze cloud computing adoption and usage. [46] examined critical success factors shaping the adoption of digital marketing devices by micro-businesses by adopting qualitative approach and underpinned by ToE framework.

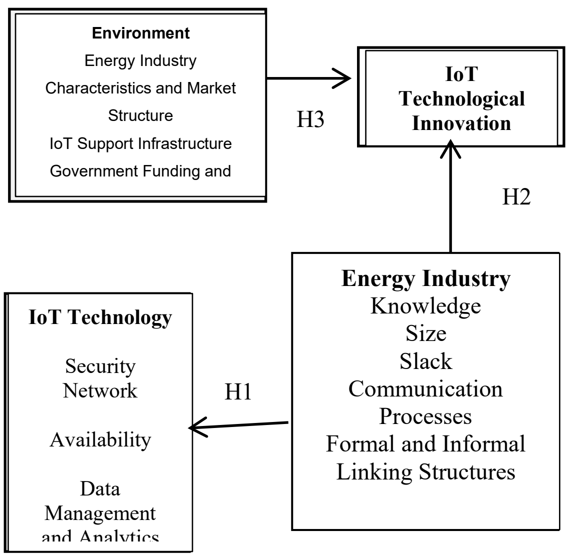

Figure 4: Proposed Conceptual Framework

V. FUTURE AND RECOMMENDATION

The future of IoT application in the energy sector looks promising, with the continued advancements and widespread adoption expected. The potential developments and recommendations for leveraging IoT in the energy section include:

A Increased Integration

As IoT technology continues to evolve, there will be a greater integration of IoT devices, sensors, and systems within the energy sector. This will enable more comprehensive data collection, analysis, and control, leading to improved energy efficiency and cost savings.

B Enhanced Energy Monitoring

IoT can be utilized to develop advanced energy monitoring systems that provide real-time data on energy consumption, production, and distribution. This data can help identify energy-saving opportunities, optimize energy usage, and reduce wastage.

C Smart Home Energy Management

IoT-enabled smart home devices can play a crucial role in optimizing energy consumption at the individual level. Smart thermostats, lighting systems, and appliances can be connected to a central hub, allowing users to monitor and control their energy usage remotely. This can lead to significant energy savings and increased awareness of energy consumption patterns. IoT in smart energy can also be used in energy sector by bringing in smart meter technology.

D Security and Data Integrity

The collection and analysis of vast amounts of data through IoT devices raise privacy concerns. It is important for energy organizations to be transparent about the data collected. Implementing strong data protection measures and adhering to privacy regulations is essential to ensure the trust and confidence of customers. Also, the implementation of robust protocols to protect IoT devices should be encouraged.

VI. CONCLUSION

The future of IoT in the energy sector holds great potential for improving energy efficiency, reducing costs, and optimizing renewable energy usage. With increased integration, enhanced energy monitoring, smart home energy management, IoT can revolutionize the way energy is produced, distributed and consumed. Furthermore, is also important for businesses and individuals in the energy industry to embrace and leverage IoT technologies to stay competitive and contribute to a more sustainable future. Finally, it is crucial to address the challenges and risks associated with cybersecurity and data privacy to fully harness the benefits of IoT technology in the energy industry. Future work is on the implementation of the proposed conceptual framework.

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