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Integrating Human-Computer Interactions in Nigerian Energy System: A Skills Requirement Analysis

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Abstract: The energy sector constitutes an important contributor to the growth and development of the Nigerian economy. Despite Nigeria's abundant energy resources, the sector faces multiple challenges, such as infrastructural deficits, policy inconsistencies, regulatory uncertainties, and overreliance on non-renewable energy sources. Industry 4.0 technologies and Human-Computer Interaction (HCI) present opportunities that address the challenges of the energy sector in Nigeria. This research explores the impact of HCI in the adoption of technologies of 4IR (Artificial Intelligence, the Internet of Things, Big Data, and Cloud Computing), in Nigeria's energy sector. The research assesses the current level of implementation of Industry 4.0, requirements for the implementation of Industry 4.0 technology, demand, and skills for HCI in the implementation of 4IR technology in Nigeria's energy generation sub-sector. This study adopted a comprehensive and critical systematic review of existing literature on the subject matter. The findings reveal the level of 4IR implementation in its infancy, with some energy companies and start-ups beginning to integrate digital technologies to enhance their operations and services. The study further revealed the potential of HCI in facilitating the integration and social acceptance of 4IR technologies and identified significant skills demand for HCI, such as digital literacy, data analysis, critical thinking, problem-solving, and system thinking to facilitate the adoption of 4IR. The research concludes that the development of HCI skills in the adoption of 4IR presents a great opportunity to transform the energy sector in Nigeria. The research recommends policy formulation, to embrace Industry 4.0 and multifaceted process development of HCI skills for the application of 4IR in the energy sector.

Keywords: *Human-Computer Interaction, Fourth Industrial Revolution, Energy System, Skills Requirements*

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1.0 Introduction

The economic fabric of Nigeria is strongly interwoven with its energy generation subsector, particularly oil and gas, which play a crucial role in propelling the country's gross domestic product (GDP). The energy subsector does not significantly influence the nation's economic landscape alone, but also fuels the operations of other industries, thereby paving the way for direct and indirect employment opportunities. Given Nigeria's wealth of resources ranging from oil, gas, and coal, to hydroelectric power and an increasing focus on renewables such as solar and wind, the energy generation sub-sector holds significant potential to support the country's economy further. The energy generation landscape in Nigeria is dotted with numerous players, which include state-owned corporations and private entities. In terms of energy generation within Nigeria, key organizations include entities like Egbin Power Plc and Kanji Hydroelectric Plc which are privately and state-owned organizations respectively. These companies contribute significantly to Nigeria's energy landscape, focusing on hydroelectric power generation to fuel the national grid. Additional key contributors to the energy generation sector would be solar energy companies such as Solar Century and Energy- a privately owned company, which is pioneering the use of solar energy to supplement the national grid and provide off-grid solutions [1]. These companies and their respective energy generation methods represent crucial subsystems of Nigeria's energy system.

However, while this sector is ripe with potential, it is equally beset with many challenges. Among these challenges are infrastructural deficits. Nigeria’s energy infrastructure remains significantly underdeveloped, restricting its capacity to produce and distribute energy effectively. Existing facilities are obsolete and in dire need of modernization, while the growth of new infrastructure is stunted by limited investments and inefficient planning [2]. This infrastructural decay manifests itself in recurrent power outages and inadequate electricity supply that stifles economic activities, leaving a significant proportion of the population without reliable access to electricity. These challenges significantly undermine the sector's growth trajectory and its capacity to utilize the nation's abundant energy resources optimally.

The previous industrial revolutions have resulted in the initiation and development of the consumption of energy sources, such as oil, natural gas, coal, and nuclear energy, and recognized an energy consumption pattern subjugated by fossil fuels. Nigeria's energy infrastructure, especially the power transmission system, need to be updated and efficiently handle the generated energy, leading to substantial energy losses. Additionally, the prevalence of regulatory uncertainties and issues of corruption deters potential investment, thereby restricting the sector's growth [3]. However, the advent of Industry 4.0 provides a glimmer of hope to mitigating these challenges and propelling the energy sector toward efficiency and growth. This latest industrial revolution, also known as the Fourth Industrial Revolution (4IR), is characterized by a strategic integration of traditional manufacturing with digital technology, creating a new paradigm in industrial development [4]. The bedrock of Industry 4.0 lies in advances such as artificial intelligence (AI), the Internet of Things (IoT), robotics, and advanced human-computer interaction (HCI).

Human-Computer Interaction, a burgeoning interdisciplinary field, emphasizes the interaction between users (humans) and computers, focusing on the design and use of computer technology. As digital transformation sweeps across various industries under the umbrella of Industry 4.0, HCI gains prominence. It enables the seamless integration between human and digital systems, thus facilitating productivity and efficiency. The existing literature indicates a positive correlation between the advent of Industry 4.0 and energy generation. Technological breakthroughs integral to Industry 4.0, such as IoT, AI, and big data analytics, can improve efficiency, productivity, and sustainability within the energy sector [5]. For example, implementing smart grids and predictive maintenance enabled by AI and IoT can drastically improve the reliability and efficiency of power generation.

Research focusing on the nexus between Industry 4.0 and energy generation within the Nigerian context appears to be scarce and nascent. There needs to be more in-depth investigations assessing the level of implementation of Industry 4.0 technology in Nigeria's energy sector and the role of HCI in the integration of 4IR technologies. This

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research gap underscores the need for this study, with the aim of assessing the level of implementation of Industry 4.0 technology in the energy generation sector in Nigeria, with a specific focus on the role of HCI in the integration process. This research will perform a comprehensive assessment of the skill requisites for HCI within the domain of energy generation [6]. This, in turn, could set the stage for the evolution of a technology-centric energy sector in Nigeria.

The role of Human-Computer Interaction (HCI) becomes pivotal. HCI provides the means through which humans and computers can interact seamlessly, enabling better control and optimization of energy systems. At the heart of Industry 4.0 in the energy sector lies the concept of smart grids. Smart grids, powered by IoT and big data analytics, can potentially improve the efficiency and reliability of power generation. They provide real-time data on consumption patterns, enabling energy companies to adjust their operations according to demand, thus optimizing energy use and reducing waste [7]. Furthermore, predictive maintenance, another critical aspect of Industry 4.0, can significantly improve the lifespan and efficiency of energy infrastructure [7]. Through AI and machine learning, predictive maintenance systems can predict potential failures in the system, allowing proactive measures to be taken before a complete breakdown occurs.

Despite the promising prospects of Industry 4.0 in the energy sector, its implementation in Nigeria's energy generation sub-sector has yet to be fully explored. There is a pressing need to investigate the current implementation of Industry 4.0 technology within Nigeria's energy sector and to identify the barriers that may be hindering its full adoption. Moreover, the role of HCI in the context of Industry 4.0 in Nigeria's energy sector deserves attention. The interaction between humans and computers is a crucial aspect of implementing Industry 4.0 technologies. As such, it is necessary to determine the level of HCI in the implementation of these technologies in the energy generation sector [8]. This assessment will provide information on the current state of HCI in Nigeria's energy sector. It will offer clues on the necessary steps that need to be taken to improve HCI and fully realize the potential of Industry 4.0.

In addition, the skill requirements for HCI in energy generation in Nigeria need to be thoroughly examined. The advent of Industry 4.0 will inevitably require new skills and competencies. The workforce must be adept at using new technologies, interpreting data, and making decisions based on the insights derived from these data. Therefore, assessing the existing skills landscape and identifying the existing skills landscape and identifying skill gaps can guide future training and education initiatives, ensuring that Nigeria has a workforce ready to take advantage of Industry 4.0 in the energy sector. Implementing Industry 4.0 in Nigeria's energy sector presents an opportunity for the country to overcome challenges plaguing the industry and improve its efficiency and sustainability. However, a comprehensive understanding of the current level of industry 4.0 technology implementation, the role of HCI, and the required skills for HCI is critical to navigate this digital transformation. This study seeks to contribute to this understanding and to provide information that can guide Nigeria's journey toward a digitally transformed energy sector. Consequently, the study aims to achieve the following objectives:

(i) Assess the level of implementation of Industry 4.0 technology in energy generation in Nigeria.
(ii) Examine the requirements for the implementation of Industry 4.0 technology in energy generation in Nigeria.
(iii) Examine the skills required for Human-Computer Interaction in energy generation in Nigeria; and
(iv) Determine the development of Human-Computer Interaction skills in the application of 4IR in energy generation.

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2.0 Review of Literatures

2.1 The Energy Generation System and the Integration of Industry 4.0 in Nigeria

As Nigeria remains one of the most populous nations in Africa, its energy sector is crucial to driving its economic growth and development. Indeed, the energy sector in Nigeria is highly characterised by its considerable potential and the abundance of resources available. The importance and role of the energy sector cannot be overstated.

In addition, the sector needs to improve at different levels of the value chain, from production and distribution to end-user application. Operational inefficiencies in power stations, distribution losses due to outdated or poor-quality infrastructure, and inefficient consumer energy use collectively contribute to a poorly performing energy sector. Policy inconsistencies and regulatory uncertainties further complicate the situation. The energy policies in Nigeria have been described as inconsistent and ambiguous, causing uncertainty for investors and other stakeholders[9]. Regulatory challenges include the need for enforcement of existing regulations, corruption, and the absence of comprehensive and coherent energy policies and planning [9].

There is also the issue of overreliance on non-renewable energy sources. Despite Nigeria's enormous renewable energy resources, such as solar, wind, biomass, and hydropower, the energy sector remains heavily dependent on nonrenewable sources, mainly oil and gas. This overreliance is unsustainable and exposes the country to economic volatility linked to fluctuating global oil prices and environmental issues associated with fossil fuel-based energy generation [10]. Collectively, these issues hamper the realization of their full potential, leading to negative impacts on the economy, social development, and environmental sustainability.

However, the advent of the Fourth Industrial Revolution, or Industry 4.0, offers the possibility of a new era for the Nigerian energy sector. Defined by a fusion of technologies blurring the lines between the physical, digital, and biological spheres, Industry 4.0 represents a potential turning point to address issues of the Nigerian energy sector. Industry 4.0 introduces various innovative technologies, such as cyber-physical systems (CPS), the Internet of Things (IoT), artificial intelligence (AI), Big Data, Cloud Computing, and others [11]. These technologies could be instrumental in resolving numerous problems currently impeding the growth and efficiency of Nigeria's energy sector.

For example, CPS can provide enhanced control and coordination of distributed energy resources, leading to improved reliability and efficiency in energy generation and distribution. IoT can enable real-time monitoring of energy infrastructure, improving operational efficiency, and enabling predictive maintenance to reduce downtime and lower operational costs. AI can help forecast energy demand more accurately, optimize energy distribution, and enable more intelligent and efficient energy management. Big data can provide valuable insights for energy planning and policy formulation, while cloud computing can facilitate the integration and sharing of energy data, promoting transparency and efficiency in the sector. However, the transition to Industry 4.0 in Nigeria's energy sector has been considerably slow. Multiple factors have contributed to this slow pace [12]. Lack of a conducive policy environment, inadequate infrastructure, high implementation costs, lack of technical expertise, and cybersecurity concerns are some of the primary impediments.

The absence of a supportive policy environment inhibits the integration of Industry 4.0 technologies into the Nigerian energy sector. Effective policy frameworks are crucial in setting clear directions, creating incentives for innovation and investment, and establishing the necessary regulatory controls. Similarly, inadequate infrastructure, both in terms of energy and ICT infrastructure, presents a significant barrier. Implementing Industry 4.0 technologies requires a robust and reliable ICT infrastructure in many parts of Nigeria [13]. Furthermore, existing energy infrastructure may not be compatible with these new technologies, which requires substantial investments in upgrading or replacing existing infrastructure.

The high costs of implementing Industry 4.0 technologies also pose a significant challenge. These costs include the acquisition of the technology itself and the associated costs of training personnel, maintaining the technology, and upgrading the infrastructure, among others. The lack of technical expertise is another hurdle. Industry

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4.0 technologies are complex and require a high level of expertise to implement and manage effectively [14]. However, Nigeria currently faces a skill gap in this area, with a shortage of trained professionals capable of handling these technologies.

Lastly, cybersecurity concerns cannot be ignored. The increased digitization and connectivity inherent in Industry 4.0 technologies raises the potential for cyberattacks, which could disrupt energy services and compromise sensitive data. Therefore, robust cybersecurity measures are critical to ensure the secure adoption of these technologies. Addressing these challenges to enter an era of Industry 4.0 in the Nigerian energy sector requires a holistic approach [15]. A combination of policy reform, infrastructure investment, capacity building, and public-private partnerships is needed to facilitate the transition.

Policy reform should aim to create a conducive environment for the adoption of Industry 4.0 technologies. This could involve introducing incentives for technology adoption, establishing clear regulatory frameworks for the operation of these technologies in the energy sector, and incorporating the goals of Industry 4.0 into national energy policies. Investment in infrastructure is also necessary, both in terms of upgrading the existing energy infrastructure and developing the ICT infrastructure needed to support Industry 4.0 technologies [16]. These investments could be facilitated through public-private partnerships, with the government providing the necessary policy and regulatory support, and private entities bringing in investment and technological expertise.

Capacity building initiatives are required to develop the technical expertise needed to handle Industry 4.0 technologies. This could involve collaborations with educational institutions to introduce relevant training programmes, as well as on-the-job training and reskilling initiatives within energy sector organizations. In summary, while the road to Industry 4.0 in the Nigerian energy sector is fraught with challenges, it also holds significant promise [17]. If properly harnessed, Industry 4.0 technologies could revolutionize the sector, leading to improved efficiency, cost reductions, and improved service delivery, ultimately contributing to Nigeria's economic growth and development.

2.2 Overview of Human-Computer Interaction

Human-Computer Interaction (HCI) represents a dynamic and multidisciplinary domain dedicated to understanding and optimizing the interplay between humans and computers. At its core, HCI investigates the design and use of computer technology, with a particular emphasis on the interfaces between people (users) and computers [18]. Being an intersection of several other fields of study, HCI is critical to the design of technological systems that are not only useful and usable but also offer gratifying and pleasant interaction experiences.

2.2.1 The Human Factor

The "human" facet of HCI fundamentally underscores the importance of understanding user needs, capabilities, and behaviours in the context of their interaction with computer systems. It delves into human factors such as cognition, perception, anthropometry, physiology, and various social aspects that are instrumental in molding a human's ability to interact with a computer system. Understanding human cognition, including memory, attention, and decision-making processes, is crucial, as these elements shape how humans process information and interact with technology [19]. Understanding these cognitive aspects helps to design systems that align with human mental capacities, thus improving usability and performance.

In addition, physical abilities, such as motor skills and sensory perception, also play a crucial role in HCI. For instance, a system's design should consider the user's capability to use input devices such as a mouse or keyboard and their ability to perceive output such as text or graphics. Moreover, the user's emotional state can significantly impact their interaction with a system [20]. Therefore, creating emotionally intelligent systems that can recognize and respond to a user's emotional state can enhance the overall user experience.

Furthermore, cultural contexts and socioeconomic conditions can significantly influence user needs and preferences. HCI, thus, must consider these factors to ensure that technology is accessible, inclusive, and equitable

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across diverse user groups. User-centered design (UCD) represents a pivotal approach in HCI that emphasizes involving users throughout the design process [21]. By integrating user input at all stages of design and development, UCD ensures that the final product aligns with user expectations and abilities.

2.2.2 The Computer Factor

In HCI, the "computer" aspect relates to the technological components of the interaction, which include the hardware, software, and interfaces that facilitate the user-computer interaction. This requires a thorough understanding of computer technology, its capabilities, and its limitations. Hardware considerations include the physical elements of a computer system that a user interacts with, such as the display screen, keyboard, mouse, and touch interface [22]. These elements should be designed with usability and accessibility in mind to facilitate efficient and comfortable user interaction.

Software considerations, on the other hand, involve the capabilities of the software to perform tasks, respond to user input, and present output in a user-friendly manner. Software should be designed to align with user needs, offering a seamless, intuitive, and enjoyable user experience. Interfaces, which serve as the link between the user and the computer, are another critical aspect. They should be designed to facilitate easy and efficient interaction [23]. This includes not just the graphical user interface (GUI), but also other interaction modes such as voice interfaces, haptic interfaces, and augmented/virtual reality interfaces.

2.2.3 The Interaction Factor

The interaction in HCI encapsulates the communication and participation between the user (human) and the computer system. This involves understanding how users interact with digital system, including their input methods (like typing, touching, or speaking) and how they perceive the system output (such as text, graphics, sound, or haptic feedback). Interaction design plays an important role in HCI. It focuses on creating engaging and efficient interfaces that enable users to understand how to use a system intuitively, predict the system's response, and accomplish their tasks efficiently [24]. The interaction should not only be functional but also enjoyable, leading to user satisfaction and a positive overall user experience.

In addition, the interactions must be adaptable and flexible, catering to different user styles and preferences. This can be achieved through personalization and adaptivity features that allow the system to learn from user interactions and adjust accordingly. The role of HCI is particularly significant in the context of Industry 4.0, the digital revolution characterised by advanced technologies such as AI, IoT, cyber-physical systems, and big data [25]. The complexity and sophistication of these technologies require an equally sophisticated approach to HCI.

This involves designing interfaces and interaction models that allow users to utilize these technologies, making technology more transparent and understandable to users. It also involves integrating AI into interfaces to personalize user experiences, making interaction more natural and intuitive. Moreover, given the extensive data collection and processing capabilities of Industry 4.0 technologies, ethical considerations become paramount. HCI must consider data privacy, consent, transparency, and fairness to ensure that technology respects user rights and societal norms [26]. In conclusion, HCI plays a critical role in shaping the interaction between users and computer systems, making it an essential field of study and practice in our increasingly digital world.

3.0 Methodology

A systematic literature review will help the research methodology to explore the use of Industry 4.0 technologies in Nigeria's energy sector and the skills required for effective Human-Computer Interaction (HCI). The approach encompassed a comprehensive search strategy, screening and selection, quality assessment, data extraction, critical analysis, and synthesis. In the search phase, databases such as Google Scholar, IEEE Xplore, ScienceDirect, JSTOR, Energy Information Administration (EIA), and World Energy Council were used to identify pertinent research papers, articles, and reports. The search leveraged on keywords like 'Industry 4.0', 'energy generation', 'Nigeria',

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'Human-Computer Interaction', and 'digital skills'. The intention is to capture an exhaustive understanding of the evolution and current state of the topic, unrestricted by time constraints.

Screening involves carefully examining titles, abstracts, and keywords of the identified materials. Those that align closely with the research objectives were selected for a full-text review. Subsequently, a quality assessment of each selected study was performed, with the criteria for evaluation encompassing the research methodology, the validity and reproducibility of the results, the sample size, and the reputation of the publication source. The next phase entails data extraction, focusing on information such as the status of Industry 4.0 implementation in Nigeria's energy sector, the role and significance of HCI, and the required skills for effective HCI. A critical analysis was performed to identify trends, patterns, and knowledge gaps. The final stage involved synthesizing data and insights into a comprehensive report that elucidates the current state of Industry 4.0 adoption in Nigeria's energy sector and the role and skills of HCI. The systematic literature review methodology was chosen due to its rigorous design and comprehensive coverage. The potential limitations, such as the availability of research on the specific context and potential bias in published studies were mitigated through rigorous quality assessment and critical analysis.

4.0 Discussion of Findings

4.1 Level of Implementation of Industry 4.0 Technology in Energy Generation in Nigeria.

The transformative potential of Industry 4.0 to revolutionise Nigeria's energy sector is significant. Characterised by the integration of digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics and cloud computing, the fourth industrial revolution stands to enhance energy generation, distribution, and consumption. Through the advent of intelligent systems capable of monitoring, analysing and controlling energy flows, we can anticipate improvements in cost savings, energy efficiency and greenhouse gas emission reduction, thus progressing towards a more sustainable energy future. However, the implementation of these technologies in Nigeria's energy sector requires a detailed examination. While Nigeria has made commendable strides in adopting digital technologies across various sectors, its energy sector trails behind. Currently, the energy infrastructure is heavily reliant on manual controls, making it prone to inefficiencies, losses, and system failures [27]. Currently, Nigeria's policy framework catering to Industry 4.0 is still in its infancy, with a dearth of specific policies and regulations guiding the integration of these technologies in the energy sector.

Despite these challenges, there are promising developments in the integration of Industry 4.0 technologies within Nigeria's energy sector. Several energy companies and start-ups are beginning to integrate digital technologies to enhance their operations and services. For example, the Nigerian Electricity Regulatory Commission (NERC) has implemented smart metering initiatives, enhanced revenue collection and improving customer service. Furthermore, international development agencies are supporting efforts to integrate Industry 4.0 technologies into Nigeria's energy sector, as exemplified by the World Bank's Nigeria Electrification Project. However, the adoption of Industry 4.0 in Nigeria's energy sector is not just about keeping up with global trends. At its core, it is about addressing perennial sectoral challenges such as unstable power supply, inadequate infrastructure, and high costs [28]. The integration of Industry 4.0 technologies can be instrumental in this regard, enabling real-time monitoring and control of energy systems, predictive maintenance of infrastructure, and efficient management of energy resources.

Addressing these risks requires robust cybersecurity measures and regulations to protect energy systems and consumer privacy. Ultimately, the integration of Industry 4.0 technologies is not an end in itself, but a means to an end - ensuring reliable, affordable, and sustainable energy for all Nigerians. In summary, the incorporation of Industry 4.0 technologies into Nigeria's energy sector is an intricate undertaking, brimming with potential but fraught with challenges. Currently, the level of implementation of these cutting-edge technologies remains low due to several critical impediments [29]. These barriers include inadequate infrastructure, an inconsistent policy framework, limited investment, a significant skill gap, and challenges related to governance and cybersecurity.

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Despite these obstacles, Industry 4.0 holds the promise of fundamentally transforming the energy sector and significantly contributing to the development and energy goals of Nigeria. However, to fully realise this potential, concerted efforts must be made to address these impediments. This involves developing robust policies that promote the adoption of Industry 4.0 technologies, making significant investments in the upgrading of infrastructure and training the workforce, fostering public-private collaborations and fortifying cybersecurity measures. Moreover, it is imperative that future research and initiatives concentrate on understanding how to effectively and ethically leverage these technologies within the context of Nigeria's specific needs and circumstances. This involves designing user-friendly interfaces, ensuring the ethical use of these technologies, and understanding the needs and preferences of the users [30]. Through a concerted and strategic approach, the energy sector in Nigeria can fully harness the benefits of the Fourth Industrial Revolution, leading to a more sustainable, efficient, and prosperous future.

4.2 Requirements for the Implementation of Industry 4.0 Technology in Energy Generation in Nigeria

The slow Industry 4.0 technologies implementation in Nigeria's energy sector can be traced back to a combination of interrelated factors. Primarily, inadequate infrastructure, characterized by unstable power supply and unreliable internet connectivity, presents a significant barrier to the adoption of these advanced technologies. Additionally, inconsistencies in the policy framework contribute to the sluggish pace of implementation. The absence of clear regulations and supportive policies for technological advancements often results in uncertainty, thus deterring potential investments in Industry 4.0 technologies. Governance challenges also play a critical role in slow implementation. Lack of transparency, inefficient regulatory practices, and corruption all serve to stifle progress and innovation in the sector. Finally, insufficient investment, public and private, in the energy sector and specifically in the technologies of Industry 4.0, hampers the pace of implementation. Without adequate financial support, the development, deployment, and maintenance of these technologies become challenging tasks. Thus, it is clear that the slow Industry 4.0 technologies implementation in Nigeria's energy sector is not due to a single isolated issue [31]. Rather, it is a complex issue rooted in a variety of infrastructural, policy-related, governance and financial constraints.

Furthermore, the transition to Industry 4.0 technologies is a profound change in energy generation and management methods, necessitating the introduction of new skills and business models and a shift in organizational culture, which can be resisted by both staff and management. The effective implementation of Industry 4.0 technologies also depends on a supportive policy environment that fosters innovation and addresses associated risks. This includes the creation of financial incentives, data privacy safeguards, cybersecurity policies, and fair competition norms[28].

An exploration of the realm of Human-Computer Interaction (HCI) within Nigeria's energy generation sector illustrates the urgent need for a diverse set of skills [27]. These competencies range from technical proficiency to cognitive aptitude and effective interpersonal communication, all of which contribute significantly to the successful integration of Industry 4.0 technologies within this sector.

Digital literacy, one of the core skills, goes beyond a basic understanding of how to operate digital devices such as smartphones or computers. This skill embodies an extensive comprehension of digital systems, requiring an individual to grasp the complexity of effective and secure interactions with these systems and fully leverage their potential [10] . Digital literacy is far-reaching, calling for an intricate understanding of the digital realm.

In the context of Nigeria's energy sector, digital literacy implies deep knowledge of advanced technologies such as Artificial Intelligence (AI), cloud computing, big data analytics, and the Internet of Things (IoT). Energy sector workers must understand how to incorporate these technologies into their daily operations, extending from energy generation to distribution and consumption[32]. This comprehensive understanding of digital technologies equips

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them with the skills to effectively manage digital resources and optimize their use for the benefit of the sector and consumers.

Effective HCI in the energy sector also requires critical thinking abilities, which involve the capacity to analyze and interpret results from these advanced technologies. This skill is imperative to understand the implications and potential consequences of these technologies [33]. Critical thinking allows for the careful scrutiny and analysis of complex concepts and ideas, which are essential in a technical sector like energy production.

As we dive deeper into the information age, data literacy has gained prominence as a critical skill for HCI within Nigeria's energy sector. In an era where big data is increasingly becoming a cornerstone for operational efficiency, data literacy, the ability to understand, interpret and effectively use data—provides organizations with a competitive advantage in terms of efficiency, cost savings, and decision-making capabilities [34]. Within the energy sector, data literacy involves proficiency in statistical analysis, data mining, predictive modelling, and data visualisation techniques, all crucial in making sense of IoT devices generated data.

Another critical skill required for effective HCI in the energy sector is systems thinking, which refers to the ability to comprehend complex systems, including the interaction of various components and the overall behaviour of the system [35]. This skill is vital to understanding the interactions between different energy sources, technologies, and infrastructures, and for strategising ways to optimize these interactions to enhance energy efficiency and reliability.

The interdisciplinary nature of the energy sector requires collaboration across disciplines, emphasising the need for effective teamwork skills. This becomes particularly crucial when professionals from different fields join forces to problem-solve or innovate, creating comprehensive and effective solutions. This form of collaboration leads to more holistic and informed approaches to the challenges and opportunities within the energy sector. Cultural awareness is another indispensable skill in the complex tangle of HCI skills in the energy sector [36]. Understanding local customs, traditions, beliefs, and social dynamics helps ensure that new technologies and systems are implemented in a culturally sensitive and respectful manner, enhancing their acceptance and acceptance among end users.

Information Communication Technology (ICT) skills are integral to the successful implementation of HCI within the energy sector. In this context, these skills extend beyond basic computer literacy to include proficiency in working with specialized software and hardware related to energy generation and management, database management, cloud computing, and cybersecurity. Another cornerstone skill within HCI is problem-solving, often considered one of the most critical skills in this field. Within the energy sector, problem-solving involves the ability to identify, analyze and solve complex, often interdisciplinary, problems that arise in the design, implementation, and operation of energy generation systems.

Communication skills are fundamental to effective HCI, especially within a complex and interdisciplinary field such as energy production. Effective communication involves the ability to listen to, understand, and respond appropriately to the needs, concerns, and ideas of others, significantly affecting the success of energy generation projects. Additionally, the ability to work effectively in a team is paramount in the interdisciplinary domain of energy production. This includes the ability to collaborate, negotiate, manage conflicts, and understand team dynamics, along with the roles and responsibilities of team members.

In an industry that is constantly evolving due to technological advancements and changing market dynamics, adaptability is a crucial skill. The ability to adapt to new tools, technologies, procedures, and regulations is essential for professionals in the energy sector.

4.3 Adoption of HCI in 4IR Technology in Energy Generation.

In the landscape of Fourth Industrial Revolution (4IR) technologies, the domain of Human-Computer Interaction (HCI) has emerged as a significant player, especially within the sphere of energy production. HCI, a

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discipline rooted in the design, evaluation, and implementation of interactive computer systems crafted for human use, has immense potential for enhancing communication between human operators and digital elements of the industry 4.0 infrastructure. The digital elements referred to here encompass advanced technologies such as big data analytics, Artificial Intelligence (AI), and the Internet of Things (IoT). These 4IR technologies are complex by nature, and it is within this complexity that the role of improving their accessibility, usability, and intuitiveness becomes paramount. This not only enhances the experience for users but also equips human operators with the means to manage these systems more effectively [37]. For example, the role of HCI is evident in designing interactive dashboards and visualization tools that simplify the process of monitoring and controlling energy generation systems, allowing early detection of potential issues, and facilitating informed decision-making.

Zooming into the context of Nigeria, the potential for HCI in facilitating the integration of 4IR technologies in energy production is significant. Nigeria's energy sector is plagued by numerous challenges, such as infrastructural limitations, operational inefficiencies, and issues of transparency. The introduction of HCI in this landscape can enhance the human-digital interface, making these systems more manageable, user-friendly, and ultimately more efficient. Despite the apparent advantages, the adoption of HCI in Nigeria's energy sector presents its own challenges. Among these, capacity building and skill development emerge as primary obstacles. The new wave of 4IR technologies demands a new set of skills, encompassing digital literacy, data analysis, and systems thinking, competencies that are not commonly found in Nigeria's energy sector[38]. Therefore, it becomes imperative to invest substantially in training and education at both the individual and organizational levels to bridge this skills gap.

Another considerable challenge is the need for a user-centric design, a cornerstone for successful HCI implementation. Achieving this necessitates an in-depth understanding of the users, their operating context, and constraints, which are vital for effective technology design. Unfortunately, the practice of user-centric design remains underutilized in Nigeria, primarily due to a lack of research and the required expertise in the field. Although these challenges are significant, it is encouraging to note that there are early signs of progress. Increasing recognition of the importance of Nigeria's energy sector is leading to the growth of research and development projects. Initiatives that promote digital skills and promote user-centric design are also beginning to emerge [39]. These initiatives, while still in the early stages, signal a paradigm shift towards a more human-centered approach in technology integration within the energy sector.

The potential to bridge the gap between human operators and digital technologies enables it to address the multitude of challenges in the energy sector, setting the stage for the sector to tap into the potential benefits of 4IR. However, this process necessitates significant investments in capacity building and user-centric design and a firm commitment to placing individuals at the heart of the technology adoption process. The importance of HCI becomes even more pronounced considering the diversity of the workforce in Nigeria's energy sector. The workforce ranges from highly skilled engineers to low-skilled workers, and from those already familiar with digital technologies to those just beginning to adapt to them. HCI has the potential to design interfaces and interactions that are inclusive, flexible, and intuitive for all users, regardless of their skill level or familiarity with technology.

Beyond the domain of energy generation, HCI has a pivotal role to play in driving the social acceptance of 4IR technologies. Social acceptance is a crucial factor when introducing new technologies that carry the potential to significantly alter work practices and social norms. By involving users in the design and implementation process, addressing their concerns through user-friendly designs, and clear communication, HCI can help foster social acceptance of these new technologies. Furthermore, the benefits of HCI are not confined to the energy sector. They have far-reaching implications for energy conservation and sustainability. They also contribute to the digital transformation of the Nigerian economy, creating a conducive environment for innovation and growth in various sectors.

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Despite the potential, it must be acknowledged that the adoption of HCI in the context of 4IR technology in Nigeria's energy sector is still in its early stages. There are few, if any, successful examples of HCI applications and the field remains largely unexplored in Nigerian research and practice. This presents vast research and development opportunities, with the aim of understanding HCI's specific challenges and opportunities and devising effective strategies for its integration. In summary, the potential of HCI for the integration of 4IR technologies into Nigeria's energy sector is immense. By improving the human-digital interface, HCI can address the sector's challenges, enhance the efficiency and effectiveness of energy systems, and contribute to broader social and economic objectives. However, achieving this potential requires a deep understanding of Nigeria's energy sector, significant investments in capacity building, a commitment to user-centric design, and an unwavering focus on a human-centric approach [40]. As Nigeria embarks on its journey towards Industry 4.0 in the energy sector, HCI provides a valuable compass, promising inclusivity, sustainability, and benefits for all.

4.4 Skills Requirement for HCI in Energy Generation in Nigeria

The incorporation of human-computer interaction (HCI) into the heart of Industry 4.0 technology within Nigeria's energy sector necessitates a vast array of skills that extend beyond traditional technical competencies. These skills encapsulate a broad spectrum, including digital literacy, data analysis, systemic thinking, user-centered design, cross-disciplinary collaboration, and an in-depth understanding of societal and cultural implications. When we delve into the intricacies of digital literacy, we are not talking merely about proficiency in using digital tools and technologies. Digital literacy, in the context of Industry 4.0, involves the ability to understand, evaluate, and create digital content. It extends to the domain of digital ethics and safety, encapsulating an understanding of data privacy, intellectual property, and cybersecurity. The energy sector in Nigeria can greatly benefit from a workforce equipped with digital literacy skills [41]. It will enable workers to operate advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics, all of which are vital components of Industry 4.0.

Understanding and making sense of data is an indispensable skill in the age of HCI and Industry 4.0. The energy sector is inundated with data generated by ubiquitous IoT devices and sensors, which have enormous potential to optimize energy production, distribution, and consumption. However, harnessing this potential requires the ability to interpret this data and convert these data into actionable insights. This, in turn, requires a combination of statistical and computational skills, critical thinking, effective communication skills and problem-solving abilities to articulate complex data in an understandable manner. Another critical competency is systems thinking, the ability to understand how different elements within a system interact with each other, and the ripple effects that changes in one part can have on the entire system. Within the energy sector, systems thinking can help manage the complex interplay between various technologies, processes, and stakeholders. It equips workers with the ability to anticipate potential issues and devise strategies to address them.

The skill of user-centred design plays a fundamental role in HCI within Industry 4.0. This involves understanding the needs, preferences, and contexts of users and developing technologies and systems that are intuitive, accessible, and satisfactory. In the energy sector, this translates into creating user-friendly technologies that are adaptable to the specific needs and conditions of various users. Interdisciplinary collaboration is another important skill for HCI within Industry 4.0. It involves the ability to effectively collaborate with individuals from various disciplines and backgrounds [42]. In the energy sector, interdisciplinary collaboration can bring together expertise from fields as diverse as engineering, computer science, psychology, sociology, and design. This melding of different expertise can lead to comprehensive and innovative solutions to tackle the challenges posed by Industry 4.0.

Finally, a deep understanding of social and cultural factors is crucial for a successful HCI within Industry 4.0. This involves understanding how technology is ingrained in social and cultural contexts and how it influences and is influenced by social norms, values, and practices. In the energy sector, such understanding can pave the way

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for broader social acceptance of advanced technologies and ensure that they are designed and implemented in a manner that respects and responds to the cultural diversity and social needs of different stakeholders. The diverse and complex skills required for HCI within Industry 4.0 in the Nigerian energy sector require significant investments in education and training. Additionally, a paradigm shift towards a more human-centric approach to technology is required. Despite the daunting nature of this task, these skills should not be viewed simply as a means to an end. They are valuable assets that can improve the creativity, adaptability, and resilience of the workforce and contribute to Nigeria's overall social and economic development. As Nigeria embarks on its journey to Industry 4.0 in the energy sector, the need to invest in these skills is not merely a necessity, but an opportunity. An opportunity to lay the foundations for a more inclusive, sustainable, and prosperous future [43]. The path to Industry 4.0 is undeniably challenging, but with the right skills and a human-centric approach, Nigeria can not only navigate this path, but can do so in a way that ensures maximum benefit for all stakeholders involved.

4.5 The Development of HCI Skills in the Application of 4IR in the Energy Generation

The advent of the Fourth Industrial Revolution (4IR), characterised by its blending of physical, digital, and biological technologies, has brought about a paradigm shift in various industries, including the energy sector. As part of this transition, human-computer interaction (HCI) skills have emerged as an essential competency, given the increased dependence on technology and digital interfaces [44]. This discourse will focus on how these HCI skills can be developed for the effective application of 4IR in energy generation in Nigeria.

The development of HCI skills in the context of 4IR begins with education, which extends from the primary to the tertiary levels. It is widely acknowledged that today's digital era necessitates the integration of digital literacy into the core curriculum. This implies not only teaching students how to use technology but enabling them to understand how technology functions and how it can be harnessed to solve problems. In particular, students should be exposed to aspects of HCI, such as understanding user needs, creating intuitive interfaces, and testing usability [45]. In Nigeria, this could be facilitated by reviewing academic curricula, incorporating HCI principles and practices into relevant subjects like computer science, engineering, and design.

In higher education, specifically, universities could consider offering specialised courses and programs in HCI and related fields. These courses could go deeper into subjects such as interaction design, user experience design, and usability testing. They could also touch on emerging topics such as artificial intelligence, virtual reality, and data visualisation, given their relevance to 4IR technologies [40]. The goal should be to equip graduates with both theoretical knowledge and practical skills, preparing them for the demands of the evolving energy sector.

Beyond formal education, training programmes play a pivotal role in the development of HCI skills. Training can be particularly effective for professionals already working in the energy sector who need to update their skills in light of the integration of 4IR technologies. Employers can organise in-house training sessions, workshops, or seminars focused on HCI skills [46]. These programmes could cover topics such as how to design intuitive interfaces for energy management systems, how to implement user-centred design approaches in the development of new tools and technologies, and how to ensure the accessibility and inclusion of digital solutions.

In addition, online learning platforms offer a vast range of courses and tutorials covering various aspects of HCI. These platforms can be advantageous as they offer flexible learning options, allowing individuals to learn at their own pace and convenience. In Nigeria, where physical infrastructure and resources may be limited, leveraging online learning platforms could be a viable strategy to facilitate widespread and affordable access to HCI education and training.

Mentorship and apprenticeship programmes are another avenue to develop HCI skills. These programmes provide a platform for experienced professionals to pass on their knowledge and expertise to less experienced individuals. In the context of HCI, such programmes could involve tasks such as shadowing a user experience

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designer, participating in usability testing sessions, or assisting in the development of an interactive system [47]. These hands-on experiences can offer invaluable insights into the real-world applications of HCI principles and practices.

Lastly, the role of continuous learning and professional development should be emphasised. The rapidly evolving nature of 4IR technologies means that HCI skills will need to be continuously updated and refined. Professionals should be encouraged to engage in lifelong learning, regularly participate in continuing education and training opportunities, attend industry conferences and seminars, and stay abreast of the latest trends and advances in HCI and 4IR technologies [48].

The development of HCI skills for applying 4IR in energy generation is a multifaceted process involving education, training, mentorship, and continuous learning. In Nigeria, this process requires concerted efforts from various stakeholders, including educational institutions, employers, government bodies, and the professionals themselves. Through these collective efforts, Nigeria's energy sector can be well-positioned to harness the transformative potential of 4IR technologies.

5.0 Conclusions

In drawing together, the conclusions from the extensive analysis that encompasses points, the transformation of Nigeria's energy sector through the application of HCI and Industry 4.0 technologies is a multifaceted and complex process, characterized by both challenges and opportunities.

The exploration of the current level of Industry 4.0 implementation in Nigeria's energy sector revealed significant constraints including infrastructural deficits and policy inconsistencies that hinder full utilization of the sector's potential. However, the inherent efficiency and predictive capabilities of Industry 4.0 technologies like Artificial Intelligence and the Internet of Things suggest substantial opportunities for revolutionizing Nigeria's energy sector. The detailed requirements for Industry 4.0 in the energy sector demonstrated a critical need for strategic planning, policy formulation, infrastructure investment, and substantial training of the workforce. These measures would be instrumental in accelerating the adoption of Industry 4.0 technologies and facilitating their transformative impact on the sector. Examining the role and status of human-computer interaction (HCI) in the application of 4IR technologies in energy generation revealed gaps in the effectiveness and ease of use of interfaces between human operators and digital technologies. This points to the importance of improving HCI by developing more user-friendly interfaces and gaining a deeper understanding of user needs and preferences. The study of the skills required for HCI within the energy sector in Nigeria highlighted a significant skill gap. The necessary skills range from digital literacy and problem-solving to systems thinking and adaptability. To meet the demands of Industry 4.0, it becomes imperative to upskill and reskill the Nigerian energy workforce. Lastly, exploring the development of HCI skills in the application of 4IR in energy generation underscored the need for a culture of continuous learning and adaptation. This would require active collaboration among stakeholders, including policymakers, industry players and academia, to foster workforce training, innovation, and alignment with national goals and strategies.

However, addressing these critical issues brings its own set of challenges, such as cybersecurity concerns, data privacy, and ethical issues. The transition to a more digitally connected system raises the potential for cyber-attacks and requires robust cybersecurity measures. Similarly, the increased data collection and processing demand not just technical but also legal and regulatory measures to ensure the privacy of individual and corporate data. As the energy sector in Nigeria navigates this complex journey towards Industry 4.0, it is vital to recognise the immense promise it holds. Using the potential of Industry 4.0 technologies, the sector can gain in terms of efficiency, reliability, and sustainability in energy generation. This offers opportunities to diversify energy sources and foster resilience in the face of global energy challenges. It is through concerted efforts and strategic planning, involving all stakeholders, that the energy sector in Nigeria can fully leverage the benefits of the Fourth Industrial Revolution and herald a more sustainable, efficient, and prosperous future.

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