REVIEW ON THE IMPACT OF THE FOURTH INDUSTRIAL REVOLUTION ON ENERGY EFFICIENCY AND SUSTAINABILITY IN AFRICA

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ABSTRACT

The Fourth Industrial Revolution is reshaping the way societies interact with their environment and the way they use energy. This paper seeks to investigate the impacts of the Fourth Industrial Revolution on energy efficiency and sustainability. To do so, this paper focuses on the implications of digital technologies such as the Internet of Things, Industrial IoT, Big Data, and Artificial Intelligence, which are transforming the way energy is produced, stored, and consumed. Additionally, the study investigates the effects of digital technology as a means of improving energy efficiency and eco-sustainability. It provides insights into the potential of digital technologies to reduce energy consumption and promote green energy solutions. Furthermore, this paper will identify the challenges that digital technologies pose in the development of energy efficiency and sustainability practices. By conducting a rigorous literature review, this paper identifies best practices for the implementation of energy efficiency and eco-sustainability initiatives, in the context of the Fourth Industrial Revolution. Furthermore, it also seeks to identify areas of potential improvement in the current state of energy efficiency and sustainability initiatives.

Keywords: Renewable energy, Energy efficiency, Eco-sustainability, and 4IR ·

1. Introduction

Efficient power and energy generation, transmission, and distribution are key to the development of economic and social stability and sustainability. The advent of Information and Communication Technologies has tremendously impacted Technology advancement and in almost all spheres of life, the technology industry has experienced exponential growth.

In the last century, mankind has seen unprecedented growth in technology as compared to the previous centuries. Within a century we have taken the sky, landed on the moon, and sent spacecraft deep into the solar system. From simple messaging across the Atlantic, we now send pictures and videos across the globe and beyond in multitudes. There is not a single aspect of our lives that has not seen an exponential advancement in technology. Be it medicine, transportation, construction, or aerospace, everything is touched by technology. This unprecedented growth in technology has been made possible partly by the easy and vast availability of electrical energy. The advent of electricity has ushered in an era of growth based on technologies that run on electric power (Kim et al., 2009). The electricity-dependent systems consume a huge amount of energy overall for technologies dependent on these systems. The computing power in today's smartphones is more than the computing power of the computers that sent man to the moon (Butler, 2011).

The challenge of electricity power begins from its generation, and transmission to efficient distribution. The instability of power impacts development in Nigeria, despite a large population and abundant natural resources, Africa as a continent lagged due to the absence of stable electricity and energy needed for powering batch systems and other mass-production technology. The concept of smart-enabled energy efficiency and sustainability as a possible way forward, taps into advanced ICT which has gradually become the new normal-which is regarded as the Fourth Industrial Revolution (4IR).

The China economy has deployed and tapped into various features of this technology (4IR). The continent of Africa continues to lag (Sutherland, 2019), except for African countries like South Africa which seems to have championed the deployment of technologies for industry 4.0. Power energy was key in the success of the third industrial revolution and seemed to be the same for the success of the current fourth industrial revolution (Stern and Kander, 2012). However, with the challenge of global warming, there is a shift towards clean and sustainable energy for the fourth industrial revolution. Notwithstanding, affordability and ease of energy usage and development are other parameters in selecting an appropriate energy source in Nigeria and Africa at large (Ukoba et al., 2018).

Africa can tap the sun's energy, wind, ocean currents, and human movement. The continent has sunshine for the entire year (Kothe et al., 2017; Mahlobo et al., 2018) in Nigeria and particularly the northern region. Nigeria lies in a high solar radiation belt with an average solar irradiation of 2011 kWh/m2 per year. The northern part has greater potential with a horizontal irradiation of 7kWh/m2 per day suitable for large-scale solar photovoltaic (PV) electricity or solar thermal electricity projects (Ohiero and Ogbeche, 2018). The entire Nigerian space receives average solar radiation of about 7.0kWh/m2 (25.2MJ/m2 per day) in the far north and about 3.5kWh/m2 per day (12.6MJ/m2 per day) in the coastal latitudes. Nigeria's Size is 923,768km² or 923,768,000,000m², adding the average solar radiation of (3.5kWh+7kWh)/2/m² = 5.25kWh/m² (Sahara Reporters). Nigeria's global solar radiation average compared to 100 W/m2 and 150 W/m2 for Europe and America, respectively is a wide margin (Khobai et al., 2020).

Similarly, the current population of Nigeria is 220,356,008 as of Sunday, April 16, 2023, based on Worldometer elaboration of the latest United Nations data, Nigeria can benefit from energy obtained from human movement (Benson et al., 2021). Nigeria is surrounded by a body of water that generates electricity from tidal currents, which is one of the major sources of electric energy in Nigeria. In addition to other renewable energy sources, Nigeria can benefit from to help achieve Smart-Enabled Energy Efficiency and Sustainability by actualizing the Fourth Industrial Revolution.

The relevance of this study lies in its alignment with the article's demonstration of the total coherence, to vital importance for humanity, and equality of all as stated in 17 United Nations (UN) Sustainable Development Goals (SDGs). The increase in the energy intensity of the economy and the consumption of fossil fuels conflict with sustainable energy's core principles, a decrease in energy consumption and a shift to clean and sustainable energy, and the high complexity of the simultaneous implementation of SDGs 7 and 9.

This paper is organized to review the literature on the Fourth Industrial Revolution (4IR) and the opportunities it holds for energy efficiency and sustainable ecosystem. Other sections explore energy generation, transmission, and distribution, this is followed by emphasis on affordable, clean, sustainable renewable energy sources with minimal maintenance. The rest of the work is on renewable energy the actualization of the fourth Industrial Revolution and the way forward for the African continent.

2. Literature Review

The fourth industrial revolution (Industry 4.0) is a leading technology that is frequently characterized by high energy efficiency, which enables the reduction of specific energy consumption. The widespread automation, on the other hand, increases the total amount of energy needed by the economy since processes that formerly relied on human labor (or conventional manual work, which has a low energy intensity) are now automated and need more energy as a result. In 2014, for instance, electric power consumption in the global economy increased quickly, reaching 3,131.68 kWh per capita (up from 2,274.94 kWh per capita in 2009) (World Bank, 2022).

The energy efficiency of Industry 4.0's sophisticated technologies, particularly industrial robots, is a topic that receives a lot of attention in the literature currently. The cost-effectiveness and energy efficiency of industrial robots are noted in the works of Aubin et al. (2022), Huang et al. (2022), Luan et al. (2022), Nonoyama et al. (2022), Ntsiyin et al. (2022), and Wang et al. (2022). The robotization of the economy is viewed in this context as an energy-neutral process.

Xuan and Ocone (2022), Dreher et al. (2022), Fang et al. (2022), and Anthopoulos and Kazantzi (2022) all gave excellent reviews of the fourth Industrial Revolution and Artificial intelligence (AI), as essential technological innovation driving the economy, and specifically, from the perspective of energy efficiency. It was established from the literature that AI has a lot of potential to be used to improve the energy industry, for efficient optimization.

Cui et al. (2022), Ng et al. (2021), Popkova et al. (2021), Popkova and Sergi (2021), Tabor et al. (2018), Taghizadeh-Hesary et al. (2022), and Zaidan et al. (2022) noted that Fourth Industrial Revolution-related technologies known as "Industry 4.0" facilitate the shift to "clean" energy. In light of this, the state regulation of the development of sustainable energy noted by Chen et al. (2022), Deng et al. (2022), Inshakova et al. (2022), Iqbal and Bilal (2021), Liu et al. (2022), and Nyenno et al. (2021) must be implemented through encouraging the use of smart modern technology, of industry 4.0's cutting-edge technologies in the context of the Fourth Industrial Revolution.

The International Federation of Robotics (2022), noted that the top 10 countries in the world in terms of automation are the driving force behind the Fourth Industrial Revolution. For these nations, analysis is done, scenarios are created, and their applicability in the real world is determined. The Fourth Industrial Revolution has received a lot of attention in literature and industry since the middle of the previous decade. The primary characteristics of the 4IR as noted by Ukoba et al., (2018), Bragança et al. (2019), Contreras (2020), Hayhoe et al. (2019), Jin (2019), and David et al., (2022) include automation based on robotics and artificial intelligence (AI).

The development of the energy economy is intricately linked to the history of the Industrial Revolution, consequently, the steam engine (a steam-powered engine), widespread use of gas lighting, more productive mining, and improved coal handling were characterized by the First Industrial Revolution (McNeill, 2019; Tainter and Taylor, 2019). The internal combustion engine's invention marked the end of the Second Industrial Revolution, according to Peter and Mbohwa (2018). The growth of the energy sector was a defining characteristic of the Third Industrial Revolution (Matizamhuka, 2018). The key distinction between the Fourth Industrial Revolution and the others is that the Fourth Industrial Revolution is being carried out in the context of the global sustainability initiative, which is reflected in the 17 UN SDGs, specifically goal 7, and has prioritized the development of clean energy (Alimhan et al., 2019).

Several literature sources have addressed the connection between Industry 4.0 and alternative energy. The significant concerns in this relationship are identified by a thorough investigation. First among these concerns are the poor output and inconsistent volume of clean energy (wind and solar) generation. The idea of economic expansion in general and automation, in particular, is opposed by the transition to clean energy, which implies a decrease in energy consumption and mandates a rigorous framework for energy consumption in the economy (Mangla et al., 2020; Mascarenhas et al., 2020).

Secondly, Industry 4.0's total automation is drastically increasing the energy intensity of every economic operation, which is leading to an exponential rise in energy consumption (Matsunaga et al., 2022). Thirdly, consistent production and distribution of efficient energy distribution are the basis of creation and the viability of innovative businesses. This demands a constant supply of a significant amount of energy, which is not feasible with only clean energy (Ang et al., 2017; Huang et al., 2017; Junker and Domann, 2017).

However, Li. (2022), Matsunaga et al. (2022), and Saikia et al. (2020) argue that the aforementioned conflict can be resolved because Industry 4.0's high-performance and energy-saving technologies can be used to resolve it. The relevant experience of certain nations that are leading in the development of Industry 4.0 such as the United Kingdom and China, is established as proof of this effect (Hargreaves et al. (2022), Kang and Reiner (2022)).

However, current publications are only focused on the present potential of 4IR and do not sufficiently explore the potential future directions for the development of alternative and clean energy in the Fourth Industrial Revolution era. The major goals of the study are to explore possibilities for the growth of smart-enabled energy efficiency that fosters sustainability of the environment and create suggestions that could lead to developing policy that makes the African continent benefit from the alternative clean energy efficiency by implementing the Fourth Industrial Revolution.

3. Energy Generation, Transmission and Distribution

The Electric Power Sector is one of the most important sectors to national development. The power sector is critical to the developmental reform of any country (Chinwuko et al., 2011). Electricity generation, transmission, and distribution are three stages of delivering electricity to consumers. The delivery of electricity to consumers in Nigeria has multidimensional problems. Sule, (2010) focused on the capacity of electricity generation in Nigeria and the major factors affecting electricity generation, transmission, and distribution in the country. Nigeria's power generation is mostly thermal and hydro with an installed capacity of about 12,522 MW. West African Power Pool (WAPP) was initiated to promote and develop power generation and transmission infrastructures as well as to coordinate power exchange among the ECOWAS member states. Nigeria currently supplies electricity to the Republic of Benin, Togo, and Niger.

In Nigeria, the electricity generating stations are interconnected in radial form with a single National Control Centre (NCC) in Oshogbo. This has led to a low-reliability index of the Nigerian National grid (Yusuf, et al, 2007). Nigeria uses three types of electricity generation stations namely Hydro generating stations three (3), Steam turbine generating stations two (2), and gas turbine generating stations eight (8), making it a total of thirteen (13) generating stations (Sule, 2010). The factors are no diversification of sources of energy used in electricity generation, poor maintenance culture, and electrical power transmission line losses due to long distances between generating stations and load centers.

Chinwuko et al. (2011), attempt to address the problem of extreme electricity shortage in Nigeria, they attributed the problem to inadequate infrastructure, inadequate funding of this sector, and energy losses from generation to billing. The generated power cannot all be utilized at the generating stations and its immediate environment. Therefore, it must be distributed at a suitable voltage to points and consumers. Distribution involves primary and secondary transformation of high voltage to the standard medium and low voltage by the appropriate transforming equipment.

Power transmission is the process in which a large block of electricity is carried from the generating stations to distribution stations using 330KV EHV transmission lines; 132KV transmission lines and 33KV sub-transmission lines either at 50KHz or 60KHz transmission frequency (Sule, 2010). The overloading of distribution transformers in Nigeria is seriously affecting the distribution of electricity to consumers. Uwaifo (1994) noted that "since 1991, in Nigeria, the average number of consumers for each distribution transformer had increased to 220 compared to 10 in the USA.

Nigeria has an abundant supply of energy sources. It is endowed with thermal, hydro, solar, and oil resources, and yet it is described as an energy-poor country because the sector is relatively underdeveloped. The statistics available show that only about one-third of Nigerians or approximately 40 percent of the population have access to electricity. The distribution of electricity shows great disparities between rural and urban, and between residential and industrial areas in the urban centres (Ali-Akpajiak and Pyke, 2003).

4. The Fourth Industrial Revolution (4IR)

The fourth industrial revolution is the current revolution in the 21st century occasioned by information and communication technologies along with cyber-physical systems and the Internet of Things. This present revolution is called the digital revolution, where activities are done, controlled, or regulated digitally. The Fourth Industrial Revolution (4IR) is a fusion of advances in artificial intelligence (AI), robotics, the Internet of Things (IoT), Web3, blockchain, 3D printing, genetic engineering, quantum computing, and other technologies. It is the collective force behind many products and services that are fast becoming indispensable to modern life (Klaus Schwab, 2016).

In some parts of the world, the fourth industrial revolution (4IR) is sweeping across all sectors, from companies to research centers (Hvelplund, 2006). The key technologies of the Fourth Industrial Revolution (4IR) accelerating digitalization, artificial intelligence (AI), cloud computing, robotics, and 3D printing. Figure 1 shows key technologies driving the Fourth Industrial Revolution

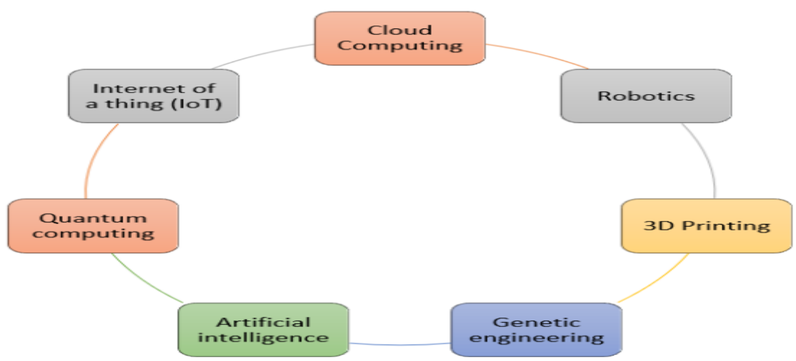

Figure 1. Key technologies of the Fourth Industrial Revolution. Source: Ukoba et al., 2023

4.1 The International Experience and Modeling of the Impact of the Fourth Industrial Revolution on Energy

A review of worldwide data and the simulation of the level of impact of how the energy sector is affected by the Fourth Industrial Revolution. Analyzing the top ten countries globally regarding automation to assess their experience in the integration and implementation of robots and AI into the energy development process, as noted by (Vorozheykina et al., 2022). Table 1 provides an overview of the experience of the leading ten countries in implementing the Fourth Industrial Revolution within the realm of energy development.

Table 1: Top 10 countries experience in the implementation of Robot and AI in Energy Development

Country	Robot density in the manufacturing industry, robots installed per 10.000 employees	The global AI index, score 0–100	Alternative and nuclear energy (% of total energy use)	Renewable electricity output (% of total electricity output)	Renewable energy consumption (% of total final energy consumption)	Fossil fuel energy consumption (% of total)
	rb	Ai	ANE	REO	REC	FFE
Republic of Korea	932	38.60	15.96	1.89	3.18	81.03
Singapore	605	38.67	0.19	1.82	0.73	90.58
Japan	390	30.53	3.09	15.98	7.39	93.03
Germany	371	36.04	12.86	29.23	15.80	78.86
Sweden	289	29.85	43.24	63.26	52.48	25.12
United States	255	100.00	11.87	13.23	10.11	82.43
China	246	62.92	5.11	23.93	13.12	87.67
Denmark	246	30.87	11.75	65.51	35.33	64.93
Italy	224	24.45	6.33	38.68	17.07	79.95
Netherlands	209	36.35	3.37	12.44	7.38	93.46
Arithmetic mean	376.70	42.83	11.38	26.60	16.26	77.71
Standard deviation	228.23	22.60	12.30	22.94	15.96	20.32

Source: International Federation of Robotics, (2022), Tortois, (2022) and World Bank, (2022)

The International Federation of Robotics(2022) is the forerunner of the Fourth Industrial Revolution. Statistical data gathered on these nations on robotics (International Federation of Robotics, 2022), AI development (Tortois, 2022), and energy (World Bank, 2022), are based on the most recent data for the 2020-2021 study. Given the relative stability of energy development, they generally reflect the scenario for 2020-2021 in a reliable/acceptable manner. Table 1 provides the foundation for basic facts. Such that;

$$\begin{aligned} ANE &= 14.15 - 0.0010rb - 0.06ai \\ REO &= 67.34 - 0.06rb - 0.42ai \\ REC &= 38.53 - 0.03rb - 0.23ai \qquad (1) \\ FRE &= 62.07 + 0.02rb + 0.22ai \end{aligned}$$

Formula (1) states that the proliferation of Industry 4.0's advanced technologies (robots and AI) as a result of the Fourth Industrial Revolution causes a reduction in the proportion of alternative and clean energy sources and an increase in the economy's reliance on fossil fuels. The four equations' high correlations of 10.24, 67.89, 53.46, and 28.55%, respectively, show that the system of equations that resulted from them is reliable (Vorozheykina et al., 2022).

4.2 Energy Development in the Era of the Fourth Industrial Revolution

The prospects for the growth of energy in the Fourth Industrial Revolution era have been examined using several scenarios. Forecasts of changes in each of the variables in Table 1 have been made using the Monte Carlo approach and are based on arithmetic averages and standard deviations. The relationships between the variables are taken into consideration based on the system that Eq. 1 generates as a result. In the context of the Fourth Industrial Revolution, the first scenario presupposes limitless expansion of automation as well as open access to Industry 4.0 technologies.

Industry 4.0 technologies are most likely to enhance robotization to 452.58 robots per 10,000 industrial workers (+20.14% with a probability of 20%) and raise AI activity to 49.94 points (+16.61% with a probability of 16%) in this instance. The system of Eq. 1 was changed to incorporate the obtained values of the factor variables, which revealed the following implications for the energy sector (Vorozheykina et al., 2022);

→ Reduction of the share of alternative and nuclear energy by

4.17% (to 10.90%);

→ Decrease in the share of renewable electricity output by

28.44% (up to 19.03%);

→ Decline of renewable energy consumption by

25.47% (up to 12.12%);

→ Growth of the share of fossil fuel energy consumption by

3.63% (up to 80.53%).

The development of this scenario has taken into consideration the possibilities for automation in Industry 4.0 to the best extent possible. The development of AI and increased robotization, which regrettably come at the expense of clean energy and significantly raise the energy intensity of the economy, make this scenario's real-world application unique and raise the risk of the emergence of an energy crisis. The second scenario has to do with maintaining the current trajectory of alternative and clean energy development. The following values of the energy development indicators in this scenario proved to be the most plausible ones:

→ Increase in the share of alternative and nuclear energy by

49.42% (up to 17% with a 20% probability);

→ Increase in the share of renewable electricity output by

9.03% (up to 29% with a probability of 25%);

→ The growth of renewable energy consumption by

66.75% (up to 27.11% with a probability of 17%);

→ Reduction of the share of fossil fuel energy consumption by

12.74% (to 67.81% with a probability of 14%).

The execution of this scenario would necessitate a complete abstinence of the use of AI as well as a limitation of robotics by 8.52% (up to 344.60 robots per 10,000 industrial workers), according to the dependencies from the system of Eq. 1 determined by the least squares approach. The construction of this scenario has been guided by the need to realize renewable energy's potential to the utmost extent possible. The quick decarbonization rate in the practical application of this situation is remarkable. Unfortunately, decarbonization hinders the innovative and technological advancement of the industry and works against the interests of economic growth.

The last scenario is the balanced growth of advanced technologies and renewable energy in EnergyTech. This is an alternative to the two extreme scenarios previously discussed, which are predicated on an obvious conflict between high technology and clean energy. The most ideal situation is EnergyTech because it enables the simultaneous development of sustainable energy and cutting-edge industry 4.0 technology. The parameters of this scenario cannot be quantified given the way robotics and AI are used now. Despite being the least likely, it merits thorough consideration.

5. The way forward for the African continent in 4IR for efficient energy sustainability

Renewable energy sources provide Africa with enormous potential for achieving its Industry 4.0 objectives. Due to their connection to the Indian or Atlantic Oceans whether directly or indirectly almost all African nations can produce hydropower. In addition, several African nations have very tall waterfalls that should be used to produce hydropower. The Erin Ijesha waterfall in Osun State, Gurara waterfalls suleja-Minna in Niger State, and many others in Nigeria (Guardian.ng). The Menchum waterfall in Cameroon's northwest serves as an excellent illustration. If used, it is estimated that this waterfall could provide electricity for roughly half of West Africa. In addition to hydropower, the majority of sub-Saharan African nations especially in northern Nigeria, have enormous amounts of land that are appropriate for producing solar energy but have not yet been utilized. The lack of political will on the part of African governments to create effective innovation and digital policies to hasten the implementation is the main issue slowing down Africa's involvement in the fourth industrial revolution. Africa already dominates the world in terms of youth population and resource availability. However, Africa needs to catch up to fully realize its potential. Regarding connectivity, data ownership, privacy, and security, digital infrastructure, and general digital initiatives, it must catch up to the rest of the world.

Solar energy has a significant deal of potential for use in the African continent. Clean, universally accessible, and able to produce more energy than is required. However, given that the initial cost of solar energy farms is out of reach for the majority of African households, the government or business organizations should be prepared to finance this investment for the country's rural residents. The establishment of solar energy harvesting equipment manufacturing facilities on the continent would be a great approach to reduce costs. This will cut down on the cost of importing solar equipment from the few African manufacturing facilities. The issue of reliability due to weather fluctuation in solar technology in Africa will be avoided by the construction of sizable solar farms in various areas for the national grid.

The African leaders need to create appropriate legislation that will aid in implementing 4IR elements in the continent through institutions like the African Union and the Pan-African Parliament. There are no existing official guidelines or regulations to that effect. Africa's school curriculum has to include new skill sets that include big data management, cognitive abilities, social media management, processing, problem-solving, and critical thinking abilities. This will increase the manpower capacity with the relevant skills to make the African continent benefit from the potential of the fourth industrial revolution for efficient renewable energy and sustainability of the environment.

6. Conclusion

The need to reduce energy consumption and mitigate environmental damage has become increasingly pressing as the effects of climate change become more visible. This has led to a need for more effective and efficient methods of achieving energy sustainability. Smart-enabled energy efficiency and sustainability are methods of increasing energy efficiency while reducing environmental impact. These methods involve the use of advanced technologies, such as the Fourth Industrial Revolution (4IR), intelligent automation, and high-performance computing, to increase efficiency in energy generation and consumption while reducing emissions of carbon and other pollutants. Additionally, energy-efficient technologies, such as solar and wind power, can also be used to decrease energy usage and emissions. The use of these methods has the potential to drastically reduce energy usage and emissions, as well as improve the overall sustainability of energy production and consumption.

7. Compliance with Ethical Standards

Conflict of Interest: The authors report that we do not have any conflicts of interest associated with this research work.

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