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Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis

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ABSTRACT

The technologies of the fourth Industrial Revolution (4IR/Industry 4.0) have been a technological catalyst for all fields of human endeavor, permeating the water, energy, and food (WEF) nexus. However, there is no empirical evidence of the extent of applications and the permeability level in ensuring the three resources' security. This study explored the relationship of the fourth industrial revolution technologies and the water, energy, and food nexus by evaluating the applications of the various technologies of 4IR on WEF nexus and examined the effect of 4IR on WEF nexus. The objectives were achieved using the qualitative methodology and bibliometric analysis of content analysis. The result showed that most fourth industrial revolution technologies had not been integrated with the WEF nexus. The result showed that only the Internet of Things (IoT) and Big Data analytics had permeated the nexus, which shows that data of the resources will be the foundation of the nexus. The systematic collection, accuracy of data, and empirical analysis of data will determine the level of security of WEF nexus.

The qualitative results show that there are applications of the fourth industrial revolution technologies to the individual sectors of the nexus, birthing Water 4.0, Energy 4.0, and Food 4.0. The Bibliometric analysis result shows that the integration of the fourth industrial revolution with the WEF nexus will lead to cleaner production practices relating to the technological processes of water, energy, and food resources. These practices will ensure the environment's safety from WEF wastes and the water, energy, and food security in production processes. The empirical research and bibliometric analysis result, rooted in the concept of cleaner production, shows that the fourth industrial revolution affected the WEF nexus. The effects are; the birth of clean technologies & industrial applications, the catalyst for sustainability security of WEF nexus leveraging on life cycle thinking, enablement of technological transfer, enhancement of economic growth, and urban planning. The study concludes that the fourth industrial revolution technologies affect WEF nexus, ensuring the popularization of cleaner production strategies and processes of the resources during trade-offs and synergies. The study recommends the integration of a cleaner production concept in WEF processing. It should follow the innovation diffusion theory (IDT) and Technology acceptance theory (TAM) when applying 4IR technologies to the nexus of water, energy, and food resources, for their sustainable security.

1. Introduction

The fourth industrial revolution technologies, otherwise known as 4IR or Industry 4.0, permeate the human economy and every aspect of livelihood due to the technologies' efficiency, effectiveness, and dynamics. These technologies are also necessary for resource optimization to achieve economic, environmental, and social sustainability.

The Industrial Revolution, which has led to many technologies, entails advancements in science and technology over time, leading to the utilization of machines than hand in producing goods and services. Succinctly, the industrial revolution is the technological revolution of industrial activities, changing patterns of doing things and creating things. The history of the fourth industrial revolution can be traced to the researches of the National Academy of Science and Engineering (2013) and Liao et al. (2018), which emanated from three previous industrial revolutions. The first Industrial revolution was in the 18th century when water and steam-powered mechanization of production resulted in eight (8) times production efficiency. The second industrial

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revolution started between the end of the 19th century and 20th century, characterized by the revolution of electricity and assembly line production, leading to electrically powered mass production of goods, with minimized costs and optimized speed. The third revolution began in the mid – 1970s in the 20th century, with the advent of electronics and information technology, using memory–programmable controls and computers in production processes. 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, also known as Industry 4.0, encompasses the digitalization of industrial production that will lead to fully intelligent, interconnected, and digitized production factories and organization activities (Ruzarovsky et al., 2020). Oztemel and Gursev (2018) stated that industry 4.0 is a change in technological methodologies by applying industry 4.0 technologies in revolutionizing production from dominant machine manufacturing to digital manufacturing. Industry 4.0 is an adapted, integrated, service-oriented, optimized, and interoperable manufacturing process that uses algorithms, big data, and emerging technologies that transforms production patterns from mass production to mass customization (Lu, 2017). Ruzarovsky et al. (2020) stated that industry 4.0 is premised on Nine (9) main technologies causing the industrial revolution. The technologies are Augmented Reality, System Integration, Cloud Computing, Big data, the Internet of Things, 3D printing, Additive Manufacturing, Cyber Security, Autonomous Robots, and Simulation. Also, Koh, Orzes & Jia (2019) noted that the Fourth Industrial Revolution includes five (5) main technologies and five (5) emerging technologies. The leading technologies are the Internet of Things (IoT), Big data analytics, Cloud computing, 3D printing/Additive Manufacturing, and Robotic systems. In contrast, the emerging technologies include Machine learning, Artificial Intelligence, Digital Twin, Blockchain, and 5G. The Fourth Industrial Revolution is characterized by digital Technologies, optimizing production processes, supply chain activities, organizational culture & procedures, and transactional cum marketing mechanisms. This signifies that the 4th industrial revolution is an inevitable revolution that all activities of the human economy must embrace, for efficiency, effectiveness, competitive edge, profitability, innovation, economic development, and organizational growth.

The fourth industrial revolution is changing production, organizational processes, and economic directions in nations, necessitating a strategic approach to evaluate the extent to which the technologies of the revolution affect three vital resources (water, energy & food) to the human economy. Qi, et al. (2021); Li et al. (2021) and Sun et al. (2021) opined that these three resources are critical in ensuring the socio-economic development of any nation. The United Nations stated that the instability relating to these resources is considered a global risk (Li et al., 2016). Shannak, Mabrev, and Vittorio (2018) stated these three resources are needed to address hunger, scarcity of water, depletion of energy, health conditions of people, and building a sustainable economy, which are global issues of concern.

Olawuyi (2020) researching these three resources, stated that they are linked together, sharing an inextricable relationship and trade-offs among themselves, which affects their availability and stability. Hoff (2011) opined a relationship and nexus between the three resources and project encompassing the three resources must be integrative. Olawuyi (2020), Ogbolumani and Nwulu (2020), and Endo et al. (2015) espoused the nexus between the three resources. Their research noted that without water, food, and energy production seems impossible; without energy, production, processing, and distribution of food and energy will be a mirage. Food production is necessary for the functionality of the energy and water supply chain. This relationship has brought about a nexus thinking among the three resources.

The water, energy, and Food (WEF) nexus entail understanding the interconnectedness, trade-offs, and resource conflict accompanying processes of WEF in terms of production, distribution, and consumption for sustainable Development (Abulibdeh and Zaiden, 2020; Cansino – Loeza and Ponce – Ortega, 2021). Pueppke (2021) opined that the WEF nexus seeks to maximize the advantages of WEF synergies while avoiding the disadvantages of WEF trade-offs by shifting focus from the competitive nature of the resources to their mutual benefits. According to Ogbolumani and Nwulu (2021), the WEF nexus is a holistic framework that brings about collective solutions for the optimum allocation of the already scarce resources. David and Adepoju (2021) also noted that the WEF nexus is a global response for operationalizing the various approaches to achieve WEF resources security. The WEF nexus addresses the five (5) relevant aspects of the WEF sectors that affect the human economy (Torres et al., 2019). The first is that the economic sector relates to at least one of the three resources, connoting that the nexus of the three resources will stimulate economic activities. The second aspect is that the fundamentals of water, energy & food are interlinked; hence, the nexus of the three resources comprises other nexuses such as water – energy, water – food, and energy – water, food – water, and food – energy. In addition, the negative impact generated by consuming those elements is passed to society is the third aspect, highlighting that the nexus brings to limelight ways to manage the environmental impacts of the resources. The fourth aspect of the nexus is that the alterations in any of those elements cause chain reactions in segments associated with them; therefore, the nexus of the three resources will provide managerial solutions to the trade-offs of the resources. The last aspect is that interdependencies among those elements are increasingly apparent in crisis scenarios and scarcity of resources; hence, the nexus acts as a buffer mechanism to resource scarcity. The WEF nexus is significant in sustaining global developments and ensuring the security of WEF. The WEF nexus has a multifaceted benefit, but most importantly, it secures WEF resources, as these resources are ecosystem services that improve livelihoods, and create wealth (David and Adepoju, 2021; Ogbolumani and Nwulu, 2022). Pahl – Wostl (2019) defined WEF security as "*addressing security from the perspectives of the water-energy-food nexus refers to reducing trade-offs to acceptable levels and to enhancing synergies between efforts to simultaneously increase water, energy, and food security respectively, to sustain human well–being, economic production, and environmental integrity and to enhance the resilience of the human environment technology systems as a whole*".

Hoff (2011), the World Economic Forum (2011), and David and Adepoju (2021) averred that WEF nexus is about securing the individual resources and managing their trade-offs, in terms of accessibility, affordability, availability, stability, and productivity, given their sectoral security. According to UNESCO (2019) and U.N. – Water (2013), water security is "*the capacity of a population to safeguard sustainable access to adequate quantities and acceptable quality of water for sustaining livelihoods, human well-being and socio-economic development for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*". The International Energy Agency, IEA (2014) opined that energy security is "*an uninterrupted availability of energy sources at an affordable price while respecting environmental concerns.*" United Nation (2015) defined energy security as "*access to clean, reliable and affordable energy services for cooking, heating, lighting, communication and productive uses*". The Food and Agriculture Organization, FAO (2014) defined Food security as "*the availability and access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life*".

The demand for water, energy, and food resources has increased pressure on the resources, leading to challenges such as climate change, diminishing natural resources, and poor production processes, which are challenges that technologies of the fourth industrial revolution will solve ((Alonsoperez and Alonsoperez, 2018). PWC (2018) and Hoff (2011) opined that technologies of the Fourth Industrial Revolutions offer unparalleled opportunities to solve WEF resources challenges of climate change, Biodiversity & Conservation, healthy oceans, water security, clean air, insecurity of water, energy & food, and weather & disaster resilience. Technological innovations have been applied in various areas of the three resources to find solutions to these challenges and achieve sustainable security of the resources. In optimizing Ethiopia's Renewable Energy sources for WEF nexus, Emmanouil et al. (2021) designed a microgrid of solar and small scale hydropower for irrigation water pumping, using the technology of HOMER (Hybrid optimization of multiple energy resources) software and simulations of MODFLOW unsaturated zone flow package. Gbadamosi, Nwulu & Sun (2018) developed an optimal power flow optimization model for renewable energy sources composite expansion planning, which aided cost reduction, minimized harmonic losses, created additional lines in the power system network, and improve the quality of power. Zhang, Li et al. (2021) designed a copula-based stochastic fractional programming (CSFP) method to solve risks related to hydropower generation, arable land, and water resources. This will help plan food production, water allocation, and energy generation, used for five (5) countries in Central Asia, Uzbekistan, Tajikistan, Kazakhstan, and Turkmenistan. Also, Ahmad, Ahmad, Zaindin, and Adhami (2021) used a technological novel method called interactive neutrosophic programming approach (INPA) to solve WEF nexus environmental and socio-economic objectives of electricity conversion, optimal energy supply, food production, CO2 emission control, and water resources allocation. Moreover, for the production of freshwater from brackish water or seawater, Okampo and Nwulu (2021) elaborated on the technology of reverse osmosis desalination in optimizing renewable energy sources such as wind energy, solar energy, geothermal energy, ocean energy, and their hybrids. Furthermore, in the application of technology to WEF nexus for different wheat intensive agriculture, Fabiani et al. (2020) utilized the Variable Rate Technology (VRT), which combines digital and physical technologies such as farm machinery, drones, satellites, artificial intelligence, machine learning and hyperspectral imaging for the automation of materials like fertilizers, chemical sprays and seeds to land. Nwulu and Fahrioglu (2011) utilized the Artificial neural network aspect of Artificial Intelligence with game theory in designing power system demand management contracts for the efficient management of energy needs and bringing load reliefs to customers. Gbadamosi and Nwulu (2020) designed a multi-period composite generation and transmission expansion planning model, having the attributes of the internet of things, for energy security and boosting investment in power systems, especially for renewable energy sources in meeting electricity demand, which often arises from the production and processing of WEF resources. You, Han & Kim (2021) designed an optimization model using Biomass to minimize the total annual cost for establishing and operating a Biorefinery for bioethanol production and its supply chain underwater – energy – food – land nexus technologies.

The integration of technological innovations into the water – energy and food nexus has also led to several developmental and technological concepts within the sectors. This includes concepts such as Precision Agriculture and Precision farming (Dwivedi et al., 2017), vertical farming, hydroponic & Aquaponic systems (Royston and Pavithra, 2018), Smart grid (Vijayapriya and Kothari, 2011), water reticulation (Hydroserv, 2021), and post-harvest technologies, Irrigation & Drainage Engineering and Agro-processing (Kambolam, 2021 and Van der zee et al., 2017).

The sectoral technological applications to water, energy, and food resources, reveals a silo mentality approach in the integration of technologies with the WEF nexus, shortchanging the gains of the nexus, as envisaged by Hoff (2011), WEF (2011), and Leck et al. (2015). A silo mentality approach is an approach whereby individual sectors of WEF resources enact sectoral policies and strategies without considering the effects of such policies and strategies on other sectors of WEF, considering their interdependences. Leck et al. (2015) averred that the silo mentality approach regarding WEF resources instead of an integrative nexus approach leads to conflicting policy statements, resource constraints, and WEF insecurity. Unlike a silo mentality approach, an integrative approach will enable the easing of trade-offs, hasting synergies, identifying individual & collective WEF resources bottlenecks, and aiding effective collaboration irrespective of geographic collaboration. The World Economic Forum (2011) stated, "*Any strategy that focuses on one part of the nexus without considering its interconnections risks serious unintended consequences*." The integration of technology to the nexus among the three resources becomes a strategic approach to ensure the security of the WEF nexus.

The WEF nexus is now a global discourse. Several concepts and researches are emanating from it, which has led to several technological innovations, as seen in the studies of Zhang et al. (2021), Ahmad et al. (2021), Fabiani et al. (2020), and You et al. (2021). The researches of Dwivedi et al. (2017), Royston and Pavithra (2018), and Vijayapriya and Kothari (2011) have shown that there are technological breakthroughs in each of the WEF resources sectors. Despite the applications of different technologies to water resources, energy resources, and food resources, individually, there is a dearth of research on the level of applications of the fourth industrial revolution technologies on the nexus between the three resources and the extent of the relationship between the fourth industrial revolution technologies and WEF nexus. There is a dearth of research highlighting the effect of all the fourth industrial revolution technologies on the nexus of the three resources. This paper seeks to bridge this identified gap. This paper aims to analyze the relationship of water, energy, and food nexus with the fourth industrial revolution technologies to achieve sustainable security of the three resources. Sustainable security ensures that WEF resources security, as defined by Pahl – Wostl (2019), is sustainable for both current and future human beings. The security of the resources should not just be a contemporary issue but conscious efforts to manage the trade-offs and synergies among the resources for the resources, in every WEF process, which can be achieved through the application of the fourth industrial revolution technologies. Succinctly, sustainable security of the resources is the application of 4IR technologies to ensure the various definitions of water security, food security, and energy security, making it sufficiently stable for both the present and future generations. The aim encompasses the following objectives; evaluating the application of the various 4IR technologies on WEF nexus with the possibility of establishing a nexus 4.0 and analyzing the effect of the fourth industrial revolution on the sustainable security of water, energy, and food resources. The sustainable security of the resources entails achieving sustainable development pillars, including economic sustainability, environmental sustainability, and social sustainability (Mensah, 2019), which can aid the quantification of the sustainable security of the resources. Thomas (2015) stated that sustainability focuses on people's activities in their quest for the satisfaction of their needs, without depleting or finishing the productive resources within their domain. This will ensure appropriate equilibrium and alignment among the economy, environment, and society regarding the regenerative capacity of the planet's life-supporting ecosystems (DESA – U.N., 2018).

1.1. *The fourth industrial revolution technologies*

The Fourth Industrial Revolution was first introduced as a technological concept in 2011 by a team of scientists working for the German Federal Government at the Hannover Fair and later coined in 2016 at the Davos World Economic Forum by Schwab Klaus, Executive Chairman of the World Economic Forum (Prisecaru, 2016). According to Poljak (2018), a fourth industrial revolution is a strategic approach to integrating advanced Internet-based control systems that allow people and machines to connect anytime, anywhere with anyone and anything in the unique complex system. The fourth industrial revolution is the fusion of smart technologies, computers, gene sequencing, Nanotechnology, renewables, quantum computing, and their interactions across the physical, digital, and biological domains. It is the fusion of digital and emerging technologies such as the Internet of Things, Internet of Services, Cyber-physical systems, smart factory, artificial intelligence systems, three-dimensional printing (3D) printing, Robotics, Cryptocurrency, blockchain technology, quantum computing, bioengineering, and Nanotechnology, which are changing how materials, services & products are produced and consumed (Erboz, 2017; Skilton and Hovsepian, 2018). It is a revolutionary change affecting all industries, including primary, secondary, and tertiary industries (Lee et al., 2018). This revolves around the five (5) pillars of a stable society; Food, security, health, prosperity, and knowledge (Prisecaru, 2016). The major technologies of the fourth industrial revolution are succinctly explained;

a. **The Internet of Things (IoT):** According to Karabegovic and Husak (2018), the Internet of things is the network of physical objects, which has embedded technology to interact, communicate and sense with their internal states and external environment, which forms the very heart of the fourth industrial revolution. It is an ecosystem of the Internet, where through the Internet, there are the connections between people and things, between things & things and between people & people, which was first coined by the radio frequency identification (RFID) development community in 1999 (Patel and Patel, 2016). Communication through the Internet between the cyber-physical systems permeates everything of at least 25.6 billion things, helping to improve the quality of life and the productivity of society, individuals, and enterprises/industries (GSM Association, 2014). According to Patel and Patel (2016), IoT is the underlying pillars of smart living, smart cities, smart energy, smart transport, smart industry, smart health, smart building, and smart homes.
b. **Big Data Analytic:** Taylor – Sakyi (2016) opined that big data are large sets of complex data, both structured and unstructured, of high volume, high velocity, and a wide variety of information assets. The author further opined that this data demands innovative forms of information processing that are cost-effective and cannot be operated by traditional processing techniques and algorithms, thus enhancing insight, decision-making, and process automation. Big data analytics helps improve and increase the competitive advantage of manufacturing companies, promote data collection from multiple reliable sources, comprehensive data analytics for real-time decision making, monitoring the processes of manufacturing activities, and helps in failure detection (Lee et al., 2017; Bahrin et al., 2016; Kamble et al., 2018).
c. **Cloud computing**: According to Xu et al. (2018) cloud computing entails storing and computing huge amounts of data to promote manufacturing activities, enabling modularization and service orientation. Srinivas, Reddy, and Qyser (2012) harangued that cloud computing, as defined by the National Institute of Standards and Technology (NIST), is a technological model for enabling on-demand network and convenient access to a shared pool of configurable computing resources (such as networks, servers, services, storage, and applications), which can be released with minimal management effort or service provider interaction. It is Internet-based computing, where all information is digitalized in the cloud, whereby users can access it anytime.
d. **3D Printing/Additive Manufacturing:** Shahrubudin et al. (2019) stated that 3D printing is a digital fabrication technology, which produces physical objects in a dimensional structure using geometrical representation. Hossain, Zhumabekova, Paul & Kim (2020) highlighted that 3D printing, which is also known as additive manufacturing, is an automated process that produces three-dimensional (3D) shapes. This helps optimize smart manufacturing and lean manufacturing (Chen and Lin, 2017).
e. **Robotic System:** Umachandran (2020) opined that robotic technology is an interdisciplinary field of computer science, electro-mechatronics, and information engineering to compute and control sensory feedback and data in supporting activities & applications that substitute human actions. The Robot Institute of America (RIA) in 1979 stated that "*industrial Robots are reprogrammable multi-functional manipulators designed to move materials, tools, parts or specialized devices through variable programmed motions for the performance of varieties of tasks, which also acquire information from the environment and more intelligently in response*". Robotic technology occasioned by the fourth industrial revolution is aiding and replacing man in production activities due to their high intelligence level and efficient performance of assigned tasks.
f. **Augmented Reality:** Silva, Oliveira & Giraldi (2003) and Chen et al. (2019) averred that augmented reality is a technology between virtual reality and telepresence. The users see the real world augmented with virtual objects. According to the authors, virtual reality is a term used for computer-generated 3D environments that allows a person to enter and interact with a synthetic environment across varying degrees in the artificial computer world, which is the simulation of some reality or simulation of a complex phenomenon. Telepresence entails extending a user's sensory-motor facilities and problem-solving abilities within a confined or remote environment. Silva et al. (2003) further stated that A.R. is designed within three aspects; combining real & virtual worlds, interactivity in real-time, and registration in 3D.
g. **Artificial Intelligence:** Kayembe and Nel (2019), avowed that Artificial intelligence is the ability of computer or technological applications to perform complex functions that are associated with human intelligence, but with superior intelligence and capacity. It is a technological application with the characteristics of human beings. Perez, Deligianni, Ravi & Yang (2018) opined that artificial intelligence entails the provision of machines or designs of technological applications with the capacity to perform functions such as logic, planning, reasoning, perception, and learning.
h. **Blockchain technology:**

Holotescu et al. (2018) detailed that blockchain technology creates a decentralized technological environment, where the cryptographically validated transactions and data are not within the control of any third-party organization, whereby completed transactions are recorded in an immutable ledger in a verifiable, transparent, secure and permanent way with a timestamp and other details. Gartner (2018) discoursed that censorship resistance, global usability, and global networks of miners, who validate the transaction and maintain it through block rewards, called crypto tokens, characterized a blockchain. Rawat, Chaudhary & Doku (2021) stated that blockchain is a chronological chain of blocks. Each block is considered a page in a ledger, and the chain grows continuously as miners discover new blocks and are appended to the existing blockchain.

i. **Digital Twin Technology**: this is a simulation technology that entails the integration of a multidisciplinary, multi-physical quantity, multi-probability and multiscale in complete utilization of physical model, operation history, sensor update, and other data (Wang, 2020). The author further opined that digital twin technology is a virtual model that completely corresponds to and is consistent with the physical entities in the real world, simulating its behavior and performance in a real-time environment. According to Fei et al. (2017), it is the foundation of an intelligent manufacturing system, whereby feedback is realized from the physical system to the virtual world and vice versa for optimality.

1.2. The theory of technological acceptance model

Davis (1989) propounded the Technology Acceptance Model (TAM) theory on how readily people will accept new technology. He demonstrated it at the Massachusetts Institute of Technology (MIT) in the '80s, on the acceptance of an IBM product (Silva and Dias, 2007). According to the authors, TAM focuses on why users will accept or reject technology and improve acceptance or rejection. According to Deslonde and Becerra (2018), TAM predicts the level of technology acceptance and usage, categorized into Perceived ease of use and perceived usefulness. The authors opined that perceived ease of use (PEU) is the degree to which a user believes that using a particular technology would require minimal or easy efforts. In contrast, perceived usefulness (P.U.) entails the extent to which technology enhances job performance.

Furthermore, Wingo, Ivankova & Moss (2017) stated in their research, as seen in Fig. 1, that five (5) factors contribute to the perceived usefulness of a technology. The first one is the subjective norm, which entails how the users believe other people perceive the technology based on their experience and whether it is mandatory or voluntary. The second factor is how the technology used will affect the user. Job relevance, the third factor, deals with how the user perceives that the technology would help accomplish the job's significant goals. The fourth factor is the output quality, demonstrating how the quality of the technology will influence applied tasks. In contrast, the fifth factor, demonstrability, entails the technology's perceived tangible outputs and benefits.

The use and application of the fourth industrial revolution technologies on the water, energy, and food nexus will be subjected to the acceptance of the technologies based on the theory of the Technology Acceptance Model (David and Adepoju, 2021). Users of the WEF nexus will observe the technologies' perceived usefulness and ease of use of the technologies. This entails that WEF nexus stakeholders, policymakers, researchers, and project managers should focus on simplifying the industry 4.0 technologies for easy usage and highlight the importance as this paper attempts to speed up the acceptance of the technologies.

However, there is no research on how the technology acceptance model theory has been applied to the technological performance of 4IR integrated WEF products. This study opines that in the development of products or innovations from the application of 4IR to WEF nexus, the following factors must be considered;

i. The current level of WEF integration in the proposed product area or environment.
ii. The knowledge level and Absorptive capacity of end-users and operators of the product.
iii. The similarities and differences with other innovations and their rate of acceptability.
iv. The history of technology acceptance in the parent organization of the WEF product.
v. The interoperability and simplicity of the production system design and the system development life cycle.
vi. The expected benefits of the new technology, especially, process simplification in comparison to the existing norm.
vii. The transactional capability and managerial capability of the expected WEF – 4IR technological product.
viii. The simplification process of the learning procedures and operation manual for the new products or innovation.
ix. The integration of the products with existing organizational culture and norms.
x. The sustainability and upgrading framework, in light of constantly changing technological innovation.

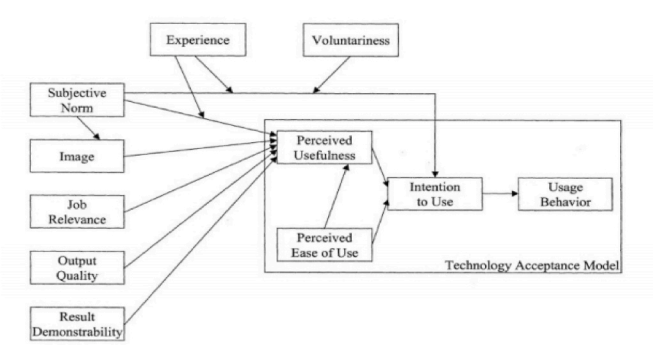

Fig. 1. Technology acceptance model (Wingo et al., 2017).

1.3. Innovation diffusion theory

Rogers propounded Innovation Diffusion Theory (IDT) in 1962 in his book titled "Diffusion of Innovation," explaining how innovation or technology spread and its acceptance among a population. Jwaifell and Gasaymeh (2013) opined that innovation diffusion theory describes how people adopt innovation. Citing Rogers (2003), the authors opined that adopting technology and experience is effective in their activities before accepting or rejecting the technology. Rogers (2010), cited by Choe and Noh (2018), defined IDT "as the process by which an innovation is communicated through certain channels over time among members of a social system."

Rogers (2003) stated that the adoption and spread of innovation is determined by five (5) qualities, which are;

a. **Compatibility**: this entails the perceived consistency with values, needs, and experience of possible users & adopters.
b. **Relative advantage**: this connotes that the more incredible, easier, and quicker technology adopters realize the benefits, merit, and importance of technology, the fast its rate of adoption.
c. **Trialability:** this is the extent to which the exploited technology can experiment on a limited basis.
d. **Simplicity and ease of use**: this is based on the technology's ease of usage and application. People will quickly adopt an easy-to-use technology that requires new skills and knowledge.
e. **Observable results**: the quicker and easier potential technology adopters see the benefits and results of using technology, the faster it is adopted.

Furthermore, according to Rogers (2003) and Sahin (2006), there are four (4) main elements in the diffusion of innovation, which include innovation, communication channels, time, and social systems.

a. **Innovation**: This is an idea, project, or practice that an individual perceives as new, even if the invention has been invented for a long time.
b. **Communication channels:** this is the process whereby participants create and share information or reach a conclusion or mutual understanding. According to Rogers (2003), the communication channels in the IDT entail five channels shown in Fig. 2. This consists of knowledge (this is, the why, what, and how of the innovation); Persuasion (this is the formation of favorable & unfavorable attitude towards the innovation based on the degree of uncertainty); Decision (at this stage, the user decides to either accept or reject the innovation); Implementation (the user is putting the innovation to practice), and Confirmation (the user has decided to use the innovation but needs further support to cement their acceptance decision or uncertainty attitude).
c. **Time:** this entails the period by which people adopt the innovation. According to Rogers and Shoemaker (1971), Rogers (2003), and Dearing and Cox (2018), the innovation process can be categorized into five (5) categories of adoptions, which are followed in the introduction of any innovation. They are innovators who are always eager to try new ideas and innovation but constitute 2.5% of the social system. The second category is early adopters, constituting 13.5%, of localite and have the highest degree of opinion leadership in the social system. The third group is the early majority constituting 34.0%, who adopt innovations before an average member of the social system and help significantly in the diffusion process. The fourth category is the late majority, constituting 34.0% of the social system, who are skeptical and cautious members of the social system, after an average member of a social system. The last category is Laggards, made up of 16.0% of the social system, who are the last to adopt an innovation due to their fixation on the past. This is shown in Fig. 3.

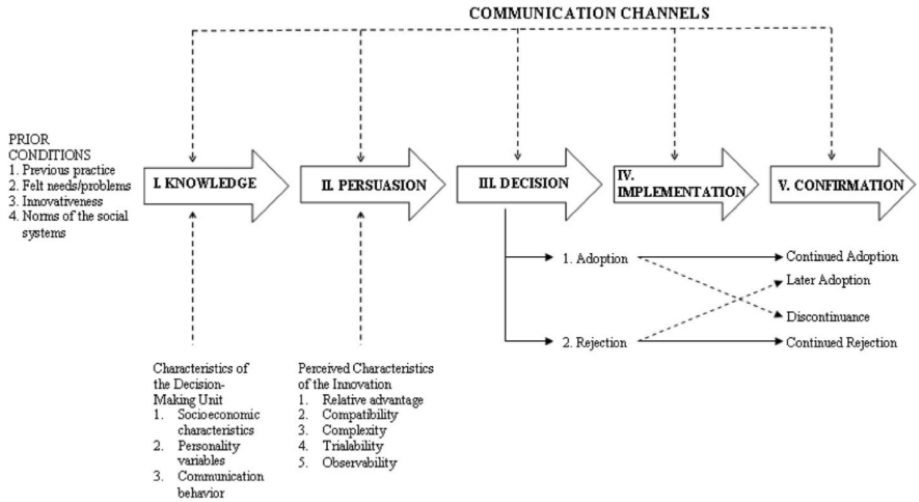

Fig. 2. IDT communication channels Rogers (2003); Sahin (2006).

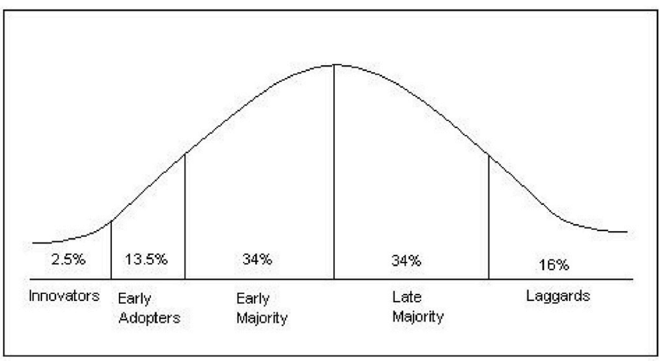

Fig. 3. IDT Time of adoption (Rogers and Shoemaker, 1971).

d. Social system is a set of interrelated units engaged in solving a problem to achieve a common goal, often influenced by a social structure.

Applying the innovation diffusion theory to the relationship between industry 4.0 technologies and the water, energy, and food (WEF) nexus entails that before accepting those technologies, they must be applied in stages and not in a forceful attempt. This will require quick acceptance of the technologies and their sustainability when applying to the WEF nexus. Relevant stakeholders in the WEF nexus must be appraised based on the five (5) communication channels of IDT and the five (5) qualities of the theories.

Nevertheless, considering the dearth of research on the application of IDT to WEF nexus and 4IR, this study, in an attempt to ensure that IDT processes and communication channels are followed for technology sustainability, postulates that the following pitfalls must be avoided. The pitfalls are drawn from the Innovation diffusion theory.

i. The underestimation of a needs assessment of the user's level of knowledge.
ii. The complexity of the technological process of the product without the learning pattern of the parent organization.
iii. Poor leadership enthusiastic attitude towards innovation.
iv. Poor R & D strategies in the parent organization.
v. Poor adaptation to technological changes by both management and staff of the product parent organization.
vi. The over-centralization and rigid sophistication of processes and data of the product.
vii. Lack of flexibility and agility.
viii. Weak innovation processes.
ix. Over concentration on marketability and not sustainability.
x. Ignoring the value of timing in the WEF nexus integration.
xi. Limited financial resources.
xii. Poor alignment of product goals with organization structure and strategic objectives.
xiii. Quick mass production, leaving no room for feedback in improving the innovation.

1.4. Methodology

In achieving the aim and objectives of the research, qualitative methodology was used, which entails the collection and analysis of empirical literature and non–numerical data to contextualize opinion, understand the experience, and review concepts (Adepoju and David, 2020). Bhandari (2020) opined that qualitative methodology helps researchers gather in-depth insights into a problem to generate new ideas and solutions. This study did a critical analysis and in-depth analysis of relevant research journals, articles, editorial, and publications from the Scopus database, web of science, and google scholar. The curated papers/publications were reviewed logically, strategically, and structurally following the study's objectives in analyzing the sustainable security of the technologies of the fourth industrial revolutions on water, energy, and food (WEF) nexus.

Furthermore, a bibliometric analysis was conducted to ascertain the research focus (Keyword co-occurrence) and research trends in applying Industry 4.0 to WEF nexus; concentrating on water 4.0, Energy 4.0, and Food 4.0. The Bibliometric analysis was done using published Journal Articles, conference proceedings, books & book chapters from the Scopus database, which is a significant database frequently used by most researchers with a wide coverage of the different fields, in comparison with other databases (Aghimien et al., 2019; Hosseini et al., 2018). The key search words were "Water 4.0", "Energy 4.0″, "Food 4.0″, "WEF Nexus 4.0″, and "Nexus 4.0". Publications that have these search words in their title, abstracts, and keywords were extracted. The period for the study was from the year 2010 to July 2021, covering the popularization of WEF nexus in 2011 by Hoff (2011) and 4IR by Schwab (2015), giving a more profound and comprehensive coverage of research on the subject matter. The initial search produced 63 papers across all fields; however, a limitation was set to the English language alone with refining done. The following fields were excluded; medicine, chemistry, nursing, immunology & microbiology, and health profession. This led to 32 documents, which were extracted. The extracted documents were analyzed using Vosviewer software. A Vosviewer is a literature review software, which offers the basic functionality needed to visualize bibliometric networks in the most accessible ways (Aghimien et al., 2019; Van Eck and Waltman, 2014). The framework used for the Bibliometric analysis is shown in Fig. 4.

2. Results and discussion

2.1. Applications of 4IR technologies on WEF nexus

2.1.1. Internet of things and WEF nexus

Mekonnen et al. (2018) stated that the Internet of Things (IoT) is highly essential in understanding the interdependency of WEF resources, using wireless sensor networks (WSN), which will help in creating real-time data for smart farming. The sensor networks will enable farmers to predict their agricultural yields, enhance water utilization through intelligent irrigation control and precisely know when to harvest, reducing labor & energy input. This will ensure environmental sustainability, as farming will be based on Precision and the maximization of efficiency, for more yield, without adverse effects on the environment. The authors avowed that IoT would help collect data. The data are analyzed using different linear regression algorithms, neural networks, support vector machines (SVM), and Artificial neural networks (ANN) to make informed decisions in the WEF systems. Using an IoT technology, the authors built a smart farm bed consisting of a distributed WSN, smart irrigation, off-grid P.V. panel, and data infrastructure to maximize vegetation yield, minimize the environmental effect, and reduce energy consumption. The advent of IoT technologies helped enhance the effective utilization and integration of data across the WEF resources, making nexus possible practical, and applicable. The management of WEF data is an integral component of ensuring sustainability, especially on operations and delivery of the resources (Etzion and Aragon – Correa, 2016).

Moreover, Kumar, Dash & Singh (2018) and Lin and Liao (2017) asserted that IoT helps maximize efficiency, quickness, productivity, effective control, simple operation, and efficient monitoring. In the WEF nexus system, IoT is essential, as various IoT(s) systems have been used and culminated in several benefits. The benefits are as follows: enabling the user to practice efficient measures, ensuring asset performance & management, assisting consumers to become energy & water efficient, ensuring food security, water quality monitoring, energy sustainability, water sustainability, and food sustainability (Kumar et al., 2018). The Research of Kumar et al. (2018) highlighted the application of IoT in the various WEF components. In the water subsystem of the WEF nexus, IoT applications include water quality monitoring, water safety, wastewater management, quality control in water reserves, water transport, monitoring the drought locations, leakage detection in water flow paths, efficient & systemic water management, and watching the water consumption patterns. IoT applications in the Energy subsystem of WEF nexus are advanced metering infrastructure (AIM), Control & operation of energy-consuming devices (Co – ECD), Battery Energy Management (BEM), Control of electrical energy system and utility (CEESU), Nano Grid (N.G.), Micro Grid (M.G.), and Energy system reliability & stability (ESRS). Other applications are Decrease in Energy Downtime (DED), Energy and Performance Optimization (EPO), energy storage & Analytics (ESA), Fault maintenance in energy systems (FMES), Predictive maintenance (PM), Hybrid Energy system intelligent Control (HES – I.C.), and Smart Grid (S.G.). It also includes Hybrid Electric Vehicle Intelligent Control (HEV – I.C.), Remote monitoring and Reliability (RMR), Smart Inverters (S.I.), Supervisory Control and Data Acquisition (SCADA), and Safety & Security (S.S.). The utilization of IoT technologies in the food subsystem of WEF nexus includes storage and handling of food products (SHFP), Food transport, Food packaging, Freshness and quality monitoring of food products that are originated from plant species & animal meat, and intelligent packaging & delivery (IPD). Others are Food delivery monitoring & Alert, vegetable washing systems, removing dried and damaged leaves from the food material from the plants, food safety & security, cereals & pulses drying at controlled temperature, sorting of vegetables, packed food products & fruits, online payment of food bills and food safety & security.

The application of IoT technologies in the WEF nexus is driven by the utilization of WEF resources data from both the users, operators, sensors, and other external systems, which will add technologies of the subsectors in communicating with each other in achieving sustainability security of the resources. Data correctness, availability, Precision, and adequacy are WEF nexus issues that IoT technologies will address, affecting the economic, social, and environmental sustainability of resources. IoT aids the WEF subsectors technologies in collating & analyzing WEF data for a WEF nexus security.

2.1.2. Big data analytics and WEF nexus

According to Abe et al. (2016), data science is needed to analyze WEF nexus datasets and the functionality of WEF subsectors technologies, especially in spatial computing. Pitts et al. (2020) opined that big data Analytic technology is a technique for modeling WEF nexus, where there are no reliance or underlying assumptions between variables; still, data is the foundational input in the model. This makes it less prone to error and uncertainty, quick to develop, and shows trade-offs in the nexus, highlighting areas that adversely affect sustainability issues. According to the authors, Big data is characterized by 5V's: volume of the data, the veracity of the data source, variety of the data needed/collected, the velocity of the data, and value of the data. These 5V's aid in effective decision-making regarding the WEF nexus, as they highlight the effects of the data source on the sustainable process of the nexus of the three resources. This is essential because the sustainability of the nexus of the three resources starts from the source, where they are processed, whereby through big data analytics, the integrated preventative environmental strategies of cleaner production (Gavrilescu, 2004) will be achieved. Moreover, big data analytics are seen in the research of Kumar et al. (2018) in terms of monitoring and predicting drought location, simplifying the usage of smart grid and food processing technologies.

A critical in-depth review of the literature shows that most of the technologies that make up the fourth industrial revolution have not yet been applied to the concept of WEF nexus, except IoT technologies and Big data analytics, as there is no research on the applications. This review shows that the significance of the technologies of the Fourth Industrial Revolution to WEF nexus is majorly in the area of data optimization. WEF resources data are highly essential for technological breakthroughs. For instance, cloud computing will require various WEF resource data to compute a WEF nexus data, stored in the cloud, accessed, and used anywhere. WEF nexus data stored from a geographical location could be accessed in another geographical location without altering utilization in the geographical source. Products of WEF nexus could be manufactured using Additive Manufacturing technologies, but will also depend on the availability, accuracy, and

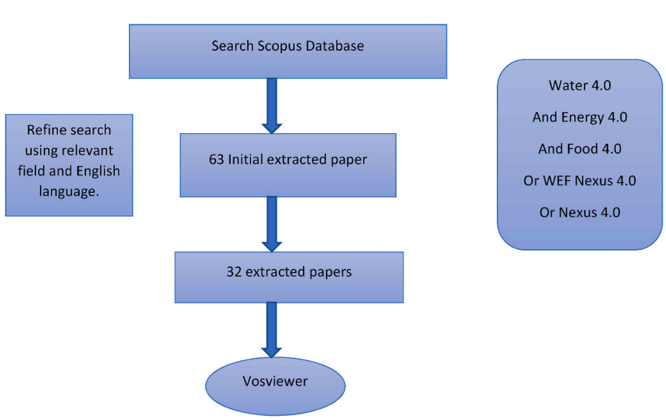

Fig. 4. Bibliometric analysis framework.

accessibility of WEF resources data. This shows the interdependence of the fourth industrial revolution technologies in the productivity of the WEF nexus. This will also be seen in the utilization of Robotic technology, which will require WEF resources data and input from other 4IR technologies like Artificial intelligence, blockchain technologies, and other big data. These facts highlight the essence of the cleaner production process in ensuring that the sustainability goals of WEF nexus and 4IR are achieved. According to Berkel (1999), cleaner production provides the efficient use of natural resources, reducing their wastes and attendant emissions at the source, using the practices of product modification, technology modification, and on-site Recycling.

2.1.3. WEF sectoral application of 4IR

However, despite the limited applications of the fourth industrial revolution technologies to WEF nexus that could have occasioned WEF nexus 4.0, there are sectoral industry 4.0 leading to the concept of Water 4.0, Energy 4.0, and Food 4.0. There are thousands of researches on the three concepts from Scopus, web of science, and Google Scholar databases. Food 4.0, also known as Agriculture 4.0 or Agric – Food 4.0, is the advancement of digital technologies application in Agriculture and Food production to meet Agric food production challenges, achieve more affordable market prices, and minimize costs for farmers (Lezoche et al., 2020). The authors opined that these objectives are solved through Precision agriculture (Food 4.0 technologies), remote sensing, robots, smart agriculture, farm management information systems, and agronomics decision support systems, which is made possible by industry 4.0 technologies of big data technologies, blockchain, Internet of Things technologies, Artificial Intelligence techniques, and Precision farming techniques. According to The Economist Intelligence Unit (2018), Food 4.0 is evidence of food cultivation in Laboratories, known as genetically modified (G.M.) food. Alimkhan, Makhambayer, and Ukaegbu (2019) stated that Energy 4.0 is the digitalization of the energy industry through the introduction of Industry 4.0 technologies such as cloud computing, IoT, big data, and other technologies into energy generation, transmission, distribution, retail, and consumption spheres. According to Teba (2021), Energy 4.0 will ensure electricity utilities address grid instability and imbalance issues, leading to the interoperability of multiple types of assets such as renewable generation and flexible loads. It will also ensure appropriate energy storage, identify process inefficiencies and faulty equipment, and reduce the energy consumption of five (5) industries by 13–29%, reducing global CO2 emissions by 4%. Alabi, Telukdarie & Rensburg (2019) and Bufler et al. (2017) opined that water 4.0, which was coined by the Germany water partnership (GWP) in 2000, entails the usage of the combination of virtual and real water systems through cyber-physical systems (CPS), real-time monitoring & forecasting, smart devices such as sensor, Internet of Things, and data management systems. According to the authors, the leading fourth industrial revolution technologies applicable to the water sector in ensuring water 4.0 are the Internet of Things, Big data technology, cloud technology, Artificial Intelligence, and Machine learning.

These sectoral applications of 4IR revealed that there would be more concentration on the economic sustainability of the resources than social and environmental sustainability. Klarin (2018) stated that economic sustainability encompasses the maintenance of human, social, and natural capital necessary for income generation and improving living standards. Liao et al. (2018) averred that economic sustainability brings satisfaction to the present level of consumption without compromising future needs. 4IR sectoral application to individual WEF resources ensures economic growth because of proceeds from the resources without considering the trade-offs and synergies. The fourth industrial revolution is a sustainability optimizer concerning the three resources.

2.1.4. 4IR and WEF nexus integration

2.1.4.1. Research focus. The Voice viewer analysis for research focus and trends was done using the co-occurrence of keywords as opined by Botai et al. (2021) and Saka and Chan (2019). In doing this, three (3) co-occurrences were used with full counting. This means that extracted keywords have three (3) co-occurrences in publications and source indexed keywords. The analysis showed that from the 32 extracted documents, there are 752 keywords, out of which 43 met the co-occurrence threshold, which through Vosviewer were grouped into five (5) clusters.

As shown in Fig. 5, the bibliometric analysis revealed no clear-cut research focus in applying Industry 4.0 to WEF nexus, relating to Water 4.0, Energy 4.0, and Food 4.0. However, the various keywords co-occurrence shows that industry 4.0 is acting as an intrinsic foundation for WEF nexus, especially in processing and circular economy. The analysis revealed five (5) clusters; Cluster 1 depict WEF nexus processing and waste control consisting of the fourteen (14) keywords: analysis, biogas, Biomass, chemistry, controlled study, food processing, food – processing industry, gas, gases, hydrogen, procedures, refuse disposal, temperature, and waste management. This shows that industry 4.0 is addressing wastes in the WEF nexus. Feng et al. (2020) opined that food waste is synonymous with wasting water & energy since food production, processing, and consumption contribute to about 70% of global water withdrawal and 30% of global energy consumed. This could lead to clean energy, water production, and waste-to-energy technologies (Feng et al., 2020). The cluster also shows that Industry 4.0 technologies seek to regulate the minimization of waste from WEF resources, conversion of waste to energy in the eventuality of waste, and production of Sludge as fertilizer or soil improver.

The second cluster focuses on oxygen optimization enabled by WEF nexus, consisting of 12 items; animals, anoxic conditions, article, diet, hydrogen – ion concentration, metabolism, nonhuman, oxygen, Ph, priority journal, water pollutant, and water pollutant chemicals. The cluster reveals the impact of WEF resources activities on oxygen purity for both men and animals. This further revealed that industry 4.0 technologies seek to regulate human activities relating to WEF resources to control biodiversity loss, encourage a sustainable ecosystem and reduce anoxic conditions. The third cluster deals with waste from food and water, consisting of 7 items: fermentation, food industry, food waste, industry 4.0, methane, waste treatment, and wastewater treatment. These deals with technologies of 4IR that could help treat wastewater, prevent food waste, and convert waste to other valuable products. 4IR technologies such as Artificial Intelligence and Robotic Technologies are vital in this cluster.

The fourth cluster depicts the industrial conversion of WEF waste, consisting of five (5) items, namely, anaerobic digestion, bioreactor, effluent, bioreactors, and sludge digestion. These deal with 4IR technologies in breaking down other wastes from WEF processing into valuable byproducts. Also, the cluster entails chemical engineering technologies, which could be enhanced by 4IR technologies of big data analytics, IoT, blockchain technology, and cloud computing. The Fifth cluster depicts water to energy technologies consisting of five effluents, rain, sewage, wastewater reclamation, water, and energy.

The Five (5) clusters have shown that the mild application of 4IR technologies to WEF nexus sustainable security focuses on integrating the byproducts & wastes of WEF resources and processing involved in WEF nexus. This highlights that 4IR technology enabling WEF sustainable security requires WEF resources data across different fields. It also shows that the application of 4IR technologies will cut across different studies because of the composition of WEF resources, which is virtually present in all areas of study.

The five (5) clusters showing the relationship between WEF nexus and 4IR aggregate the fact that 4IR in ensuring sustainable security of the resources, will ensure cleaner production of the resources. This is because the application of 4IR to WEF nexus mainly revealed processes of WEF resources in achieving a nexus among the three resources. These cleaner production processes and practices will lead to achieving sustainable Development, which of course will aid the sustainable security

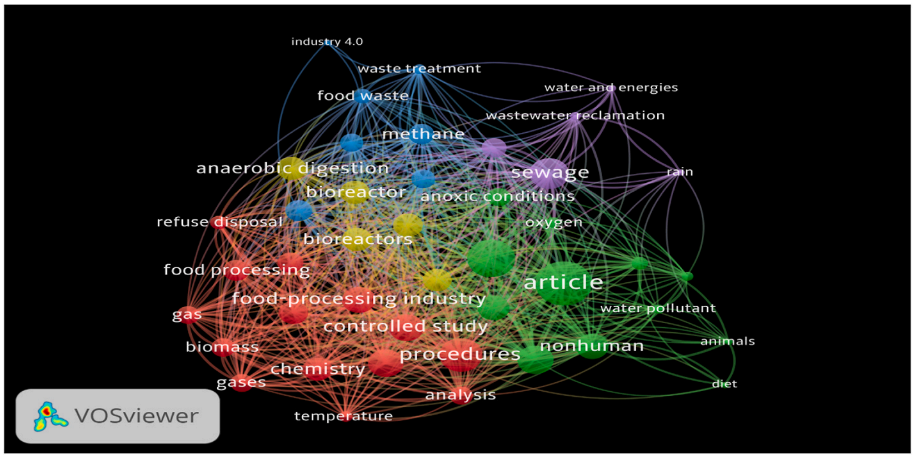

Fig. 5. Bibliometric research focus (Authors Research, 2021).

of the three resources (Gavrilescu, 2004). Hence, both the technologies of the fourth industrial revolution from different researches and the concept of cleaner production, from the bibliometric analysis will ensure that the three resources are sustainably secure for man. Giannetti et al., (2020) stated that cleaner production entails the efficient management of resources through the development of new and smart technologies, new mechanisms for policy development, and sustainable supply chain organization. Berkel (1999) and Gavrilescu (2004) opined that cleaner production focuses on production processes of resources, similar to the outcome of the bibliometric analysis, through resource conservation, elimination of toxic raw materials, reduction of toxic wastes, and incorporation of environmental concerns into product designs and service delivery. Fig. 5, the bibliometric analysis outcome of the relationship between WEF nexus and 4IR, revealed that 4IR would lead to a cleaner technology as a product of cleaner production. The organization for Economic Cooperation and Development, OECD, as cited by Simboli et al. (2014) defined clean technologies as: "*technologies that extract and use natural resources as efficiently as possible in all stages of their lives, that generates products with reduced or no potentially harmful components, that minimizes releases to air, water and soil during fabrication and use of the product; and that produce durable products which can be recovered or recycled as far as possible; output is achieved with as little energy input as is possible*". These outcomes further showed that the 4IR integrated WEF nexus would lead to the three pillars of sustainable development, economic sustainability, social sustainability, and environmental sustainability. Du & Kang (2016) and Cooper & Vargas (2004) opined that economic sustainability entails the supply of natural resources and market realities for optimum allocation of resources, resulting in technological advancement in replenishing depleted resources during production processes. Mensah (2019) stated that environmental sustainability is the ability of the natural environment and ecosystem to remain resilient and productive in supporting human life. Natural resources processes in the environment do not affect Man's economic performance both in the short run and in the long term. Saith (2006) avowed that social sustainability fosters cultural development of people and communities to achieve a meaningful life, with dependences on healthcare, education, peace & stability, and gender equality.

Succinctly, the Integration of WEF nexus with 4IR technologies will ensure WEF nexus 4.0, stemming from the water 4.0, energy 4.0, and food 4.0 in the literature reviews, which will lead to cleaner production and clean technology, thereby ensuring the sustainable security of water, energy, and food resources.

2.1.4.2. Research thread. Fig. 6 shows the research threads in applying

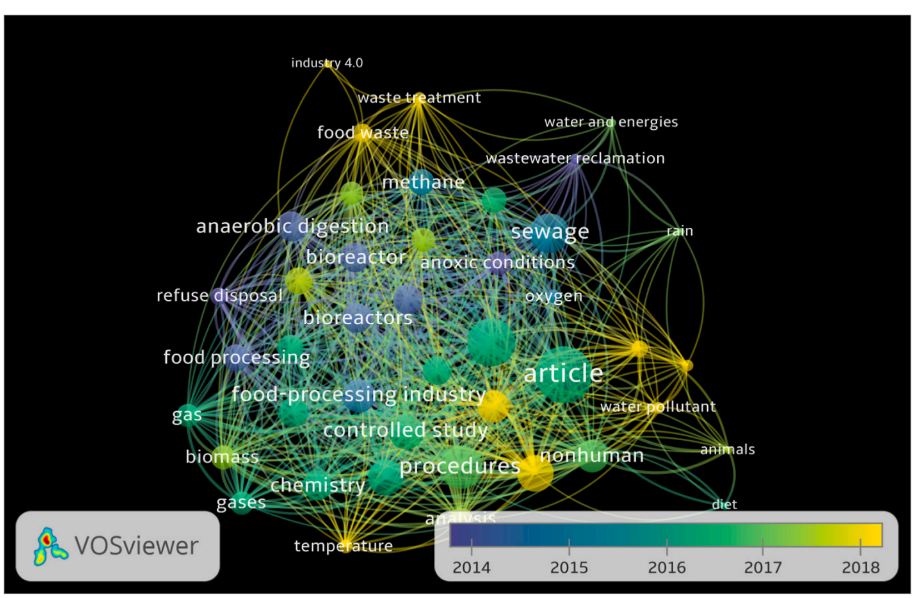

Fig. 6. Bibliometric Research threads (Authors Research, 2021).

4IR technologies to the WEF nexus in Food 4.0, Water 4.0, and Energy 4.0. The research trends show that the application of 4IR to WEF nexus started in 2014 with research in the following areas; sludge digestion, bioreactors, anaerobic digestion, anoxic conditions, refuse disposal, wastewater reclamation, and methane. From 2015 to 2016, research areas were waste management, diet, food–processing industry, waste management, gas, hydrogen, biogas, and effluent. However, current research focuses from 2017/2018 are fermentation, waste treatment, industry 4.0, wastewater treatment, food industry, food waste, metabolism, hydrogen ion concentration, water pollutants, Biomass, and water pollutants. The current thread shows that 4IR technological applications to WEF nexus are still dispersed and have no specific area of concentrations, showing the relationship between WEF nexus, cleaner production concept, and the fourth industrial revolution technologies.

2.2. Effects of fourth industrial revolution on WEF nexus

The fourth industrial revolution has emerged as a driving force in all fields of study, changing industrial applications and revamping technologies in all areas. The WEF nexus has been demonstrated as an intellectual discourse and emerging field of study altering the dynamics of the three critical resources. The application of 4IR to the WEF nexus will undoubtedly significantly affect the sustainable security of WEF resources in terms of WEF availability, affordability, preservation, accessibility, stability, and sustainability (Bizikova et al., 2013). Moreover, comparing the fourth industrial revolution to previous industrial revolutions is the efficiency of the technologies, in terms of speed, cost, and manpower required. Another significant advantage is the effectiveness of digital control of the entire system irrespective of geographical locations. The third significant advantage is optimizing data, especially for analytics, prescriptive and predictive purposes for WEF resources in different scenarios. The bibliometric analysis, highlighting the relationship between WEF nexus and the technologies of the fourth industrial revolution, will lead to the following effects of 4IR on WEF nexus, which are briefly explained.

2.2.1. Birth of clean technology and industrial applications

The Bibliometric analysis and literature reviews revealed that technologies of 4IR are permeating the WEF nexus in the area of processing resources together. This connotes that new industrial and clean technological applications will emanate from the application of 4IR technologies to WEF nexus, considering synergies and trade-offs in the sectors, ensuring an eco–friendly environment, and ensuring sustainability (Simboli et al., 2014). For instance, the application of IoT technology to the energy sector in birthing Energy 4.0, if applied to the production of food and treatment of wastewater, will lead to a new array of Industrial applications and new technologies. The fourth industrial revolution will affect the WEF nexus, especially in the production, processing, conservation, packaging, and storage of food and its byproducts, which will optimize the concept of cleaner production. Moreover, with the concentration of the world on the Development of Renewable Energy, industry 4.0 technologies will be handy in producing different technological products and industrial innovations useful for optimizing food and water resources. It will also aid in addressing the challenges of prepaid meter adoption in the quantification of energy used in producing food and water resources (Kambule et al., 2018). There will be a new technological breakthrough in the nexus between food & water, Energy & Water, and Food & Energy. This outcome also shows that the non – Integration of 4IR in the WEF nexus will lead to unsustainable technologies that will have enormous adverse effects on production processes and the environment, which will affect man, his way of life, and his ability to survive in the long term. WEF resources production technologies without the integration of 4IR technologies make sustainable innovation difficult.

2.2.2. Catalyst for sustainable security of WEF resources

The United Nations has, over the past decades, mobilized human, natural, physical, and capital resources on the security of WEF resources. However, with the advent of the 4th industrial revolution, the security of WEF resources is guaranteed as the 4IR technologies will be a catalyst for the sustainable security of the resources. This is because the bibliometric analysis of Figs. 5 and 6 shows that 4IR is permeating the conversion process of the three resources in reducing waste and ensuring the approach of “cradle to grave” and “life cycle thinking” of sustainability (Vacchi et al., 2021), for the security of the resources. This will be done majorly in the prevention of WEF waste, efficient transportation of WEF resources & products, identification & prevention of WEF resources risks, Precision of required WEF resources for a geographical location, efficiency in the production of WEF resources, and preservation of the ecosystem for WEF resources. WEF resources without the application of 4IR will stall WEF nexus, leading to unsustainable means of securing the three resources. They might lead to the pessimistic view of resource depletion by Meadows et al. (1972).

2.2.3. Enabling technological transfer

The application of 4IR technologies to the WEF nexus will lead to technological innovations in the concerned industries. However, with the disparity of technological knowledge and level of 4IR Development between developed nations and underdeveloped/developing nations, there is a high level of technological transfer. This is because of the enormous WEF resources in developing/underdeveloped countries and the high level of 4IR-technologies in developed nations. Furthermore, the application of 4IR on the WEF nexus will lead to a transfer of technological knowledge of 4IR technologies from developed countries developing/underdeveloped countries, leading to a balance of resources and equilibrium of resource supply across the developed and underdeveloped world. However, this will require a strategic approach in line with the technology acceptance model (TAM) and Innovation Diffusion Theory.

2.2.4. Enhance economic growth

Research such as Qi et al. (2021), Ruzavorsk et al. (2020), Shannak et al. (2018), and Lu (2017), has shown that WEF resources and 4IR are economic bedrock and economic stimulants, contributing to the economic growth of a nation. However, the integration of both concepts will enhance economic growth, primarily through foreign direct investment (FDI), as investors will want to optimize WEF resources through 4IR, especially in value management. This is because the full exploitation, explosion, and unbundling of the WEF nexus occasioned by 4IR will lead to a new array of business, investment, technologies, and market dynamics. According to Rafat and Farahani (2019), FDI is an amalgamation of technology, capital, management, and marketing, stimulating economic growth and ensuring economic development. Developing nations must begin investing in the applications of 4IR technologies to either the individual WEF resources sector or the resources’ nexus to avoid economic stagnation, food blockade, low energy utilization, and poor quality of water, which will impede on economic development of their countries.

2.2.5. Urban planning

The application of 4IR on WEF nexus as inferred from the bibliometric analysis will inevitably lead to the new array of developmental concepts such as precision agriculture, circular economy, value chain management, blue economy, climate change management, and fuel crops. These concepts are environmentally driven in nature and are stimulated by human activities. However, urban planning will be reconfigured with the increasing rate of human population and developmental concept occasioned by 4IR in WEF nexus. Current urban plans need to align with the strategic location, processing, and commercialization of the WEF nexus integrated with 4IR. This is also due to the integrative approach to synergies and trade-offs between WEF resources, which might require geographical cooperation/collaboration, depending on the availability and abundance of specific WEF resources. These changes and concepts will lead to a reconfiguration of urban planning to actualize a nexus for optimum availability, accessibility and transportation, and stability of WEF resources. This effect has not been popularized, going by the existing urban plans. However, failure to include the WEF nexus affects future urban plans, especially in smart cities, which will lead to resource conflicts, poor stake management, and constraint in implementing urban plans policies.

3. Conclusion and recommendation

This study conducted a comprehensive literature review on the relationship between 4IR and WEF nexus, examining the applications of 4IR technologies on WEF nexus and the effect of the 4IR on WEF nexus, using bibliometric analysis software. The content analysis of reviewed literature shows that of the significant technologies and emerging technologies of 4IR, only Internet of Things and Big data analysis have been tested and intertwined with WEF nexus. This revealed that for the applications of 4IR technologies on WEF nexus, WEF resources data is a priority for computation trade-offs and synergy. The study showed the sectoral application to WEF resources, leading to Water 4.0, Energy 4.0, and Food/Agric 4.0. These sectoral applications depict concentration on achieving Economic sustainability and social & environmental sustainability. In evaluating the relationship between 4IR and WEF nexus, using a bibliometric analysis, the clusters show a focus on cleaner production. This is because the investigation revealed that the application of 4IR to WEF nexus focused on processes of the resources in ensuring sustainable security of the resources. These applications and integration will also lead to clean technologies during the trade-offs and synergies of the resources. The study from empirical reviews of literature and bibliometric analysis shows five (5) significant effects of the Integration of WEF nexus and 4IR. These include the birth of clean technologies & industrial applications, a catalyst to achieve sustainable security of WEF resources, leveraging on life cycle thinking, the possibility of technological transfer from developed nations to developing nations, assurance of economic growth through foreign direct investment, and leads to reconfiguration of urban planning. The fourth industrial revolution technologies affect WEF nexus, ensuring the popularization of cleaner production strategies and processes. The integration of the fourth industrial revolution technology with the water, energy, and food nexus will ultimately be based on the cleaner production concept and the concept of sustainability. Failure to adhere to cleaner production practices will lead to short-lived sustainability of the resources, especially in the efficiency of the production process, development of smart technologies, waste management, product modification, eco–friendly policies, integrated preventive strategy, and environmental performance resource trade-offs & synergies.

However, as seen from the study, the application of 4IR to the WEF nexus will lead to economic sustainability, social sustainability, and environmental sustainability. Hence, for these to be achieved, there is a need for the private sector and the public sector to join efforts in optimizing and actualizing the relationship between 4IR and WEF nexus. This is highly needed for African countries, with abundant natural and WEF resources but lacks technological know-how. In addition, this study recommends that the national government invest in Research and Development (R&D), as this holds the key to the full unlocking of the benefits of 4IR for the security and attendant effect of the three economic resources of water and energy and food. The concept of cleaner production should be integrated into WEF processing. This process should involve the innovation diffusion theory (IDT) and Technology acceptance theory (TAM), during the application of 4IR technologies to the nexus of water, energy, and food resources, for their sustainable security.

CRediT authorship contribution statement

Love O. David: Conceptualization, Methodology, First Draft. **Nnamdi I. Nwulu:** Methodology, First Draft. Final Draft. **Clinton, O. Aigbavboa:** Methodology, Final Draft. **Omoseni, O. Adepoju:** Conceptualization, First Draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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