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Achieving Environmental Sustainability: the Contribution of Digital Automation Technologies of Industry 4.0 Used by Companies in Nigeria

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Abstract

The study investigated the contribution of digital automation technologies towards environmental sustainability practices of companies in Nigeria, and their level of implementation of these technologies. Four research questions were raised to achieve the study objectives. Cross-sectional survey design was used in the study. A sample size of one hundred and eighty-nine (189) respondents were drawn from a target population of accountants, top business managers, and Information Technology experts of manufacturing firms in Nigeria. Primary data were collected from the respondents with the use of a 4-point Likert-based questionnaire. Analysis of data collected was achieved by using frequency counts and Spearman Ranked Order Correlation Coefficient. The results showed that only Internet of Services have been implemented to a high degree while other elements of industry 4.0 have low implementation in Nigeria. It was equally found that digital automation technology implementation significantly enhances waste management practices, reduction in carbon emission, and natural resource use efficiency. The study recommends that managers of manufacturing firms in Nigeria should endeavour to acquire, implement and maintain digitized manufacturing facilities that use connected devices, machinery and production systems to continuously collect and share data in order to help the firms achieve more efficiency in their production processes.

Keywords: Carbon Emission, Digital Automation Technologies, Environmental Sustainability, ,Industry 4.0, Natural Resource Usage, Waste Management

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1. Introduction

The world has witnessed four different industrial revolutions, and it is currently at the eon of Fourth Industrial Revolution characterised by the integration of advanced technology, digital transformation, production processes and supply chain systems. The features of the First, Second and Third Industrial Revolutions were mainly mechanization, mass production processes and electricity (Castellani et al. 2021), and automation and information technologies, respectively (Castelo-Branco et al., 2023). Fourth Industrial Revolution came with the intertwining of digitization with other physical and biological domains that are relevant to manufacturing processes (Fredrich & Bouncken, 2021). In line with the scope of the Fourth Industrial Revolution, the business community in Germany thought up the word "Industry 4.0" (Olatunde et al., 2022; Senna et al., 2022) as a term used to explain manufacturing models that link all production and distribution functionalities for the purpose of achieving optimal outputs in a hitch free manner (Hassan et al., 2020). The linkages has a holistic system approach that starts from manufacturing value chain and cuts across supply chain.

Industry 4.0 is powered by a number of digital automation technologies majority of which are made up of communication technologies, sensors, the internet et cetera that are relevant in initiating manufacturing processes, monitoring the process, tracing changes in the process and also generating information for timely decision-making. Digital automation technologies are comprised of Big Data Analytics (BDA), Autonomous Machines and Simulation, Systems Integration, Cloud Computing, Internet of Things (IoT), Cyber Physical Systems (CPS), and Artificial Intelligence. The essence of the technologies above is to integrate production facilities with the systems of supply chain with the primary goal of enhancing production outputs by means of decision-making carried out in the real time. The

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end product of digital automation technologies is an intelligent network of inter-connected systems that are believed to make production and distribution processes more efficient, especially with respect to resource utilisation, carbon emission and waste reduction. This manufacturing efficiency is highly needed particularly in this era where industrial revolutions have given rise to environmentally-threatening challenges such as natural resource depletion, air pollution, carbon emission, climate change and other environmental degrading hazards (Li et al., 2023).

Thus, interested stakeholders have more recently raised compelling alarms for firms to adopt manufacturing or production processes that can eliminate or at least reduce the above negative impacts (Wang et al., 2022) which threaten sustainability development. In line with industry revolutions, the use of digital technologies which came as a result of Industry 4.0 has been suggested to be a veritable strategic tool with which firms can re-adjust their manufacturing processes in a way that addresses environmental responsibilities such as waste generation, carbon emission and depletion of natural resources (Bendig et al., 2023). New technology capabilities in Industry 4.0 era such as artificial intelligence, the Internet of Things and advanced robotics are designed to help firms enhance their value creation process, thereby improving firm productivity, cost savings, competitive advantage and flexibility.

However, the use of digital automation technology as a means of achieving environmental sustainability has also been criticised as a double-edged sword since increase in digital transformations may reduce the green environment aspiration of nations. Unlike in developed economies, the adoption of digital automation technology (DAT) of Industry 4.0 is still abysmally low in Nigeria (Abideen, 2020; Usoro et al., 2021). The reasons for the low adoption of Industry 4.0 DAT is predominantly lack of organisational readiness across firms in developing economies such as Nigeria. Even firms that have keyed into the adoption experience a bunch of hurdles in maintaining the Industry 4.0 DAT as a result of the huge maintenance cost required (Al Zadjali & Ullah, 2021; Oláh et al., 2020). The consequence is that most firms in Nigeria have a low adoption and a squat implementation of Industry 4.0 DAT which could have contributed towards increased environmental performance of the firms. It is based on the backdrop above that this study examines the contribution of digital automation technologies towards environmental sustainability practices of companies in Nigeria. Specifically, this paper examines the extent to which digital automation technologies is implemented by Nigerian companies and also the extent to which such implementation affects waste management, reduction of carbon emission and natural resource use efficiency.

This study is the first in Nigeria, to the best of the researchers' knowledge, to empirically analyse the nexus between digital automation technologies of Industry 4.0 and environmental sustainability practices of companies in Nigeria. This research therefore contributes to the body of knowledge in both environmental sustainability and Industry 4.0 literature. Policy makers, technologists, investors and managers of Nigerian companies shall find the result of this study significant in that they reveal not only the level of adoption of digital automation technologies by selected firms in Nigeria but also the extent to which such adoption influences the environmental sustainability practices of the adopting companies.

2. Literature Review

2.1. Environmental Sustainability

Environmental responsibility refers to the extent to which a firm carries out practices that help to protect and preserve the environment. Some of those practices include waste management, carbon management, recycling, emission control, wetland conservation, pollution, and wildlife conservation (Okafor, 2018). Environmental sustainability entails both the reports of the impacts of the firm's activities on natural environment and also the activities of the firm that are channeled towards reducing the amount of harm or damages caused by the firm to the environment.

It is no news that the world is getting increasingly globalized and industrialized with the view to further improving the position of the world economy. The globalization and industrialization strides of this present age are associated with copious environmental challenges such as climate change, global warming, natural disasters, pollution, etc. (Upadhyay, 2017). Since manufacturing firms vehemently exploit natural resources in their operations, production processes create some environmental problems that cut across erosion of natural resources, pollution problems and host of other environmental hazards. This is the reason why there is a global invitation for firms to adopt practices and activities that help to preserve the ecosystem and protect the environment from hazard and damages that stem from industrialization.

2.2. Digital Automation Technologies of Industry 4.0

The evolution of what is today known as Industry 4.0 dates back to 1960 when a project was initiated to enhance the manufacturing process of organisations (Al Zadjali & Ullah, 2021). In our day, numerous digital transformations have

been seen in the manufacturing sector as an offshoot of Industry 4.0. Those digital devices are summarily termed digital automation technologies. They are tools and network used to link physical, digital and human domains that function together in a manufacturing process for the purpose of enhancing production, distribution and information sharing. This aspect although not all encompassing is the reason Industry 4.0 is alternatively regarded as a digital transformation platform that typically heightens the value creation process of manufacturing firms. Unlike what plenty people think, Industry 4.0 is beyond just automation or digitization (Maresova et al., 2018). What differentiates Industry 4.0 from other industrial revolutions is that Industry 4.0 is based on real-time and intelligent (smart) connection of machines, people, and objects that interact together in carrying out a set of manufacturing functions (Brozzi et al., 2020). The key enabling technologies through which Industry 4.0 practices are effected are referred to as digital automation technologies of I4.0.

The four main technologies that make up Industry 4.0 DATs are the Internet of Services (loS), Cyber Physical Systems (CPS), the smart factory, and the Internet of Things (IoT) (Atik & Ünlü, 2019). IOTs "are network of physical devices which are embedded with net-worked microchip technology, software, sensors and controllers enabled to collect and exchange data, while the Internet of Services is the offering of services through the internet" (Burritt & Christ, 2016, p. 28). Smart factory is achieved when machines, people, and technology directly communicate in the production facility (Gabriel & Pessl, 2016). In cyber physical systems, computer-enabled algorithms are used to monitor and control physical things that carryout automated action via non-human intelligence.

The benefits of digital automation technologies are enormous to the extent that companies implementing them enjoy enhanced efficiency, greater flexibility, optimized production processes, quicker response to ever-dynamic market needs (Feliciano-Cestero et al. 2023). In fact, keying into digital automation technologies is a sine-qua-non for any company to remain competitive in the present-day business environment (Contini & Peruzzini, 2022; Götz, 2020) characterised by changes in customer needs, production techniques and marketing approach (Javaid et al., 2022).

2.3. Industry 4.0 Adoption in the Nigerian Context

Manufacturing processes have undergone substantial changes as a result of the adoption of Industry 4.0, which is being powered by digital automation technologies such as artificial intelligence (AI), robotics, the Internet of Things (IoT), 3D printing, genetic engineering, quantum computing, et cetera. However, Nigerian manufacturers appear to be losing out on the prospects provided by digital automation technologies of Industry 4.0 since they first started (Usoro et al., 2021). The adoption of some DATs of Industry 4.0 in Nigeria has helped some of the manufacturing, financial and non-financial companies in Nigeria such as Migo (which uses AI), United Bank for Africa (which uses the Leo chatbot), Touchabl (which uses AI), et cetera to augment their competitive edges in the business world (Bode-Harrison, 2022). The adoption of DATs in Nigeria has overwhelmingly been made more possible by the availability of high-tech companies in the country some of which are AirSmat, ImageAI, DeepQuest AI. However, even though some Nigerian firms have keyed into the march towards Industry 4.0, the degree of implementation of DATs by companies in Nigeria is not yet up to what should be written home about (Abideen, 2020; Usoro et al., 2021).

The implementation of Industry 4.0 practices or digital automation technologies is facilitated in firms that have the required resources. The resources show the extent of readiness already attained by the firm to make room for the implementation of Industry 4.0 practices. Aside being aware of the functionalities of the technologies, other enabling factors that influence the adoption of Industry 4.0 technologies range from availability of human capital, possession of innovation culture (Eze et al., 2021; Usoro et al., 2021; Abideen, 2020; Krésová, 2019), to the ability to foot the bills of installation and maintenance.

2.4. Digital Automation Technologies And Environmental Sustainability

The digital automation technologies of Industry 4.0 boost productivity by facilitating the operational flexibility and production efficiency of the firm which primarily target at sustainable production and supply chain system (Castellani et al., 2022; Zhang et al., 2022; Nick & Pongrácz, 2016). Widely across developed economies, there is a consensus that every environmental degradation currently suffered by the world is accounted for by industrial revolutions. Most of the heavily affected countries have for long swung into action with respect to developing sustainable techniques and strategies capable of reducing or perhaps eliminating the level of environmental damages caused by industrial revolution. Even though the activities of firms especially those in manufacturing sector often result in a number of environmental harms such as generation of waste, carbon emission, and natural resource depletion, a number of environmental management practices when well implemented can help address environmental challenges and bring

about green manufacturing to its fullest (Junge & Straube, 2020). Bendig et al. (2023) observed that the use of digital automated devices reduces the amount of carbon emitted by firms and also reduce the amount of natural resource use.

However, all the strategies and techniques so far suggested are also products of increased industrial revolution. The most recent being Industry 4.0, another stage of industrial revolution which advanced countries consider to be a sure sustainable manufacturing strategy which can contribute towards the realisation of environmental sustainability. This Industry 4.0 led to a number of digital automation technologies which make both production and distribution process more efficient and effective, although with attendant environmental challenges and hazards. It is now as though the introduction of digital automation technologies of Industry 4.0 is a double-edged sword that enhances environmental sustainability on one hand while raising another environmental challenges on the other hand (Li et al., 2023; Fredrich & Bouncken, 2021; Herden et al., 2021).

Dwivedi et al. (2022) submitted that integration of digital automation technologies although serves as a veritable tool for reducing environmental hazards is also seen as a part of the problems that gives rise to environmental degradation. Their study extensively discussed a number of environmentally-unfriendly consequences of the adoption of Industry 4.0 automation technologies, most of which are increase in resource usage, waste products, and CO2 emissions. To further adduce the points raised by Dwivedi et al. (2022), energy consumption is a significant environmental cost of digital automation technologies. The devices, data centres and distribution networks of the DATs consume a lot of energy, despite the fact that some of the technologies use renewable energy. The spread of Industry 4.0 technologies across developed countries of the world is rather speedy. By implication, enormous natural resources (used in building the technologies) must have been extracted in a space of few years, thereby heightening the rate of resource utilisation and generation of industrial wastes, not to talk of e-wastes.

Increased adoption of Industry 4.0 leads to resource depletion in various ways. Foremost, raw materials such as indium, palladium, magnesium, cobalt, and tantalum are extracted and used to bring to life digital automation technologies. The use of such in producing micro-electric devices including integrated circuits largely leads to fossil depletion, global warming, abiotic resource depletion among others (Liu et al., 2019; Pendergrass et al., 2019). Dusik et al. (2018) threw more light on the double-edged sword issue of Industry 4.0 with respect to environmental sustainability. They maintained that the careful management of the production and consumption systems brought about by Industry 4.0 will surely lead to better environmental sustainability relative to the existing processes. However, they equally argued that implementation of digital automation technologies without suitable environmental management systems and objectives will surely trigger-off significant adverse impacts.

Recently, Cardinali and De Giovanni (2022) tried to settle this problem by submitting that it is responsible digital automation technologies not just digital automation technologies that enhances environmental sustainability. Responsible digitization was used to explain firm practices that integrate DAT in a way that fosters corporate social responsibility practices. Before the above was found, the term, corporate digital responsibility, has been introduced in literature to capture how the responsible integration of automation technologies contributes to the march towards sustainability (Herden et al., 2021; Orbik, & Zozuľaková, 2019). How to differenciate between responsible digitization and irresponsible digitization remains another challenge even. Be that as it may, the call for environmental sustainability with respect to resource utilisation, waste reduction and carbon emission is answerable. Automation for instance makes resource use more efficient by reducing the amount of production inputs. At the same time, non-renewable natural resources must be utilised in bringing the automation to existence. A critical look at this case will show that the abundant benefits of implementing digital automation technology on environmental sustainability are therefore cut short by the adverse impacts such implementation brings about. No wonder Junge and Straube (2020) and Brozzi et al (2020) found in their study that digital automation technologies have minor positive impact on environmental performance of firms.

2.5. Existing Empirical Findings

In the study carried out by Bendig et al. (2023) to examine the effect of digital orientation on environmental performance, data were sourced from 515 U.S. Standard and Poor's 500 companies from 2009 to 2019. The findings showed that digital orientation significantly improves environmental performance. Similar to the above, Li et al. (2023) equally ascertained the nexus between digital transformation and pollution emission using micro-enterprises in China from 2000 to 2013. The findings were that digital transformation significantly leads to reduction in pollution emissions. Wang et al. (2022) determined how digital transformation drives waste gas emissions and wastewater emissions among listed Chinese firms. The result of the fixed effect regression revealed that pollution emissions are significantly reduced by digital transformation. Truong (2022) conducted empirical reviews of 319 articles published from 2011 to 2021 in order to assess how digital transformation affects environmental transformation. The result of the study indicated that

digital transformation can exert either negative or positive influence on waste generation, pollution, and resource utilisation. Similar methodology of literature critique was carried out by Oláh et al. (2020) to uncover how Industry 4.0 affects environmental sustainability. The study found that Industry 4.0 technologies provide ecological support that improves environmental performance. However, Cardinali and De Giovanni (2022) determined whether firms can realise responsible digitization through the exploitation of the positive effect of digital automation technologies on environmental attitudes. Primary data were collected from a sample of 157 managers of selected firms from which the conclusion that responsible digital automation technologies positively affects firms' environmental performance was drawn. Nara et al. (2021) carried out an empirical examination of the expected impact which Industry 4.0 technologies have on sustainable development among Brazil's plastic industry. The study found that system integration technologies and cloud computing negatively affect sustainable development in Brazil's plastic industry. Brozzi et al (2020) examined the contribution of Industry 4.0 implementation to environmental sustainability among 65 companies in Marche region, Italy. It was found in the study that Industry 4.0 implementation makes a very low contribution to environmental sustainability. Anari (2019) examine the impact of industry 4.0 on project performance in Lagos state, Nigeria, using 56 sample respondents from whom primary data were collected. The analysis of data showed that there are few companies that have already implemented Indutsry 4.0 practices in Lagos state, Nigeria. Using a sample size of 100 respondents, Akpan (2015) examined the extent to which Artificial Intelligence has been adopted by Nigerian Bottling Company (NBC), Port Harcourt. The result of the Chi-square test showed that Artificial Intelligence (AI) methods used by the firm enhances the effectiveness and efficiency of the staff.

3. Methods

The research design used in the study is cross-sectional survey. This design is suitable for studies that examines a social phenomenon by sampling the opinions of various respondents at a particular point in time. The sample respondents of one hundred and eighty-nine (189) used in the study were drawn from a target population of accounting practitioners, top business managers, and Information Technology experts of manufacturing firms in Nigeria. The population could not be ascertained because Nigerian manufacturing industry is dominated by numerous informal players (Aliogo, 2021). The study mapped the perception of 189 sample respondents on the extent of adoption of digital automation technologies alongside its effect on environmental sustainability in Nigeria. Primary data were collected from the respondents with the use of a 4-point Likert-based questionnaire developed for the purpose of this research and distributed via online. The reliability of the research instrument was assessed using Cronbach's Alpha which returned an overall reliability coefficient of .811. Analysis of data collected was achieved using frequency counts and Spearman Ranked Order Correlation Coefficient (SROCC). The essence of the SROCC was to capture the association between the variables of interest. This technique is considered suitable for use because the data were ordered or ranked. Acceptance or rejection of the null hypothesis was based on 5% level of significance.

4. Result and Discussions

This research was set out to investigate the contribution of digital automation technologies towards environmental sustainability practices of companies in Nigeria. Four research questions were raised to assess the level of implementation of digital automation technologies of Industry 4.0 by Nigerian companies; and also to ascertain whether the implementation of digital automation technologies influences waste management, reduction of carbon emission and natural resource use efficiency.

4.1. ***Research Question I:*** *To what extent do Nigerian companies implement digital automation technologies of Industry 4.0?*

Table 1. Analysis of Research Question I

S/N	To what extent do Nigerian companies implement DTAs?	VHD 4	HD 3	LD 2	VLD 1	Mean	Remark
1	We use service-oriented architectures such as smart logistics to offer our services via the internet (Internet of Services)	101	19	53	16	3.08	High Degree
2	Our organisation collects and exchanges data via a network of physical devices embedded	100	12	37	40	2.91	Low Degree

S/N	To what extent do Nigerian companies implement DTAs?	VHD 4	HD 3	LD 2	VLD 1	Mean	Remark
	with net-worked microchip technology, software, and sensors (Internet of Things)						
3	Our organisation uses any of Smart grid, industrial control systems or robotics systems to self-monitor production processes and operations (Cyber Physical Systems)	66	9	83	31	2.58	Low Degree
4	We have a digitized manufacturing facility that uses connected devices, machinery and production systems to continuously collect and share data (Smart Factory).	40	16	74	59	2.20	Low Degree

Source: Field Survey; January, 2023

The analysis of the first research question aimed at examining the extent to which digital automation technologies of Industry 4.0 are implemented by companies in Nigeria. For components of DATs were assessed: Internet of Services, Internet of Things, Cyber Physical Systems, and Smart Factory. The average responses revealed that only Internet of Services have been implemented to a high degree. The rest of the components of Industry 4.0 have a low degree of implementation in Nigeria. This finding is in line with the study carried out by Usoro et al. (2021); Abideen (2020); Hassan et al. (2020); Anari (2019); and Akpan (2015) which argued that the implementation of Industry 4.0 technologies in Nigeria is still at its infancy.

Table 2. Mean Point Analysis of Questionnaire Items for Research Questions II-IV

S/N	Items	VHD 4	HD 3	LD 2	VLD 1	Mean
5	Accounting for waste takes a paramount place in the business model of our firm	94	28	27	40	2.93
6	Information provided by our firm's Digital Automation Technologies help us to effectively measure the production waste we generate	74	6	76	33	2.64
7	We always set measurable targets for waste reduction in our organization	46	17	78	48	2.32
8	Recycling of waste products helps us to reduce the amount of wastes disposed by our firm	91	23	45	30	2.93
9	Accounting for carbon emission takes a paramount place in the business model of our firm	88	17	40	44	2.79
10	We always set measurable targets for reduction of the amount of carbon emitted by our organisation	95	15	35	44	2.85
11	Information provided by our firm's Digital Automation Technologies help us to effectively measure the amount of carbon we emit	73	4	77	35	2.61
12	Our production system consume little amount of fuel that reduces our carbon footprint	66	23	51	49	2.56
13	We use more of energy sources that can be replenished in a short time through ecological cycles	153	9	3	24	3.54
14	We retain the value of raw materials, and redirect them back to use for as long as possible	146	15	16	12	3.56
15	Our production capacity increases even when we reduce our energy consumption	147	20	1	21	3.55
16	Our intelligent manufacturing network reduces the wastages and leakages in our production processes	108	5	14	62	2.84

Source: Field Survey; January, 2023

The questionnaire items in Table 2 were analysed in order to ascertain the extent of environmental sustainability practices of the companies of which accountants, top business managers, and Information Technology experts

responded to the questionnaire. The indices from Questionnaire Item 5-8 reveals that there is a very low degree of waste management practices by the companies. The extent of carbon emission management by the companies is also low, as shown by Questionnaire Items 9 – 12. Finally, Questionnaire Items 13 – 15 show there is a high degree of natural resource use efficiency in the firms studied while Questionnaire Item 16 indicates that the intelligent manufacturing network used by the firms reduces the wastages and leakages in their production processes to a low extent.

4.2. Inferential Analysis Using Spearman Ranked Order Correlation Coefficient

The essence of the inferential analysis is to ascertain whether there is a significant association between the implementation of digital automation technologies, waste management processes, carbon emission and natural resource use efficiency. The result of the analysis is presented in Table 3 below.

Table 3. Spearman Ranked Order Correlation Coefficient

			Waste Management Practices	Carbon Emission	Natural Resource Use Efficiency
Spearman's rho	Implementation of Digital Automation Technologies	Correlation Coefficient	.332**	.282**	.157*
		Sig. (2-tailed)	.000	.000	.031
		N	189	189	189

Source: Processed Data (2023) Using SPSS Version 23

4.3. Interpretation of Correlation Coefficients

4.3.1. ***Research Question II:*** *How does the implementation of digital automation technologies of Industry 4.0 influence waste management practices of Nigerian companies?*

Table 3 shows there is a positive relationship between the implementation of digital automation technologies of Industry 4.0 and waste management practices of Nigerian companies. The correlation coefficient of .332 shows that an increase in the intensity of the digital automation technology implemented would enhance the waste management practices of the companies. This influence is significant because the *p*-value = 0.000 is less than 0.05. The strength of association is very low, just like Brozzi et al (2020) found in their own study. This finding is in line with the results found by Bendig et al. (2023); Truong (2022); Oláh et al. (2020).

4.3.2. ***Research Question III:*** *How does the implementation of digital automation technologies of Industry 4.0 influence reduction in carbon emission by Nigerian companies?*

Also, **Table 3** shows there is a positive relationship between the implementation of digital automation technologies of Industry 4.0 and carbon emission management of Nigerian companies. The correlation coefficient of .282 shows that an increase in the intensity of the digital automation technology implemented would enhance the carbon emission management (that is, lead to reduction in carbon emission) of the companies. This influence is significant because the *p*-value = 0.000 is less than 0.05. This result corroborates with the findings of Carbon: Li et al. (2023); Wang et al. (2022) but disagreed with that of Nara et al. (2021) which found a negative effect.

4.3.3. Research Question IV: *How does the implementation of digital automation technologies of Industry 4.0 influence natural resource use efficiency of Nigerian companies?*

Finally, **Table 3** shows there is a positive relationship between the implementation of digital automation technologies of Industry 4.0 and natural resource use efficiency of Nigerian companies. The correlation coefficient of .157 shows that an increase in the intensity of the digital automation technology implemented would enhance the natural resource use efficiency of the companies. This influence is significant because the *p*-value = 0.031 is less than 0.05. Similar findings were found by Oláh et al. (2020) and Brozzi et al (2020).

5. Conclusions

The digital automation technologies of Industry 4.0 increase productivity by facilitating the operational flexibility and production efficiency of the company. These technologies are primarily focused on sustainable production and supply chain systems which contribute particularly to environmental sustainability by making sure that production wastes are reduced, less carbon is emitted and less natural resources are consumed. Having seen that industrial revolutions are to be blamed for all environmental deterioration that the globe is currently experiencing, the implementation of Industry 4.0 is a significant gismo capable of improving the production systems of companies in order to guarantee sustainability of the ecosystem. It was therefore concluded that the implementation of DATs of Industry 4.0 helps to lessen the level of environmental harm brought on by manufacturing processes of companies in Nigeria. In addition, the level of implementation of digital automation technologies in Nigeria is not yet good-looking owing to firm-level and country-level barriers such as technology costs, dearth of Information Technology infrastructure, lack of manpower, et cetera that often make it difficult for firms to acquire and maintain the systems. In line with the findings realised in the study, we recommend that:

1. Managers of manufacturing firms in Nigeria should endeavour to acquire, implement and maintain digitized manufacturing facilities that use connected devices, machinery and production systems to continuously collect and share data in order to help the firms achieve more efficiency in their production processes.
2. Investors and owners of manufacturing firms in Nigeria should increase the capacity building of their firms by adequately engaging their human capital in intensive training with respect to the demands of present day digital automation technologies.
3. Government, policymakers, and the business sector should work together effectively for the Industry 4.0 technologies to be implemented in Nigeria.
4. The government and philanthropists should provide incentives to private sector participants who engage in activities that build the digital ecosystem by granting them tax breaks or helping them create free trade zones that support technological advancements.
5. Developers of digital automation technologies should responsibly utilise raw materials such as palladium, magnesium, cobalt, and tantalum used to bring to life digital automation technologies in order to avoid fossil depletion, global warming, abiotic resource depletion among others.

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The implementation of DAT of Industry 4.0 is still at its infancy in Nigeria. Thus, the results of the study are based on its expected impacts on environmental sustainability. Secondly, the study did not address all aspects of environmental sustainability since only the effect of DATs on waste management, reduction of carbon emission and natural resource use efficiency was examined.

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