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Digitalization: A Carbon Emission Apocalypse In The 4IR

Erastus Misheng'u Mwanaumo
Dept. of Civil and Environmental Engineering
(University of Zambia)
Dept. of Civil Engineering
(University of South Africa)
Lusaka, Zambia
Pretoria, South Africa
erastus.mwanaumo@unza.zm
https://orcid.org/0000-0002-2911-3207

Funmilayo Caroline Jayeola
Dept. of Civil and Environmental Engineering
(University of Zambia)
Lusaka, Zambia
funmilayocaro@gmail.com

Penjani Hopkins Nyimbili
Dept. of Geomatic Engineering
(University of Zambia)
Lusaka, Zambia
penjani.nyimbili@unza.zm
https://orcid.org/0000-0001-8271-5269

Wellington Didibhuku Thwala
Dept. of Civil Engineering
(University of South Africa)
Pretoria, South Africa
Thwaladw@unisa.ac.za

Abstract **- This research discusses the global significance of digitalization and its impact on carbon emissions in the context of the fourth industrial revolution (4IR). It highlights the fact that digitalization is deeply ingrained in all aspects of daily life and is a critical component of future development. However, the energy consumption associated with digital tools and social media platforms is a major contributor to carbon emissions. The paper examines the relationship between internet usage and social media activities and their impact on carbon emissions. Regression analysis conducted using ANOVA was used to support the finding that demonstrates that energy consumption from the increasing use of the internet, digital tools, devices and social media platforms are the primary determinant of carbon emissions from digitalization. The study, therefore, concludes that the increasing use of digital technology in the 4IR will lead to higher levels of daily carbon dioxide emissions and that there is a need for clean energy sources, as well as research on sustainable digitalization practices, in order to mitigate this impact. Overall, the paper emphasizes the importance of addressing the carbon emissions caused by digitalization and that these efforts should be supported by industries, governments, and individuals in order to achieve a sustainable future.**

Keywords - Digitalization, Carbon emission, 4IR, Social media activities, Sustainability

I. Introduction

Mankind produces an unexplainable magnitude of data which makes it difficult to fully understand the challenges faced by society and the probable solutions to them [1]. Particularly in relation to the "triple planetary crisis" of pollution, biodiversity loss, and climate change that highlight the need for high-quality and clear data in order to address these issues and achieve the Sustainable Development Goals (SDGs).

Digitalization is seen as a great transformation that has immensely assisted in reducing carbon emissions across various sectors such as waste management, agriculture, construction, and planning [2]. Digitalization can be a helpful tool in providing more solutions to these complex problems faced by society but also has negative environmental impacts. Digitalization is principally referred to as information and communication technologies that produce handling, production, storage, and other kinds of material and facts which individuals can use to interact or communicate with the help of computer languages [3].

It has been observed that 4IR era is bringing about significant changes in various sectors, including education and agriculture. The increasing automation and digitalization of work are leading to the creation of new jobs that require advanced skills in areas such as data analysis, artificial intelligence, and robotics. This implies that the education sector needs to adapt to these changes and prepare students for the new types of jobs that will emerge in the future. In the next ten years, 47% of the jobs that exist today will be automated, and 65% of students who are currently in school will work in jobs that do not yet exist. Moreover, with the fast pace of technological advancement, it is likely that over 50% of the knowledge and skills learned in today's degree programs will become obsolete in the next five years [4]. In agriculture, 4IR technologies are transforming the sector by enhancing efficiency, productivity, and profitability. For instance, precision planting, weeding, effective farm security, product traceability, tea-processing procedures and irrigation technologies can help farmers to reduce wastage, optimize water use, and increase yields. These technologies can also provide real-time information on weather and crop prices and early warning famine system [5] enabling farmers to make informed decisions on planting and harvesting. By boosting productivity and incomes, promoting the creation of new, less expensive goods and services, and expanding the economic opportunities available to young people, 4IR technologies can assist countries in getting back on track and strengthening their favourable pre-pandemic trajectory of their economic prospects [6].

The United Nations climate change conference, tagged conference of parties (COP26) in 2021 highlighted the difficulty of bringing all countries together for global climate summits for the past three decades [7]. The commitment made in Paris to prevent global warming by 1.5 degrees is unlikely to be met, and digitalization and internet usage is being ignored as a major contributor to carbon emissions with significant impacts on global sustainability [1]. It is estimated that activities such as browsing the internet, video streaming, digital banking, and online gaming contribute to internet traffic by about 58-60% and generate 300 million tons of carbon dioxide emissions annually [8], contributing to fueling the process cycle of carbon emission production.

Today, data usage mainly focuses on business email accounts, internet usage, Google searches, electricity usage for websites accessed, websites visited, hacking attempts, internet traffic, and other online activities. The use of new technologies such as engineering internet, smart development, and smart construction [9] is increasing with the help of advancements in ICT, digitization, and automation. Researchers such as [10] have noted that computer-based projects are being developed and tested through the implementation of these new technologies.

[11] stated that internet traffic can be viewed from a socio-ecological perspective. The social aspect of internet traffic refers to the high usage of websites such as YouTube and Facebook, while the ecological aspect deals with waste and parcel deliveries. The article further suggests that digitalization should not only focus on ecological sustainability, but also on social contributions and improvements. Other research by [12] highlighted the importance of digital construction in achieving integration and collaboration in construction projects. Many authors have therefore concluded that the use of appropriate digital technology is essential in improving productivity in various sectors [3].

During the pandemic, digitalization has greatly helped in reducing the need for physical communication and transportation for work and other activities. However, it is important to consider the environmental impact of increased technology usage, specifically the carbon footprint and emissions.

As a result, a hypothesis was developed to determine the major impact of increased digitalization usage on rising carbon emissions. Hence, this will provide answers to the questions of how the 4IR era's social media and internet usage can affect carbon emissions as well as what the main sources of these emissions are. As individuals, we can reduce our carbon emission by using sustainable technology. With the increase use of digitalization, there is a corresponding increase in electricity usage which could potentially contribute to carbon emissions. The fourth industrial revolution (4IR) is seeing a significant increase in the use of digital technology, which is increasing carbon emissions despite efforts to reduce carbon emissions and promote sustainability. This is primarily because of the energy use associated with internet usage, digital tools, social media platforms, and devices. In order to lessen the effects of this trend, which is unsustainable and poses a major risk to the environment and public health, sustainable digitalization techniques and clean energy sources are required. Yet, there is still a dearth of knowledge and awareness regarding carbon emissions linked to digitalization and the need for sustainable practices among businesses, governments, and people. This study, aims to address this gap by examining the relationship between digitalization and carbon emissions and identifying sustainable solutions for mitigating this impact.

II. Literature Review

Carbon emissions can be described as the greenhouse gases emitted which are rightly or systematically triggered by products, individuals, devices, and organizations [13]. Carbon emission footprint can also refer to the total life phase of carbon corresponding emissions with the products and services having effects on it. [8] defined a digital carbon emission footprint as the carbon dioxide emission that resulted from the data production, usage, and transfer of digital technologies or devices and infrastructures. Therefore, digitalization has had a significant impact on our daily lives, making many tasks and processes more efficient and convenient. Internet of things (IoT) as part of digitalization has been seen as having the potential to improve and make services efficient across various sectors such as industries, institutions, and among scientists and specialists [14].

A. Impacts of Digitalization

Digitalization, specifically the production, procurement, and usage of digital technologies, can have a significant impact on the environment, particularly in terms of carbon emissions. The production of new technologies, such as smartphones, is responsible for a large portion of carbon emissions, as the mining and manufacturing of the scarce hardware components inside these devices require a significant amount of energy. It has been estimated that the production and mining of these materials can account for up to between 85-95% of the total carbon emissions for a smartphone over a two-year period. Additionally, the energy consumption of the phone during use, such as charging and operation, can also contribute to its overall carbon footprint over its lifetime of around a decade.

The procurement of digital technologies is another aspect that can have an impact on the environment in terms of carbon emissions. Three main parts pertain to the Information and Communication Technologies (ICT) sector, and these are device users, data centres, and networks. When purchasing new devices, it is important to consider the carbon footprint of the technology, which can include factors such as the materials and energy used in production, as well as the energy consumption during use. Prioritizing technologies and services that have a lower carbon footprint can help to reduce the overall environmental impact of these devices.

The usage of digital technologies can also have a significant impact on the environment, both directly and indirectly. The direct carbon emissions include energy consumption during use, disposal or recycling of the device. The indirect carbon emissions include the effects of the technology on other industries and processes. For example, Artificial Intelligence (AI) is a technology that can have both positive and negative effects on the environment. While it can help to reduce the impact of climate change, it also requires a significant amount of energy to train and operate, resulting in a significant carbon footprint. The carbon footprint made from AI training specifically has been significant, amounting to 300,000kg of CO2 emissions which is about 125 round-trip flights between Beijing and New York [15]. Therefore, it is important to consider the environmental impact of digital technologies including AI, throughout their entire lifecycle, from production to disposal, in order to minimize their carbon footprint.

While digitalization has the potential to reduce carbon emissions by making processes more efficient and reducing the need for physical travel and transportation, it is also a significant contributor to greenhouse gas emissions. According to the World Economic Forum, digitalization has the potential to reduce emissions by up to 15% globally, but it is also estimated that the greenhouse gas emissions contribution by digitalization is between 1.4% to 5.9% [16]. Furthermore, energy consumption related to digitalization has increased by almost 70% between 2013 and 2020 and scientists predict that carbon emissions could double by 2025.

Recycling of technologies is another impact. In this regard, e-waste management is another important aspect to consider in relation to the environmental impact of digitalization. E-waste refers to electronic devices and equipment that are no longer needed and are discarded. Electronic devices contain hazardous materials that can be harmful to both human health (causing damage to the brain and other body systems) and the environment if not properly disposed of. According to the ITU report [17], only 17.4% of e-waste was collected and recycled in 2019, and globally, 53.6 million tons of e-waste are produced each year, equivalent to the weight of 350 cruise ships and enough to form a 125km long line. The practice of recycling can include re-evaluating if the technology or device is still needed, extending the life of the device by keeping it safe and avoiding overcharging, purchasing refurbished technology, and purchasing devices that are certified by the Electronic Product Environmental Assessment Tool (EPEAT) or that are environmentally friendly. Additionally, companies and organizations can build e-waste recycling plans and support better e-waste regulations.

Digitalization has the potential to provide many benefits in terms of reducing air pollution and congestion, and increasing efficiency and productivity. However, it is important to note that while digitalization can bring these benefits, it is not currently considered a net-zero carbon solution. Digital networks and social media, including email and search engines, also contribute to carbon emissions. For example, the carbon emissions of sending and receiving emails can be significant, with estimates of 4g of CO2 emissions per email sent and 135kg of CO2 emissions for incoming business email accounts. Search engines, such as Google, also have a significant carbon footprint, with estimates of 2.9 million tons of CO2 emissions and 6.2 Terawatt hours (TWh) of energy consumption. To reduce the environmental impact of digitalization, it is important to raise awareness and support digital practices that minimize carbon emissions and implement standard measurements for capacity building, such as using energy-efficient servers and investing in renewable energy sources, recycling and e-waste management among other measures. As digitalization becomes more widespread, it is important to implement policies and strategies to mitigate its negative environmental impact. This includes recognizing digital energy consumption and taking steps to reduce it [18]. The Tony Blair Institute for Global Change has emphasized the need for leaders to take quick action to reduce the environmental impact of digitalization, especially in light of the crisis arising from climate change and increasing digital carbon emissions [19]. According to the report, different sectors contribute to carbon dioxide emissions globally in different ways: farm produce from agriculture is responsible for over 25% of carbon emissions, fuel combustion from transportation for over 24%, and industry for another 25%. To reduce the environmental impact of digitalization it is important to have operative policies in place that address these different sectors and their carbon emissions. Construction is a major contributor to global electricity consumption and carbon emissions accounted for over 28% of power generation in the year 2019. The production of concrete and brick alone accounts for 5% of annual CO2 emissions [20]. Sustainability requires considering both consumption and environmental impact [13]. This study further asserted that internet activities, such as website browsing, contribute to carbon emissions. To achieve sustainability goals, the study suggests measuring internet performance and improving digitalization to support green sustainability, since the use of the internet cannot be limited or erased.

B. The Major Determinants of Carbon Emission

The statement made by Jack Amend in the article by [21] suggests that the internet is the major coal-fired engine of the entire planet having a significant environmental impact due to the energy consumption required to power servers and other infrastructure. According to the article, viewing a single webpage can result in significant carbon dioxide emissions of 0.24g, and the average website visited produces 1.76g of CO2 when a page is viewed as estimated using an online carbon calculator website. Therefore, viewing 100,000 pages of websites in a month results in 2,112 kg of carbon emission annually. The article also suggests that more complex websites require more energy to load, which increases their environmental impact. The information provided suggests that sending and receiving emails also contributes to carbon emissions, due to the energy consumption required for the transmission and storage of emails. An average email found in the spam folder is equivalent to 0.3g of CO2, a standard sent email contains 4g of CO2 while a long email with attachments yields 50g of CO2 [22]. In the analysis by [23], it is argued that the energy consumption required to send an email through an internet service provider to a data centre and finally to the recipient also contributes to carbon emissions. It is then concluded that 19g of CO2 is created when an email is stored for one year and sending an email to 10 people generates 76g of carbon emission i.e. 19g multiplied by 4 [24]. As stated in a report by [25], every google search results in carbon emissions which implies every google search has its own planet cost. When 3.5 billion searches are processed in a day the websites that are popularly visited amount to about 40 per cent of the digital carbon emission. The 'CO2GLE' counter created by Joana Moll provides real-time information on the total carbon emissions resulting from online searches. An approximate average of 47,000 requests from Google give a result of 500kg of carbon emitted in a second. According to

[25], a single request made can result in the emission of 1-10g of carbon. The application of Pinterest also results in a significant amount of carbon emissions of 1.30g, 40.65 MB of data exchange and 1083mAh (milliampere-hour) energy consumption per minute [26]. Despite a drop in the record of carbon emissions globally in 2022, the pandemic gave a driven shift to remote work and as a result, there is a substantial environmental footprint that arises from increased internet data usage, storage, and transfer around the earth [27]. Video streaming or conferencing for an hour results in 150-1,000g of carbon emission while a car emits 8,887g of a gallon of gasoline. However, turning off the camera during a web call and reducing streaming time on Netflix can significantly reduce carbon emissions by 96% and 86% of carbon dioxide, respectively. [28] estimates that one hour of video streaming consumes 7GB of data and results in the emission of 441g of carbon emission equivalent. The perspective of [16] was different and their estimate of one hour of video streaming results in 280g of carbon emissions, while [24] found that internet traffic from digitalization using means of video conferencing and social media increased by 40% in 2020 and 12% (2.5 million) in 2022, leading to an increase in carbon emissions. This study further explained that 8g of carbon is been emitted per day using Google statistics. The research conducted by [29] states that global carbon emissions increased from 21,373 billion tons to 33,513 billion tons between 1995 and 2018. They also found that electricity consumption for the internet increased from 219 TWh in 2007 to 354 TWh in 2012. As a result of this, a 1% increase in internet usage would emit 0.032% of carbon dioxide. The power consumption rate according to [30] between 2016, 2017, and 2018 was 364MW (Megawatt), 1727MW, and 5501 MW respectively. [31] estimated that in 2015 it required 0.06 kWh/GB of data to transmit through electricity intensity. [32] estimated the best and worst-case scenarios of electricity consumption for internet usage at 1GB and 3GB per hour and found that 0.304kWh of electricity was produced per hour, equivalent to 72g of carbon emissions in the best-case scenario. These studies indicate that internet usage has a significant impact on the environment, due to the high energy consumption and carbon emissions associated with internet data transfer and storage.

It has been suggested that carbon emissions associated with internet usage can be reduced through carbon trading systems, where carbon credits are used to offset emissions. [33] found that reducing carbon emissions by one ton of CO2 in a trading system is equivalent to 10 euros in a traded account using 426,108 credits amounting to almost 40 billion tons of carbon emission per annum. Carbon hacking signifies a future representation of pixels from websites to black dots. An increase in the carbon needed to run a website increases the number of pixels to be stolen. [34] supplemented her report to affirm that 73% of hacks result in the production of 0.25g of carbon. This implies that hacking activities also contribute to carbon emissions, likely due to the energy consumption required to perform the hack and the potential need for additional server resources to address the hack. [34] further suggests that reducing the carbon footprint of a website can prevent hacking and scamming, as the number of pixels on a website is directly related to its carbon footprint. [13] found that global electricity consumption of 0.304 kWh for internet usage results in 72g-216g of CO2 per hour, video conferencing using 3GB in an hour results in 84g-252g of CO2, and online video streaming consumes 0.519kg per hour produces 280g of carbon emission. The studies suggest that while digitalization has many advantages, it also has a significant environmental cost associated with energy consumption and carbon emissions.

III. Research Methodology

The methodology of this study is a quantitative approach, which relies on the collection and analysis of numerical data. The study used secondary data to examine the correlations and contributions to carbon dioxide emission from various internet live statistics websites, including data on internet users, websites, emails sent, Google searches, Pinterest users, Skype calls, websites hacked, internet traffic, electricity used, and CO2 emissions. The data were collected daily and analysed using Pearson's correlation to determine the relationship between social media activities and carbon emissions. Regression analysis, including multiple regression and ANOVA, was used to identify which factors contribute the most to carbon emissions. This methodology allows for the examination of the relationship between different internet usage metrics and carbon emissions, and the identification of the main drivers of carbon emissions in the digital world as shown in Fig. 1.

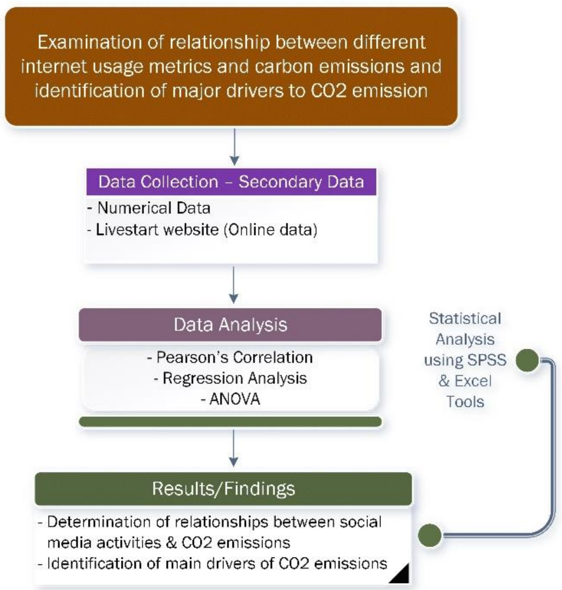

Fig. 1. Methodology Flow Chart

IV. Data Analysis, Findings and Discussion

The analysis in this study was based on data collected from live-statistics websites, using descriptive and analytical statistical methods to determine the effects of digital tools usage on sustainability. The study aimed to identify the effects of digitalization on sustainability, using information from live-statistics websites. According to [35], one of the major factors contributing to the problems of the Fourth Industrial Revolution (4IR) is climate change, which is a result of global warming and the release of carbon emissions from the usage of digital devices or tools. The study found that there are factors or determinants that contribute to carbon emissions through the usage of digitalization in daily activities, which could have severe environmental impacts on 4IR if not properly used and managed in a sustainable manner.

A. *Findings*

1) Effects of digitalization on sustainability: Table 1 presents data on various factors or determinants that contribute to the release of carbon per day using digitalization in the Fourth Industrial Revolution (4IR). These determinants include the number of internet users in the world, the total number of websites, emails sent, Google searches, Pinterest active users, Skype calls, websites hacked, internet traffic measured in gigabytes (GB), electricity used for the internet measured in megawatt-hours (MWh), and CO2 emissions measured in tons. The data was collected at the end of each month for a period of 10 months, starting from October 2021 and ending in July 2022, in order to show the level of usage of common internet websites and their contributions to the environment. Table 1 also shows the trends in which these determinants rise and fall over the 10-month period and proper analysis was done to show their correlations and differences.

TABLE I. INTERNET USAGE AND ONLINE DATA STATISTICS

TOTAL STATISTICS	OCT (1)	NOV (2)	DEC (3)	JAN (4)	FEB (5)	MAR (6)	APR (7)	MAY (8)	JUN (9)	JUL (10)
	"per million" (ppm)									
INTERNET USERS	13,674	151,984	158,177	161,427	145,815	161,446	156,759	209,980	159,934	166,021
TOTAL NUMBER OF WEBSITES	5,311	56,654	59,001	59,783	54,007	59,787	56,054	60,388	58,734	60,882
EMAILS SENT	459,743	6,331,651	6,771,787	7,625,158	6,818,808	7,453,469	7,162,793	7,526,264	7,364,410	7,837,719
GOOGLE SEARCHES	12,601	193,571	211,467	234,595	210,227	229,202	221,466	234,601	232,718	247,052
PINTEREST USERS	1,208	11,571	12,724	13,208	11,899	16,642	12,504	13,818	17,834	14,259
SKYPE CALLS	706	16,610	13,601	15,155	13,621	15,504	14,730	15,517	16,277	16,886
WEBSITE HACKED	0.274	4.8	5.6	6.1	5.7	6.3	6	6.3	6.5	6.9
INTERNET TRAFFIC	14,089	236,492	291,699	328,607	302,314	330,691	320,370	345,402	358,238	370,691
ELECTRICITY USED FOR INTERNET	7.4	107.8	116.1	126.1	115.1	124.1	121.8	127.4	129.6	132.6
CO2 EMISSIONS	6.1	83.6	90.6	98.3	88.1	98.7	96.1	96.8	100.6	102.4

Fig. 2 presents a corridor for each social media activity flow, ranging from internet users to carbon emissions. The numbers represented on the graph are the total numbers derived at the end of the tenth month, and they are in the power of 9 zeros, meaning each number is divided by 109, as represented in Table 6. Out of the nine (9) internet activities assessed, it was concluded from the data collected that emails sent per day have the highest numbers of internet usage, as illustrated in the social activities corridor graph while the other social activities used per day are almost the same with the level of carbon emitted daily. This suggests that different internet activities have different levels of usage and contribute differently to carbon emissions.

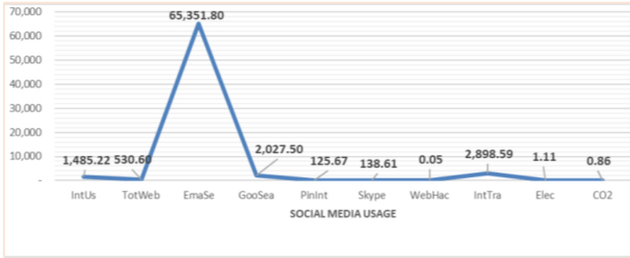

Fig. 2. Corridor for social media activities

The statistical data analysis process used Pearson correlation to investigate the relationship between the different determinants in terms of trend and strong points. Multiple regression analysis was used to discover the major determinant of carbon emission, which is considered to be the dependent variable, from the other eight (8) determinants that serve as the independent variables. This allowed the identification of the main drivers of carbon emissions in the digital world, and how they are related to each other. The results from both Pearson correlation and multiple regression analyses were used to develop a model that shows the correlation and difference in the significance level of each determinant with carbon emissions. The results from Bivariate distribution using Pearson correlation analysis shows the level of correlation of the determinants to each other and most importantly correlation with carbon emissions. From Table 2, it is revealed that all the determinants have a good relationship and correlation with themselves and all have a good correlation with carbon emissions at a high significance level [36].

TABLE II. DETERMINANTS OF CORRELATION

Correlations										
	IntUs	TotWeb	EmaSe	GooSea	PinT	Skype	WebHac	IntTra	Elect	CO2
IntUs	1									
TotWeb	.958**	1								
EmaSe	.953**	.989**	1							
GooSea	.952**	.987**	.999**	1						
PinT	.867**	.916**	.926**	.930**	1					
Skype	.930**	.978**	.966**	.965**	.911**	1				
WebHac	.939**	.972**	.993**	.996**	.940**	.951**	1			
IntTra	.929**	.950**	.981**	.986**	.940**	.926**	.996**	1		
Elect	.953**	.989**	.998**	.999**	.935**	.970**	.994**	.984**	1	
CO2	.945**	.989**	.998**	.998**	.941**	.969**	.994**	.982**	.999**	1
**. Correlation is significant at the 0.01 level (2-tailed).										

[a]Key: IntUs – Internet Users, TotWeb – Total Number of Websites, EmaSe- Email Sent, GooSea - Google Search, PinInt – Pinterest Users, Skype - Skype Calls, WebHac - Website Hacked, IntTra- Internet Traffic, Elect – Electricity used for Internet, Co2 – Carbon Emission.

The Bivariate shows that there are more than two variables associated with each other by showing their level of correlation with each other as represented in Table 2, while Pearson's correlation coefficient shows the strength of association that exists between the variables [37]. This means that all determinants analysed have a strong association with carbon emissions and the correlation coefficient is significant, indicating a strong relationship between the variables. The correlation between the main dependent variable (Carbon Emission) has significance levels (r) of 0.945 (95%) with Internet Users, 0.989 (99%) with the Total number of websites, 0.998 (99%) significance level with Emails sent as well as Google searches, 0.941 (94%) with Pinterest, 0.969 (97%) with Skype calls, 0.994 (99%) with Website hacked, and finally 0.999 (100%) with Electricity used for internet. The statistical significance of the identified relationship between the determinants is also supported by utilizing the asterisk sign of '*' which signifies that the p-value is <0.05 and '**' which means the p-value is 0.01 and gives a positive correlation between the variables [38].

TABLE III. THE MODEL SUMMARY R^2 OF THE MAJOR DETERMINANT OF CARBON EMISSION

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	0.998	0.998	1345905.59346

a. Predictors: (Constant), Electricity Used For Internet

b. Dependent Variable: CO_2 Emissions

It was further verified using regression analysis to determine the major determinants of carbon emission (dependent variable) out of the independent variables. Model summary of the multiple regression analysis showed that out of all the independent variables analysed, the only determinant or variable contributing to the variation which is the constant dependent variable is electricity used for the internet by showing the significant relationship and strength it has with carbon emission. This, therefore, suggests that carbon emission are directly related to and depends solely on electricity used for the internet. Also, the model summary of the regression analysis shows that the electricity used for the internet is the best predictor of carbon emissions, with an R-value of 0.999 and a predictor value of 0.998. The adjusted R-squared value is also high, indicating that the model has a good fit and that the prediction is accurate. This supports the assertion that carbon emissions are primarily determined by electricity used for internet usage [39]. It is then established using the ANOVA in Table 4 that the p-value of electricity used for the internet is 0.000, which is less than 0.05. This indicates that there is a statistically significant relationship between electricity used for the internet and carbon emissions. This supports the inference that electricity used for the internet is the major determinant and only predictor of carbon emissions.

The beta coefficient analysis (Table 5) confirms the results of the previous analyses, with a beta value of 0.999, a significance level of 0.789, a tolerance value of 1.000 and a confidence interval of 95%. The beta coefficient measures the strength and direction of the relationship between the independent and dependent variables. With the Beta coefficient, it is easy to determine how best and largely each variable depends on the other. The standardized beta value (β) shows the different analyses of the independent variables with the effects and changes they have on each other and in this case, their contributions to carbon emission by signifying that electricity used for the internet is the strongest independent variable that is most effective on the dependent variable. The collinearity statistics further perfect the analysis by accepting all the independent variables processed and giving results of how the variables contribute to each other as presented in Fig. 3. Collinearity statistics also support the conclusion that electricity used for the internet is the major determinant of carbon emissions. The high R-value and low p-value, as well as the confidence interval for beta, all support the conclusion that electricity used for the internet is the major determinant and only predictor of carbon emissions [39].

TABLE IV. ANALYSIS OF VARIANCE OF THE MAJOR DETERMINANT

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7422111561071580.00	1	7422111561071580.00	4097.305	.000[b]
	Residual	14491694932092.10	8	1811461866511.52		
	Total	7436603256003670.00	9			

a. Dependent Variable: CO_2 Emissions

b. Predictors: (Constant), Electricity Used For Internet

TABLE V. BETA COEFFICIENT VALUE OF THE MAJOR DETERMINANT

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% CI Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	388339.825	1405624.679		0.276	0.789		
	Electricity used for the internet	0.774	0.012	0.999	64.010	0.000	1.000	1.000

a. Dependent Variable: CO_2 Emissions

After the multiple regression analysis has shown that electricity used for the internet is the major and only determinant contributing to carbon emission, a further analysis was done to find out the variables contributing to electricity used for the internet. The results of the multiple regression analysis show that google searches are direct determinant of electricity used for the internet. Additionally, the analysis found that emails sent and websites hacked also contribute to google searches. This suggests that the amount of electricity used for the internet is influenced by the number of google searches conducted, as well as the number of emails sent and websites hacked. Therefore, it can be inferred that the variables contributing to electricity used for the internet are google searches, emails sent, and websites hacked.

The results of the multiple regression analysis indicate that electricity used for the internet is the major determinant of carbon emissions with a value of 0.774 and a high significance level indicated by three asterisks. Google search is the only determinant of electricity used for the internet with a value of 0.001 which is <0.05 and <0.01 and a high significance level indicated by three asterisks. Emails sent and websites hacked are found to be determinants contributing to google searches, with a probability of F-value of 0.050 and 0.100 and a significance level of 0.000^b and 0.000^c, respectively. These variables are indicated by asterisks in Fig. 3, indicating that they depend on each other. This suggests that the amount of electricity used for the internet is influenced by the number of google searches conducted, as well as the number of emails sent and websites hacked, and these in turn are the variables that contribute to the carbon emission.

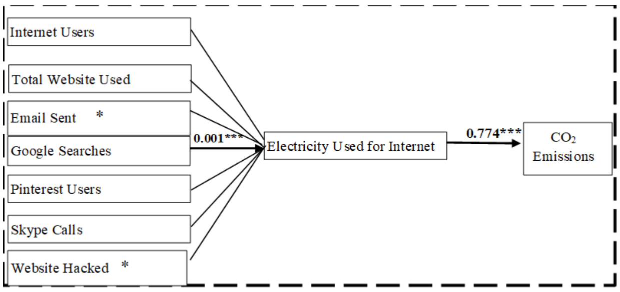

Fig. 3. Model for Social Media Activities and Contribution to Carbon Emission

Note: —— significant positive relationships confirmed by correlation only, and
→ significant positive relationships confirmed by correlation and multiple regression analysis.

B. Discussion

The results of the multiple regression analysis indicate that carbon emission which is the dependent variable depends largely on electricity used for the internet but also receives some contribution from google searches, while google searches in turn depend largely on emails sent and websites hacked which are also contributing factors to the carbon emissions. This suggests that the relationship between these variables is interconnected and that they all play a role in determining the level of carbon emissions.

Table 6 is a summary of the statistics of various social activities at the end of the 10th month (Oct 2021 to July 2021). The table shows the total number of internet users, websites used, emails sent, google searches, Pinterest users, Skype calls, websites hacked, and internet traffic in Gigabytes (GB). The electricity used for the internet is measured in megawatt-hours (MWh) and the carbon emissions are measured in tons per day. The table provides a snapshot of the activity levels for each of these variables during the specified time period and can be used to analyse trends and patterns in usage and emissions.

TABLE VI. TOTAL STATISTICS AT THE END OF THE 10TH MONTH

S/N	SOCIAL MEDIA ACTIVITIES	STATISTICS
1	INTERNET USERS	**1,485,216,422,927**
2	TOTAL NUMBER OF WEBSITES	**530,602,235,818**
3	EMAILS SENT	**65,351,801,060,082**
4	GOOGLE SEARCHES	**2,027,500,937,696**
5	PINTEREST USERS	**125,668,067,949**
6	SKYPE CALLS	**138,605,711,739**
7	WEBSITE HACKED	**54,513,690**
8	INTERNET TRAFFIC	**2,898,591,776,300 (GB)**
9	ELECTRICITY USED FOR INTERNET	**1,107,854,073 (MWh)**
10	CO2 EMISSIONS	**861,389,370 (Tons)**

This study uses previous research on the amount of carbon emitted by each social media activity per gram to establish the amount of carbon emitted based on the number of users and usage of each activity. Based on this, the study determined the number of users per day, hour, minutes and the amount of carbon emitted from the number of each activity usage from the total number of internet users to the amount of electricity consumed using the internet and each activity explained based on the duration in which the data collection was done daily over the course of 10 months, from October 2021 to July 2022 (Table 7).

TABLE VII. CARBON EMITTED PER HOUR BY EACH ACTIVITY

SOCIAL MEDIA ACTIVITIES	FINDINGS	STATISTICS	DAILY USAGE	HOURLY USAGE	MINUTE USAGE	CO2 EMITTED PER MINUTE
		"Per million" (ppm)				
INTERNET USERS	An internet displayed page produces 0.24g of CO2	**1,485,216**	**5,460**	**228**	**3.8**	**0.9**
TOTAL NUMBER OF WEBSITES	1.76g of carbon emission per page. Therefore 100,000 pages viewed in a month is equal to 2,112kg CO2e annually	**530,602**	**1,951**	**81**	**1.4**	**2.4**
EMAILS SENT	Spam folder = 0.3g, Standard email = 4g, email with attachments = 50g of CO2. An email sent is 19g CO2, then emails sent to 10 people = 76g i.e. 19g *4g	**65,351,801**	**240,264**	**10,011**	**167**	**667**
GOOGLE SEARCHES	47,000 google searches	**2,027,501**	**7,454**	**311**	**5.2**	**28.5**

	produce 500kg of CO2 in a second. Therefore 0.01kg or 1g -10g is produced per request					
PINTEREST USERS	A Pinterest user produces 1.30g of CO2	**125,668**	**462**	**19**	**0.3**	**0.4**
SKYPE CALLS	While Video streaming produces 441g of CO2 in an hour and another study estimated 280g of Carbon emitted in one hour	**138,606**	**509.6**	**21**	**0.3**	**156**
WEBSITE HACKED	73% of a webpage hacked produces 0.25g of carbon	**55**	**0.2**	**0.008**	**0.0001**	**0.000035**
INTERNET TRAFFIC	Video conferencing increases internet traffic by producing 8g of CO2 per day	**2,898,592**	**10,657**	**444**	**7.4**	**0.99**
ELECTRICITY USED FOR INTERNET	1GB and 3GB of data of electricity used for the internet produce 0.304kWh which is equivalent to 72g of CO2. 0.304kWh of electricity consumption produces 72g-216g of CO2	**1,108**	**4.1**	**0.2**	**0.003**	**0.4**

According to [21], the carbon emitted by internet usage is 0.24g per page viewed and it is assumed that a page is viewed in one minute. On this basis, the study found that 3,791,912.84GB of internet were used per minute, resulting to a total CO_2 emission of 910,059g (3,791,912.84*0.24g). Additionally, the study indicated that the total number of websites visited emits 1.76g of carbon per page per minute, resulting in 1,354,683GB of websites visited and a total of 2,384,242g of carbon emissions per minute. This analysis can be used to understand the environmental impact of internet usage and social media activities. As reported by [22], a standard email sent emits 4g of carbon, based on this the study found that 166,849,982.28GB of standard emails were sent and this number resulted in a total of 667,399,929g of carbon emissions per minute. [25] states that using Google produces an emission of 1g-10g (5.5g on average) per request and assuming that a request takes a minute, the study found that 5,176,421.92GB requests were made which resulted in 28,470,321g emissions per minute. [26] affirms that Pinterest users emit 1.3g of carbon per minute per user, this means 320,843.72GB of users and 417,097g of carbon emissions per minute. The Shift Project [16] and [25] express that video conferencing and Skype calls release 280g and 441g per hour respectively, the study found that 353,874.88GB of Skype calls were made which resulted in 156,058,821g of carbon emissions per minute. [34] points out that hacked websites emit 0.25g of carbon per website, the study found that 139.18 websites were hacked and this resulted in 35g of carbon emissions per minute. [24] observe that internet traffic produces 8g of CO2 per GB, the study found that 7,400,407.93GB of internet traffic resulted in 986,721g of carbon emissions per minute. Lastly, [31] and [13] determine that electricity used for the internet emits 72-216g of carbon on average, the study found that 2,828.47Mwh of electricity was used and this resulted in 407,299g of carbon emissions per minute.

It is important to note that, according to a study by [15], the major contribution of digitalization to the release of carbon is the production of digital technologies such as smartphones, laptops, and other devices, as well as the mining of the scarce resources used in their production. Additionally, the procurement and usage of these devices also contribute to carbon emissions. However, it is also acknowledged that digital tools, such as Artificial Intelligence (AI), have the potential to reduce the impact of climate change by improving productivity and supporting digital awareness to reduce carbon emissions. However, it is not considered as a net zero carbon solution but can be enhanced using standard measurement of building capacity [17].

It was also established that the major contribution to carbon emissions is electricity used for the internet, which is in line with the findings of [13] that construction consumes half of the global electricity and contributes 28% of power generation, resulting in carbon emissions. It was also confirmed that the electricity usage for the internet is based on google searches, meaning that the more google is used, the more electricity is generated, which reduces the sustainability of the built environment. The trend of this model starts from the production or building of the digital tools, which are mostly downloaded from google, and getting trial licenses for each one before they are installed and used. Some tools are also downloaded from sites, which is also from google, where the full specifications of a tool are stated. Sometimes, the tools are bought on a disc, which is referred to as buying off, where the tools are installed and configured for use. Google searches also have a significant contribution from emails sent, as it is a major platform used for means of communication in the construction industry. Additionally, Google provides an avenue for downloading tools like Zoom and Google Meet for virtual meetings and other offsite activities. All of these activities contribute to a large amount of electricity used and consumed, which definitely has an effect on sustainability and may not make environmental sustainability workable.

In the Fourth Industrial Revolution (4IR) era, it is important for governments and individuals, including construction players, to develop suitable guidelines for using digital tools to bring about systems that will develop new digitalization and clean energy such as renewable sources of energy (wave, wind, and solar) [18] to help the country as well as the construction industry assure energy autonomy, protection, and sustainable use of oceans and other available water resources, biodiversity protection, guide against desertification, protection, and sustainable use of forests, sustainable industrialization, and production of infrastructure, programs, and algorithms for predicting life-threatening weather. This will help to ensure that digitalization is not only efficient but also environmentally friendly, creating a balance between technological advancement and environmental conservation.

V. CONCLUSION

It can be concluded that social media and online platforms can aid the adoption of digitalization, and social media activities are ways in which digitalization can be used by various sectors such as construction, manufacturing, agriculture, etc. However, the increase in the usage of digitalization, which involves social media platforms, has greatly increased the emission of carbon dioxide. The study aimed to identify the digitalization means contributing to carbon emissions using social media activities and it was shown that the electricity used for the internet is the major determinant contributing to carbon emissions and part of the contribution comes from google searches. It was also established that emails sent and websites hacked are major determinants and activities contributing to google searches.

The sustainability of the environment depends largely on all industries, governments and individuals by developing clean energy such as wave, wind, and ocean to assure energy autonomy and protection. In addition, more research is needed on innovations to improve digitalization and support sustainability in our environment, and as a result, reduce the amount of carbon emitted from the tools or platforms used daily.

REFERENCES

[1] UN, "Geneva Environment Network: Digital Cooperation SDG17", *UN environment programme,* 2021. Retrieved August 17, 2022, from https://www.genevaenvironmentnetwork.org/resources/updates/data-digital-technology-and-the-environment/

[2] H. Brunton, "Digital carbon footprint: the enviromental impact of digital transformation", *The Knowledge Exchange*, 2017. Retrieved August 18, 2022, from https://theknowledgeexchangeblog.com/2022/01/17/digital-carbon-footprint-the-environmental-impact-of-digital-transformation/

[3] E. O. Ibem, E. B. Aduwo, E. A. Ayo-Vaughan and P. F. Tunji-Olayemi, "A survey of digital technologies used in the procurement of building projects: Empirical Evidence from Nigeria", *Asian Journal of Scientific Research*, vol. 11, pp. 456-465, 2018.

[4] S. Elayyan, "The future of education according to the fourth industrial revolution", *Journal of Educational Technology and Online Learning*, 4(1), pp. 23-30, 2022.

[5] A. Desa, "Fourth Industrial Revolution (4IR) and Digital Economy", Presentation: Destination Digital Africa: Preparing our youth for the future, Kenya, 2021.

[6] L. Fox and L. Signé, "The Fourth Industrial Revolution (4IR) and the Future of work: Could this bring good job to Africa", *Report,* 2021.

[7] C. P. COBO, "Are Digital Technologies Carbon Footprint Neutral or Not?", *FUTURO, INNOVACIÓN, RESEARCH,* 2021. Retrieved August 17, 2022, from https://www.cristobalcobo.net/blog/post/are-digital-technologies-carbon-footprint-neutral-or-not

[8] H. Evangelidis and R. Davies, "Are you aware of your digtal carbon footprint", *Capgemini invent, Capgemini engineering*, 2021. Retrieved from https://www.capgemini.com/gb-en/insights/expert-perspectives/are-you-aware-of-your-digital-carbon-footprint/

[9] T. D. Oesterreich and F. Teuteberg, "Understanding the implications of digitization and automation in the context of Industry 4.0: A triangulation approach and elements of a research aagenda for the construction industry", *Journal of Computers in Industry*, vol. 83, pp. 121-139, 2016.

[10] X. Wang, P. Yung, H. Luo and M. Truijens, "An innovative method for project control in LNG project through 5DCAD. A case study", *Automation in Construction*, vol. 45, pp. 591-135, 2014.

[11] S.-I. Jungblut, "Our digital carbon footprint: What's the Environmental impact of the online world ?", 2019. Retrieved August 18, 2022, from https://en.reset.org/our-digital-carbon-footprint-environmental-impact-living-life-online-12272019/

[12] A. Skebeika, "Digital delivery of infrastructure projects: Proceedings of the 11th International Post Graduate Research Conference", *Impact and Management issues within the project-based enginerring firm*, Media city, Manchester, pp. 354-363, 2013.

[13] A. Batmunkh, "Carbon ffotprint of the most popular social media Platforms", *Sustainability,* 2195(14), 2022. https://doi.org/10.3390/su14042195

[14] F. Yusuf, G. Ifijeh and S. Owolabi, "Awareness of internet of tings and its potential in enhancing academic library service delivery in a developing country", *Journal of Library Philosophy and practice* (e-journal), 2019.

[15] M. I. Nature, "The carbon impact of artificial intelligence", vol. 2, pp. 423-425, 2020. doi: https://doi.org/10.1038/s42256-020-0219-9.

[16] The Shift Project, "The Carbon Transition Think Tank", 2019. Retrieved August 17, 2022, from https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

[17] ITU, "Sustainable Development Goals", *United Nations University*, 2010. Retrieved August 17, 2022, from https://us02web.zoom.us/j/8935863496

[18] L. McMahon, "Is staying online costing the earth?", *Policy Connect, UK*, 2018. Retrieved 8 18, 2022, from www.policyconnect.org.uk

[19] O. Oguntoye, "Should Tech Make Us Optimistic About Climate Change?", *Tony Blair Institute for Global Change, Policy Lead, Science & Innovation Unit*, London, 2021. Retrieved August 18, 2022, from https://institute.global/policy/should-tech-make-us-optimistic-about-climate-change

[20] ASITE, "DIGITAL ENGINEERING: Optimizing construction's digital future", 2022.

[21] D. Chan, "Your website is killing the palnet", 2021. Retrieved 8 22, 2022, from https://www.wired.co.uk/article/internet-carbon-footprint#:~:text=According%20to%20online%20carbon%20calculator,the%20greater%20its%20climate%20impact.

[22] E. C. Richards, "The carbon cost of an email", 2018. Retrieved 8 22, 2022, from https://carbonliteracy.com/the-carbon-cost-of-an-email/

[23] P. V. Upadhyay, "Digital poluution: Emails and carbon Emmissions", *The International Journal of Analytical an Experimental Modal Analysis*, vol. XII(V), p. 556, 2020.

[24] E. Myanmar and S. Advocates, "A study on environmental impacts of Internet Emissions: a case study of Yangon, Myanmar", *The environment, Health and Safety Myanmar, Non-Governmental organization; Advocates for sustainable lifestyle and culture, environmental education organization,* 2022. Retrieved from file:///C:/Users/User/Desktop/RESEARCH/CARBON%20EMISSION/new%20data/interner%20users/A_Study_on_environmental_impacts_of_Internet_Emissions_a_case_study_of_Yangon_EHSMyanmar.pdf

[25] A. Quito, "Every google search results in CO2 emissions. This real-time data viz shows how much", 2018. Retrieved from https://qz.com/1267709/every-google-search-results-in-co2-emissions-this-real-time-dataviz-shows-how-much/

[26] K. Derudder, "What is the environmental footprint for social media application?", 2021. Retrieved from https://greenspector.com/en/social-media-2021/

[27] K. Wiles, "Turn off that camera during virtual meetings, environmental study says, Simple tips to go green with your internet use during a pandemic", 2021. Retrieved 8 23, 2022, from https://www.sciencedaily.com/releases/2021/01/210114134033.htm

[28] R. Obringer, B. Rachunok, D. Maia-Silva, M. Arbabzadeh, R. Nateghi and K. Madani, "The overlooked environmental footprint of increasing internet use", *Resour. Conserv. Recycl*., vol. 167, pp. 1-4, 2021.

[29] J. Wang and Y. Xu, "Internet usage, human capital and CO2 emission: A global perspective", *Sustainability*, 13(8268), 2021. https://doi.org/10.3390/su13158268.

[30] C. Stoll, L. Klaassen and U. Gallersdorfer, "The carbon foot print of bitcoin", *Massachusetta Institute of Technology, MIT center for energy and environmental policy research,* 2018. Retrieved from CARBON%20EMISSION/new%20data/crytocurrency.pdf

[31] J. Aslan, K. Mayers, J. G. Koomey and C. France, "Electricity intensity of internet data transmission", *Journal of Industrial Ecology*, 2017. doi:10.1111/jiec.12630.

[32] A. S. Andrea, "New perspectives on internet electricity use in 2030", *Journal of Engineering Applied Science*, vol. 3, pp. 19-31, 2020.

[33] M. Funk, "The hack that warned the world", 2015. Retrieved from https://foreignpolicy.com/2015/01/30/climate-change-hack-carbon-credit-black-dragon/

[34] M. R. Castillo, "Carbon Hacking", 2022. Retrieved from https://lowcarbondesigninstitute.org/2022-reme-martinez-castillo/

[35] E. K. Zervoudi, "Fourth Industrial Revolution: Opportunities, Challenges and Proposed Policies", 2020.

[36] E. I. Obilor and E. C. Amadi, "Test for Significance of Pearson's Correlation Coefficient (r)". *International Journal of Innovative Mathematics, Statistics & Energy Policies*, 6(1), pp. 11-23, 2018. Retrieved August 02, 2022, from https://www.researchgate.net/publication/323522779

[37] A. H. Abu Baker, M. N. Mohd Hassan, A. Zakaria and A. A. Abdul Halim, "Pearson's correlation analysis of non-invasive jaundice detection based on colour card technique", *Journal of Physics: Conference Series*, 2019. doi:10.1088/1742-6596/1372/1/012012.

[38] P. M. Sedgwick, "Pearson's Correlation Coefficient", 2012. *BMJ Clinical Research*. doi:DOI: 10.1136/bmj.e4483.

[39] E. Mooi "Regression Analysis. In E. Mooi, & M. Sarstedt, A Consice Guide to Market Research: The Process, Data, and Methods using IBM SPSS Statistics", *New York: Springer*, 2011. doi:10.1007/978-3-642-53965-7_7.