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Impact of higher education, research, institutional quality, and information and communication technology on carbon emissions: Evidence from West Africa

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Abstract

The study analyzes the impact of institutional quality, information and communication technology (ICT), higher education enrollment, and research on carbon emissions and intensity in West Africa. The study used panel data from 12 West African countries, covering the 2009-2020 period, which were obtained from the World Development Indicators database. We applied econometric methods such as fixed and random effects and the generalized method of moments for data analysis. Our findings indicate that while higher education increased carbon intensity, research (proxied as the number of scientific publications) increased carbon emissions in the region. However, both ICT and institutional quality significantly decreased carbon emissions and intensity in West Africa. That is, as the quality of institutions and governance in West Africa improves and ICT usage increases, carbon intensity and emissions decrease, invariably supporting the carbon neutrality objectives of West African governments. The findings will help to shape policy discussions on how to integrate economic development and climate goals, as well as provide insights for regional and global sustainability efforts.

Keywords: Carbon emissions, Carbon intensity, Higher education, ICT, Institutional quality, Panel data, Research.

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1. Introduction

As countries increasingly recognize the need to reduce greenhouse gas (GHG) emissions while maintaining economic growth, the worldwide goal of carbon neutrality has emerged as a crucial solution to the problems posed by climate change [1, 2]. A multifaceted strategy that considers various socioeconomic and institutional aspects is required to achieve carbon neutrality [3-5]. ICT, research, higher education, and institutional quality are all crucial in promoting sustainable environmental outcomes in this context [6-8]. However, little is known about how much these factors contribute to carbon intensity and GHG emissions, especially in West African countries [8]. By encouraging environmental awareness, providing individuals with the information and skills they need to adopt green habits, and stimulating research and innovation, higher education acts as a catalyst for sustainable development [9, 10]. According to empirical research, an increase in the number of students enrolled in post-secondary education enhances their climate knowledge and policy advocacy, which in turn encourages sustainability-focused legislation and reduces carbon emissions [9, 11]. However, due to barriers to educational access and disparities in the distribution of information, the relationship between higher education and carbon neutrality requires further empirical support in developing nations like West Africa.

Innovation and research are essential for developing mitigation methods for climate change [12, 13]. According to Eyuboglu and Uzar [14] and Herzer [15], scientific research helps develop technologies that improve energy efficiency, encourage the use of renewable energy sources [8], and create carbon capture and storage systems. One measure of research intensity that reflects a country's dedication to sustainability-driven knowledge creation is the number of scientific and technical journal articles produced [16, 17]. The relationship between research production and carbon emissions is still unclear, as a high level of research effort can both spur green innovation and increase industrial energy use [18-20]. By influencing governance procedures, policy enforcement, and regulatory frameworks, institutional quality has a major impact on environmental sustainability [3]. Robust institutions provide accountable and transparent governance, which lowers corruption and encourages efficient environmental laws [6, 10]. On the other hand, inadequate enforcement of emission restrictions and resource mismanagement might worsen environmental deterioration due to weak institutions. Understanding the significance of institutional quality in carbon neutrality is crucial for developing effective climate policy in West Africa [8], where governance systems differ greatly among nations.

ICT's explosive growth has transformed social and economic structures, posing both potential and problems for environmental sustainability [3, 21]. Through digitalized industrial processes, smart grids, and remote work capabilities, ICT improves energy efficiency and can lower overall carbon footprints [5]. However, energy consumption and environmental deterioration are further exacerbated by the growth of data centers, digital infrastructure, and electronic waste [11]. Thus, empirical investigation of the overall impact of ICT on carbon emissions in the West African environment is required.

There has been a remarkable increase in ICT penetration in West Africa in recent years. However, this region still lags in ICT advancement [22]. West Africa can take advantage of the technological development of industrialized countries by improving governance, institutional quality, research, and higher education. However, the effects of governance, institutional quality, research, higher education, and ICT usage on carbon neutrality in West Africa are understudied. The current literature on the impacts of higher education, research, ICT, and institutional quality on carbon intensity and emissions largely focuses on Asia and countries in the northern latitudes. The literature on the West African perspective of the linkage between ICT, research, higher education, institutional quality, and carbon intensity and emissions is scant and devoid of in-depth analysis. It is therefore scientifically and morally appropriate to investigate the impacts of higher education, research, ICT, and institutional quality on carbon intensity and emissions.

This study looks at the individual and combined contributions of higher education, research, institutional quality, and ICT to carbon emissions in West Africa. We use fixed and random effects models, as well as generalized method of moments (GMM) estimations, to analyze the impact of these variables on carbon intensity and GHG emissions in 12 West African nations from 2009–2020. Our analysis seeks to fill knowledge gaps by offering strong empirical evidence about the importance of education, government, technological breakthroughs, and research in creating environmental sustainability. The findings suggest that while higher education increased carbon intensity, research (proxied as the number of scientific publications) increased carbon emissions in the region. However, both ICT and institutional quality significantly decreased carbon emissions and intensity in West Africa. That is, the quality of institutions and governance in West Africa improves and ICT usage increases, carbon intensity and emissions will decrease, invariably supporting the carbon neutrality objectives of West African governments. The focus of research and higher education in the region might not have sufficiently focused on carbon neutrality. The findings will help to shape policy discussions on how to integrate economic development and climate goals, as well as provide insights for regional and global sustainability efforts.

This article answers the research question: do institutional quality, higher education enrollment, research, and information and communication technology (ICT) influence carbon emissions and carbon intensity in West Africa? Even though knowledge abounds in the conventional wisdom space on this question, the related extant literature appears scarce and inconclusive in sub-Saharan Africa (SSA) and West Africa in particular.

Overall, our paper, in explicit terms, presents in a single study a snapshot of the impact of institutional quality, higher education, research, and ICT on carbon neutrality in West Africa, which so far remains scant and inconclusive. The quest to achieve quality carbon neutrality (SDG-13) in West Africa is of prime importance, but how covariates such as higher education enrollment, research, institutional quality, and ICT impact carbon emissions and carbon intensity remains largely underexplored.

2. Literature Review

2.1. Institutional Quality and Carbon Intensity and Emissions

A strong correlation exists between tripartite institutional quality, carbon intensity, and emissions [23, 24]. Given its potency in shaping environmental outcomes, institutional quality remains an indispensable determinant of carbon intensity and emissions [25]. Institutional quality encompasses effective governance, transparency, and robust regulatory enforcement mechanisms, among others [3]. These relevant traits contribute immensely to positive outcomes such as clean energy adoption, efficient resource usage, and a substantial reduction in carbon emissions [26].

By upholding institutional quality, environmental policies move beyond rhetoric to become actionable, properly implemented, and firmly enforced, prompting a sustainable reduction in carbon emissions [27]. The existing literature extensively supports the assertion that robust institutions act as catalysts for the effective implementation of energy policies and the regulation of consumption behaviors [28-30]. This ultimately deters corruption, attracts green investments, and promotes reduced energy consumption, increased efficiency, and lower carbon emissions [31].

Evidence from well-governed nations depicts that implementing institutional quality is imperative for achieving carbon neutrality and sustainable economic growth at large [32, 33]. In stark contrast, weak institutions are riddled with a glut of policy roadblocks, corruption, and a lack of enforcement, which leads to higher carbon intensity and deepens inefficiencies [34].

2.2. Higher Education and Carbon Intensity and Emissions

A deep dive into the existing literature lays bare that higher education is a double-edged sword, with the ability to either allay or aggravate carbon intensity and emissions [35]. On the positive side, research consistently highlights an inextricably intertwined link between higher educational attainment and increased environmental awareness [36]. Most studies acknowledge that the environmental awareness gained through higher education translates into proactive behaviors, such as waste reduction and energy conservation, among educated individuals [37-39]. Notably, invaluable gains, such as the reduction of carbon emissions at the source, are realized when higher education is strategically steered toward a path of sustainability and innovation [40].

Investing in higher education has proven to be a germane means of equipping minds to make informed decisions and an apt way of empowering people with technological solutions to reduce carbon emissions [41]. Through research, the integration of climate change into curricula, innovation, and awareness, higher education plays an instrumental role in mitigating carbon emissions [42]. Universities and other higher levels of education drive advancements in clean technologies, energy efficiency, and climate policies, furnishing individuals with the knowledge to implement sustainable practices [43].

However, expanding higher education without deliberate efforts to integrate sustainability into such initiatives tends to increase carbon intensity and environmental degradation [44]. Unchecked industrial expansion and consumption, typically driven by a more educated workforce and higher education, can end up pushing carbon emissions to higher levels [45].

2.3. Information And Communication Technologies and Carbon Intensity and Emissions

Information and Communication Technologies (ICT) can have both positive and negative impacts on carbon emissions and intensity [46]. As such, to truly reap its benefits in reducing emissions, intentional and strategic efforts should be made to manage and utilize ICT in a way that prioritizes sustainability [47]. Positively, ICT transforms energy efficiency through waste reduction, industrial process optimization, and the creation of smart grids that improve power consumption and distribution [48]. In the same vein, real-time monitoring and adaptive energy consumption made possible by digital solutions like artificial intelligence (AI) and the Internet of Things (IoT) help lower carbon emissions [49]. Through remote work and virtual communication, ICT reduces the need for travel, thereby lowering carbon footprints [50]. Markedly, such developments pave the way for a low-carbon economy, allowing individuals and companies to work more productively while minimizing their environmental impact [51].

Notwithstanding these countless advantages of ICT in lowering carbon emissions, the rapid development of ICT infrastructure comes with its own set of challenges [52]. Energy consumption is on the rise due to the increasing need for data centers, cloud computing, and electronic devices linked to ICT [53]. Likewise, ICT is a major source of e-waste, as the production and disposal of electronic devices pose environmental threats [54]. The short lifespan of ICT products and unsustainable manufacturing practices further contribute to carbon emissions and resource depletion [55].

Transitioning to renewable energy data centers, circular e-waste management, and eco-friendly digital practices have emerged as useful for reducing ICT's environmental footprint [56]. Similarly, by responsibly utilizing ICT and aligning it with sustainability goals, its potential can be maximized to reduce emissions while minimizing environmental impact [57].

2.4. Research and Carbon Intensity and Emissions

Research serves as a catalyst for sustainable innovation and policy development [58]. Nonetheless, the very processes involved in conducting research can also be energy-intensive, adding to carbon emissions [59]. Research has been phenomenal in driving advancements in clean energy, sustainable technologies, and in the efficient management of resources [60]. Scientific research continues to play important roles in the reduction of emissions because it informs policymakers and equips them with data-driven strategies useful for crafting effective emission reduction policies [61]. By the same token, research promotes environmental responsibility by raising awareness and encouraging sustainable business practices [62].

Research, by its nature, entails energy-intensive laboratories, high-performance supercomputing, and extensive international travel for conferences and fieldwork, which contribute adversely to emissions [63]. The reliance on large-scale experiments, chemical processing, and resource-heavy data centers for research work further worsens this challenge [64]. Financial constraints, institutional inertia, and bureaucratic obstacles slow down the adoption of sustainable practices within research institutions [65]. This makes full decarbonization cumbersome to achieve in research institutions [66]. Implementing sustainable research frameworks, such as green lab certifications and carbon offset initiatives, can be significant in bridging the gap between scientific progress and environmental responsibility [67].

3. Methodology

3.1. Data Source and Variables Explanation

We utilized panel data from twelve (12) West African countries covering a period of 12 years (2009 – 2020). The countries include Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Ghana, Guinea, Mali, Mauritania, Niger, Nigeria, Senegal, and Togo. The key variables of the study include tertiary school enrollment, research, institutional quality, carbon emissions, carbon intensity, gross domestic product per capita, and ICT (See Table 1).

Table 1.
Description of variables and data source.

Variable	Data source
School enrolment, tertiary (% gross)	WDI
Research (scientific and technical journal articles)	WDI
GDP per capita (current US$)	WDI
Institutional Quality (Principal component score)	WDI
Information and Communications Technology (Principal component score)	WDI
Carbon intensity of GDP (kg CO_2e per 2021 PPP $ of GDP)	WDI
Total greenhouse gas emissions in (Mt CO_2e)	WDI

Note: WDI is World Development Indicators.

3.2. Econometric Framework

Our dependent variable, carbon neutrality, was proxied by carbon intensity and greenhouse gas emissions. Our independent variables include institutional quality, research (proxied by the number of scientific and technical journal articles), higher education (proxied by enrollment in tertiary education institutions), information and communication technology, and a control variable – gross domestic product per capita. Institutional quality was computed using principal component analysis. There are six indicators of institutional quality identified. They include control of corruption (number of sources), political stability and absence of violence/terrorism (number of sources), government effectiveness (number of sources), rule of law (number of sources), regulatory quality (number of sources), and voice and accountability (number of sources). These indicators/proxies were subjected to factor analysis, and the data were reduced to one principal component, which we used as the index of institutional quality in this paper. The index was not transformed into a natural logarithm for further analysis since it has already been subjected to factor analysis. Information and communication technologies (ICT) were computed using principal component analysis. Four ICT-related variables were subjected to principal component analysis, and the score produced by the main component was used in this study as the ICT index. The ICT-related variables include mobile cellular subscriptions, individuals using the internet (% of population), fixed telephone subscriptions, and fixed broadband subscriptions. The implicit model of our fixed and random effects and generalized method of moment regression models is stated as follows:

$$\mathrm{CO2Int} = \mathrm{f(INSQ, RES, TERT, ICT, GDP)} \quad (1)$$

$$\mathrm{GHG} = \mathrm{f(INSQ, RES, TERT, ICT, GDP)} \quad (2)$$

Where;
TERT = Tertiary school enrolment (% gross)
INSQ = Institutional quality (Principal component score)
RES = Research (number of scientific and technical journal articles)
ICT = Information and communication technologies (Principal component score)
GDP = Gross domestic product per capita (current US$)
CO2Int = Carbon intensity of GDP (kg CO_2e per 2021 PPP $ of GDP)
GHG = Total greenhouse gas emissions in (Mt CO_2e)
We controlled potential heteroscedasticity by converting the real values of the variables to natural log. We present the fixed and random effects and generalized method of moment regression models thus:

$$\mathrm{lnCO2Int_{it}} = \beta_0 + \beta_1\mathrm{INSQ_{it}} + \beta_2\mathrm{lnRES_{it}} + \beta_3\mathrm{lnTERT_{it}} + \beta_4\mathrm{ICT_{it}} + \beta_5\mathrm{lnGDP_{it}} + \varepsilon_{it} \quad (3)$$

$$\mathrm{lnGHG_{it}} = \beta_0 + \beta_1\mathrm{INSQ_{it}} + \beta_2\mathrm{lnRES_{it}} + \beta_3\mathrm{lnTERT_{it}} + \beta_4\mathrm{ICT_{it}} + \beta_5\mathrm{lnGDP_{it}} + \varepsilon_{it} \quad (4)$$

Where; i:1, 2, 3, …, 12 countries; t: 2009, 2010, 2011, …, 2020 year; ln is natural logarithm; ε is the error term. Furthermore, β_1, β_2, β_3, β_4, β_5, and β_6 are percentage change in school enrolment as a result of unit change in institutional quality, research, gross domestic product per capita, tertiary education institution enrolment, and information and communication technologies, respectively, while all other factors are constant. ε_{it} is the unobserved country-specific fixed effects.

This study first applied fixed and random effects regressions to provide baseline estimates that are resilient to cross-sectional and temporal dependency. Following the relevant empirical literature and our knowledge of the topic, the schematic diagram in Figure 1 was drawn to explain the relationships among the main variables of interest in our model. Carbon intensity and carbon emissions are the dependent variables, and they are affected by the independent variables, which include institutional quality, research, tertiary education institution enrollment, and information and communication technologies (ICT), as well as the control variable – gross domestic product per capita.

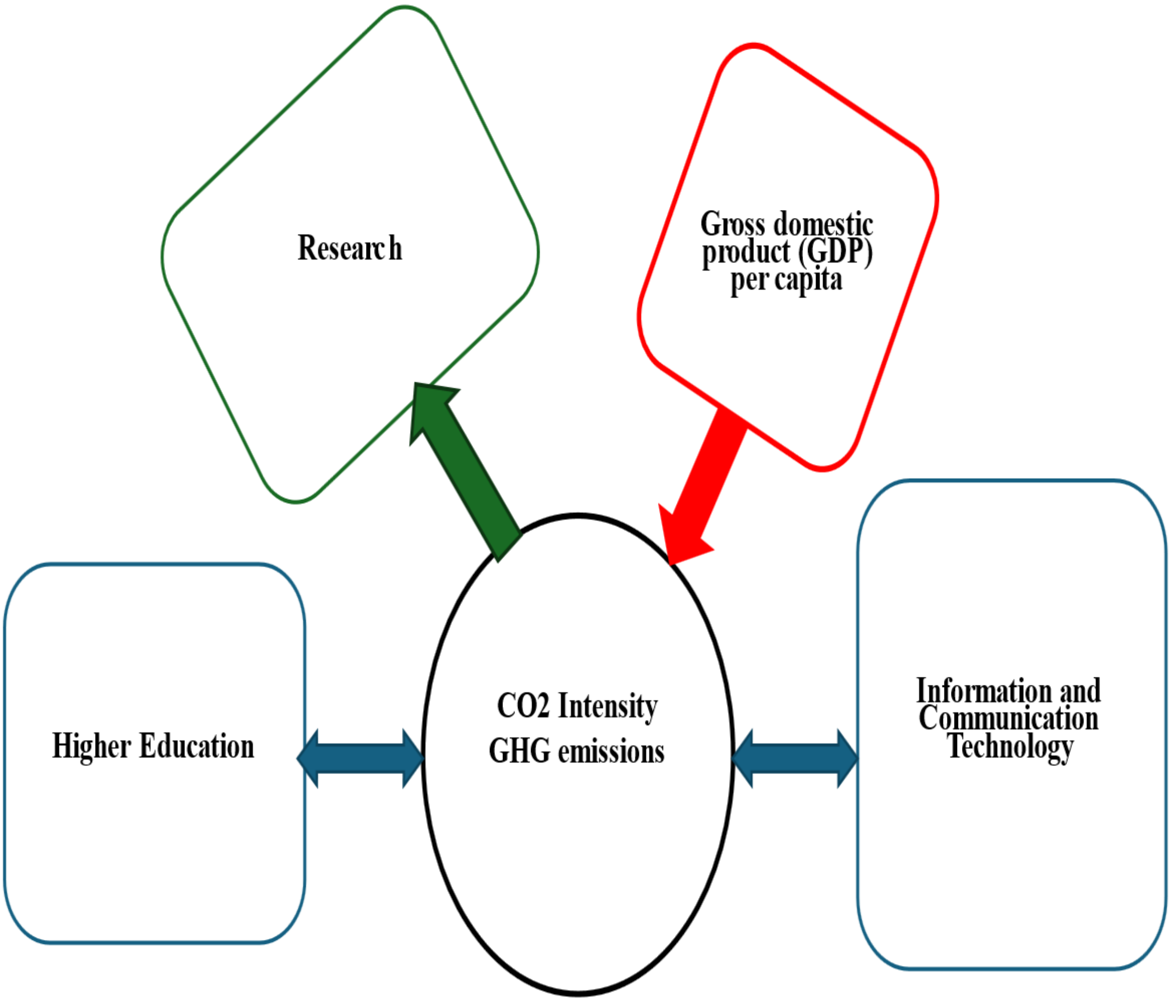

Figure 1.
Impact of institutional quality, research, tertiary school enrolment, and information and communication technologies (ICT) on carbon intensity and carbon emissions.

The static econometric model specification is as follows:
The dynamic models can be specified as:

$$\ln CO2Int_{it} = \beta_1 \ln CO2Int_{it-1} + \beta_2 INSQ_{it-1} + \beta_3 \ln RES_{it-1} + \beta_4 \ln TERT_{it-1} + \beta_5 \ln ICT_{it-1} + \beta_6 \ln GDP_{it-1} + \varepsilon_{it} + u_i + \delta_t \quad (5)$$

$$\ln GHGInt_{it} = \beta_1 \ln CO2Int_{it-1} + \beta_2 INSQ_{it-1} + \beta_3 \ln RES_{it-1} + \beta_4 \ln TERT_{it-1} + \beta_5 \ln ICT_{it-1} + \beta_6 \ln GDP_{it-1} + \varepsilon_{it} + u_i + \delta_t \quad (6)$$

There are two extra error terms in Equations (5 and 6): μ_i and δ_t which are the idiosyncratic error terms and the unobserved time effects, respectively. Based on our *a priori* expectations (see Figure 1), we expect that GDP would increase carbon emissions and intensity, research would decrease carbon emissions and intensity, while ICT and higher education enrollment may increase or decrease carbon emissions and intensity. At this point, it is necessary to state that in estimating Equations (5 and 6), an endogeneity problem may arise because of the inclusion of the lag of the dependent variables as an independent variable in each equation. However, this concern was addressed by applying the system of the generalized method of moments (GMM) econometric procedure proposed by Arellano and Bover [68]. The GMM results were further subjected to two standard robustness tests, namely, the Breusch-Pagan and Hausman tests. This was done to validate the GMM results. Other post-estimation tests were carried out to check if the instruments are valid. The pre- and post-estimation tests ensured the reliability of our GMM results.

4. Results and Discussion

4.1. Descriptive Statistics

Table 2 shows the summary statistics on all the variables analysed in this study for the 12 West African countries. The table shows an average higher education enrolment, on average, constitute 9.61% of the gross for the West African countries between 2009 and 2020. The corresponding figures[1] for the European Union, Middle East and North Africa, Latin America and Caribbean region, and East Asia and Pacific region are as high as 69.66%, 36.55%, 47.78% and 40.58%, respectively. In relative terms, therefore, West African countries have one of the lowest higher education enrolment rates in the world. In line with this, Table 2 further shows that the average scientific articles produced in West Africa in the period understudy was 516.31. This is well below that produced by the European Union, Middle East and North Africa, Latin America and Caribbean region, and East Asia and Pacific region. Within the period, the [2]average number of scientific papers published in the European Union, Middle East and North Africa, Latin America and Caribbean region, and East Asia and Pacific region, were 524839, 92936.99, 95997.21, and 738663.2, respectively. The average carbon intensity in the region was 0.12 kg CO_2e per 2021 PPP $ of GDP and this figure was that recorded in the European Union (0.15 kg CO_2e per 2021 PPP $ of GDP), Latin America and Caribbean region (0.15 CO_2e per 2021 PPP $ of GDP), Middle East and North Africa (0.33 CO_2e per 2021 PPP $ of GDP), and East Asia and Pacific region (0.40 CO_2e per 2021 PPP $ of GDP)[3]. Similarly, the table indicates that the average total greenhouse gas emissions recorded in West Africa between 2009 and 2020 was 64.49 Mt CO_2e. [4]This figure was far below the total emissions recorded in East Asia and Pacific region (17873.38 Mt CO_2e), European Union (3638.09 Mt CO_2e), Latin America and Caribbean region (3897.40 Mt CO_2e) and Middle East and North Africa (2659.21 Mt CO_2e). Carbon intensity and emissions data show that West Africa is a marginal contributor to global warming.

However, it is important to note that there are wider variations in scientific publications, school enrollment, carbon intensity, and total greenhouse gas emissions, as indicated by the measure of dispersion (standard deviation) presented in Table 2. In other words, there appears to be significant heterogeneity in the levels of carbon intensity and emissions, as well as in research and higher education enrollment across West African countries.

Table 2.
Summary statistics result.

Variables	N	Mean	Std. Deviation	Skewness	Kurtosis
School enrollment, tertiary (% gross)	144	9.61	4.88	0.65	0.05
Scientific and technical journal articles	144	516.31	1231.91	3.64	14.43
GDP per capita (current US$)	144	1468.44	882.14	1.16	0.67
Institutional Quality (Principal component score)	144	0.64	0.60	-0.69	0.14
Information and Communications Technology (Principal component score)	144	0.00	1.00	2.05	7.49
Carbon intensity of GDP (kg CO_2e per 2021 PPP $ of GDP)	144	0.12	0.05	0.81	-0.42
Total greenhouse gas emissions in (Mt CO_2e)	144	64.49	194.71	2.52	5.92

4.2. Multicollinearity Test

We computed the variance inflation factor (VIF) to determine whether there is multicollinearity among the independent variables, and the result is presented in the Table 3. The result does not suggest the presence of multicollinearity, as the VIF values were less than 5 and the tolerance values of all the variables were above 0.20. VIF values of approximately less than or equal to 5 indicate a complete absence of multicollinearity in the data. Several other studies have utilized this value as a benchmark for the absence of multicollinearity [69-73].

Table 3.
Multicollinearity test result

Variables	Tolerance	Variance Inflation Factor
lnTERT	0.523	1.912
lnRES	0.278	3.596
lnGDP	0.473	2.115
INSQ	0.404	2.476
ICT	0.315	3.171

[1] The averages for the obtain regions were also computed using data from WDI for 2009-2020 period. https://databank.worldbank.org/source/world-development-indicators#
[2] The averages for the obtain regions were also computed using data from WDI for 2009-2020 period. https://databank.worldbank.org/source/world-development-indicators#
[3] The averages for the obtain regions were also computed using data from WDI for 2009-2020 period. https://databank.worldbank.org/source/world-development-indicators#
[4] The averages for the obtain regions were also computed using data from WDI for 2009-2020 period. https://databank.worldbank.org/source/world-development-indicators#

4.3 Cross-Section Dependence Test

Table 4 shows that there is cross-section dependence in our dataset. The null hypothesis of cross-section independence was rejected. Applying the Pesaran [74] cross-sectional dependence tests for the panel data (see Table 4) shows the existence of cross-section dependence in all model variables.

Table 4.
Cross-section dependence test

Variable	CD-test	p-value
lnTERT	7.14	0.000
lnRES	19.90	0.000
lnGDP	16.50	0.000
INSQ	18.74	0.000
ICT	9.30	0.000
lnCO2Int	5.50	0.000
lnGHG	23.21	0.000

4.4. Stationarity Test

We tested unit roots in our dataset using Pesaran's CIPS test to check the unit root properties and order of integration of the model variables. The results are presented in Table 5. The results indicate that only the institutional quality variable (INSQ) is integrated of order zero; that is, it is stationary at level across all panels. Table 5 further shows that the first difference of all the variables passes the unit root test. This means that all the variables that are not integrated of order zero are stationary at first difference or are integrated of order 1 across all panels.

Table 5.
Unit root test.

Pesaran Panel Unit Root Test (CIPS)				
	At level I(0)	At first difference I(1)		
Variable	*t*-statistic	*t*-statistic	Decision: H_0	Result
lnTERT	−1.807	−2.910***	Reject	I(1) at 1%
lnRES	−2.058	−2.995***	Reject	I(1) at 1%
lnGDP	−2.097	−3.272***	Reject	I(1) at 1%
INSQ	−2.284**	−3.714***	Reject	I(0) at 5%
ICT	−1.588	−3.813***	Reject	I(1) at 1%
lnCO2Int	−2.180	−3.107***	Reject	I(1) at 1%
lnGHG	−1.656	−3.625***	Reject	I(1) at 1%

Note: ** is p<0.05, *** is p<0.01

4.5. Cointegration test

A model that includes I(1) variables suggests that cointegration between these variables should be tested. As a result, the Pedroni test for cointegration was carried out. The results of the cointegration test, provided in Table 6, show that all panels are cointegrated. Most importantly, this result implies the existence of a long-run relationship between the variables analyzed in this study for all panels or countries [75-77].

Table 6.
Cointegration test

Pedroni test for cointegration		
Statistic	Carbon intensity	Carbon emissions
Modified Phillips–Perron t	4.805***	4.786***
Phillips–Perron t	− 12.295***	− 4.805***
Augmented Dickey–Fuller t	− 8.061***	− 4.072***

4.6. Empirical Findings

The results of the static models, fixed effects, and random effects estimators are presented in Table 7. To understand which of the two estimators is most unbiased, efficient, and consistent, the Breusch–Pagan Lagrange multiplier and Hausman tests were conducted. The null hypothesis of random effects was rejected, and a fixed-effect estimator was applied.

The important condition of stringent exogeneity of the independent variables requires a consistent fixed effects estimator. We used the Wooldridge test for exogeneity of the independent variables. The Wooldridge test was significant, and the null hypothesis of no first-order serial correlation was rejected. This suggests that the fixed effects model's parameter estimates are not only skewed but also inconsistent.

This led us to carry out the GMM analysis, which controls for unobserved heterogeneity and prevents the tendency of the estimates of the dependent variable from being biased [78]. The results of the Hansen test indicate that our chosen instruments – the lag of the dependent variables – meet the criteria for suitable instruments and confirm the appropriateness of the chosen model.

Table 7.
Static estimates of our models.

Variables	**Carbon intensity**		**Carbon emissions**	
	Fixed Effects	**Random Effects**	**Fixed Effects**	**Random Effects**
lnTERT	−0.02 (0.06)	0.004 (0.06)	−6.74 (5.96)	−6.26 (5.81)
lnRES	0.03 (0.04)	−0.03 (0.03)	0.996 (4.23)	0.69 (3.69)
lnGDP	0.13 (0.12)	0.18* (0.10)	16.37 (12.46)	16.97 (11.30)
INSQ	−0.19*** (0.05)	−0.20*** (0.05)	−9.83* (5.24)	−10.16** (4.94)
ICT	0.03 (0.03)	0.03 (0.03)	8.39*** (2.93)	8.19*** (2.82)
Constant	−2.81*** (0.79)	−3.20*** (0.64)	−111.83 (78.97)	−115.50 (74.21)
Post-estimation diagnostics				
Wooldridge test (p-value)	p-value = 0.000		p-value = 0.000	
Breusch–Pagan LM test	chi2 (12) = 709.15 Prob > chi2 = 0.0000		chi2 (12) = 54845.15 Prob > chi2 = 0.0000	
Hausman (p-value)	Wald chi2(4) = 4.656 Prob > chi2 = 0.3244		Wald chi2(4) = 4.582 Prob > chi2 = 0.3329	
Test of H_0: Difference in coefficients not systematic	chi2(5) = 5.60 Prob > chi2 = 0.3472		chi2(5) = 1.43 Prob > chi2 = 0.9209	

Note: The parentheses contain the standard errors.
Abbreviations: LM, Lagrange multiplier
* is p<0.1, ** is p<0.05, *** is p<0.01

The GMM results are presented in Table 8. The findings show that a percentage increase in tertiary school enrollment leads to a 0.27% increase in carbon intensity (see Table 8)This is a substantial contribution of tertiary school enrollment to carbon intensity in West Africa. This finding is against our *a priori* expectation that higher education enrollment is expected to decrease carbon intensity. Perhaps, higher education enrollment in the region is not sufficiently focusing on initiatives and studies to achieve carbon neutrality. Additionally, the tertiary school enrollment may increase the total energy needs of tertiary institutions [79, 80] in West Africa, as many of the institutions still use fossil fuels as their energy source. This calls for concerted efforts by West African governments to deliberately enact policies and programs to support tertiary institutions' transition to green/renewable energies. Furthermore, promoting enrollment in courses/subjects that advocate for carbon neutrality and climate action in tertiary institutions is essential. Perhaps, establishing universities of environmental sciences may increase enrollment in courses that support carbon neutrality. Tertiary institution enrollment also increased carbon emissions, but the relationship is insignificant.

A percentage increase in scientific research paper publications leads to a 7.45% increase in carbon emissions. This indicates a significant contribution of research to carbon emissions. This finding is also contrary to our *a priori* expectation. The relationship between research and carbon intensity is also positive but insignificant. Research publications in the region may not have sufficient focus on carbon emissions reduction initiatives. Additionally, researchers in the region still engage in printing papers for most of their studies. This singular activity contributes to greenhouse gas emissions. Felling trees to produce paper used for research purposes in the region discourages carbon neutrality. Increasing awareness among researchers in the region to avoid or reduce printing papers for research purposes should be intensified. Furthermore, research in other areas not related to carbon neutrality and climate action does not produce results that could reduce carbon emissions [12]. The result substantiates the findings of Churchill et al. [81] and Petrović and Lobanov [12] who found positive relationship between carbon emissions and research and development.

A percentage increase in institutional quality decreased carbon intensity by 0.24% and carbon emissions by 15.35%. This finding is in line with our *a priori* expectation. One of the most important drivers of carbon neutrality and environmental sustainability is the quality of governance and institutions [82]. This ensures that resources for climate action and environmentally friendly initiatives are allocated effectively and efficiently with no or minimal corruption. This creates an ecosystem where all stakeholders actively participate in climate protection and carbon neutrality initiatives. Our findings support the analyses of Li et al. [82]; Bernauer and Koubi [83]; Ibrahim and Law [84] and Mehmood et al. [85] who observed that institutional quality negatively impacts CO_2 emissions, which ultimately promotes carbon neutrality.

Our results indicate that ICT has a negative impact on carbon intensity and carbon emissions. A percentage increase in ICT significantly decreases carbon intensity by 0.008% and carbon emissions by 5.13%. The use of ICT is associated with increased energy efficiency, which in turn reduces carbon intensity and emissions. ICT usage encourages low-carbon living, which invariably reduces carbon footprints. ICT tools make life more convenient and efficient. ICT has led to dematerialization, which has induced a shift from material resources and paper to immaterial resources and e-papers. In most organizations, emails have replaced letters, which has also reduced energy consumption and dependence on paper [86]. This implies that ICT promotes low-carbon development, which reduces carbon emissions and intensity [28]. Our results support the findings of Appiah-Otoo et al. [5] and Wen et al. [18], who found that ICT negatively impacts carbon intensity and emissions, thereby promoting environmental sustainability and carbon neutrality.

Table 8.
Generalized method of moments, estimation results (one-step difference)

Variables	Carbon intensity	Carbon emissions
	Estimates	**Estimates**
lnTERT	0.27*** (0.05)	4.86 (5.17)
lnRES	0.01 (0.02)	7.45*** (2.83)
lnGDP	0.11** (0.05)	15.42*** (6.14)
INSQ	−0.24*** (0.06)	−15.35* (8.80)
ICT	−0.008** (0.003)	−5.13** (2.28)
Constant	−3.50*** (0.36)	−156.24*** (49.18)
Post-estimation diagnostics		
Sanderson-Windmeijer multivariate F test of excluded instruments (p-value)	F(5, 138) = 91.95 Prob > F = 0.000	F(5, 138) = 3.39 Prob > F = 0.006
Hansen–Sargan (p-value)	Chi-sq(4) p-value = 0.324	Chi-sq(4) p-value = 0.332
Kleibergen-Paap rk LM statistic (p-value)	Chi-sq(5) p-value = 0.000	Chi-sq(5) p-value = 0.004
Cragg-Donald Wald F statistic	27.62	26.87
Stock-Yogo weak ID test critical values: 5% maximal IV relative bias	18.37	18.37

Note: The parenthesis contains the robust standard errors.
***p < 0.01, **p < 0.05, *p < 0.1.

5. Conclusions and Recommendations

This study, motivated by SDG 4 and SDG 13, the paucity of evidence on the linkages of ICT, research, higher education, institutional quality, and carbon intensity and emissions comprehensively examines the nexus between institutional quality, ICT, higher education, research, and carbon emissions and carbon intensity. This topic has not been effectively explored in the literature, especially in the context of West Africa. The analysis involves 12 countries in West Africa over the period 2009–2020 and uses fixed and random effects, and generalized method of moments regression models. The results show that higher education, research, ICT, and institutional quality have statistically significant effects on carbon neutrality via carbon intensity and carbon emissions. Specifically, research and higher education enrollment positively influence carbon emissions and carbon neutrality, while ICT and institutional quality have negative effects on both carbon emissions and carbon neutrality.

The results have several important policy implications. The fact that institutional quality negatively affects carbon emissions and carbon intensity makes regulating and strengthening the functions and efficacy of institutions and governance structures in West African countries essential to reduce carbon emissions and intensity, thereby achieving ecological sustainability and carbon neutrality.

ICT decreased carbon emissions and carbon intensity in the region. Therefore, the governments of West African countries should provide tax rebates and subsidies to those firms that promote and produce environmentally friendly ICT products. It is also important to provide a conducive regulatory environment that will attract investment in ICT infrastructure in West Africa. Governments can use ICT tools to increase awareness and information regarding the adverse impacts of climate change and promote suitable ways to enhance environmental quality.

Research and higher education demonstrate positive relationships with carbon emissions and carbon intensity. Promoting environmental education should be considered and pursued vigorously in higher education institutions in the region. Additionally, managers of tertiary institutions should address energy-related issues in higher education institutions. West African governments should stimulate and support research on the clean and green revolution that acts as a mechanism for a low-carbon economy.

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