Structural transformation and sustainable development in sub-Saharan Africa

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Abstract

Purpose – The study investigates the link between structural transformation and sustainable development in sub-Saharan Africa.

Design/methodology/approach – The study adopts the traditional ordinary least square method and the Driscoll and Kraay covariance matrix estimator to address every form of cross-sectional and temporal dependence in panel data.

Findings – The study finds the structural transformation of the SSA economy will engender sustainable development. Specifically, the study finds that knowledge exerts a positive and statistically significant impact on sustainable development in SSA. Similarly, we found that technology (mobile cellular subscription and fixed telephone line subscription) promotes sustainable development. The results also show that all the economic transformation promotes sustainable development in SSA. Further, we also found that economic development and physical capital are important drivers of sustainable development in SSA. However, trade openness does not contribute to sustainable development in SSA. This might be because the combined scale effect in trade outweighs the combined technology and composition effects in SSA. This suggests the technology component in total trade activities in SSA does not promote sustainable development. The study recommends that governments across SSA should invest more in ICT and mobile cellular infrastructure or create an enabling environment that encourages digitization and the development of financial technology in the manufacturing, mining, construction, agriculture and services sectors to enhance green and quality growth for sustainable development in SSA.

Originality/value – The study uncovers the role of structural transformation in promoting sustainable development in SSA.

Keywords Structural transformation, ICT, Knowledge, Economic transformation, Sustainable development, SSA

Paper type Research paper

1. Introduction

In 2015, world leaders under the United Nations umbrella adopted the 17 sustainable development goals (SDGs) as an action plan towards sustainable development. The aim is that in 15 years (that is, by 2030), the world would be transformed, and everyone would live a life of dignity. Unfortunately, socio-economic conditions across sub-Saharan African (SSA) countries continue to deteriorate. Some scholars (see Ferreira *et al.*, 2010) argued that the continued deterioration of socio-economic conditions in SSA may not be unconnected to the fact that SSA economy may be structurally defective. For instance, the SSA economy relies heavily on the production of primary commodities—dominated by the manufacturing and

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agricultural sectors— which are characterized by the excessive utilization of non-renewable sources of energy. In SSA, due to the region's abundance of natural resources, the extractive sector is a major part of the economy in many economies. The international Monetary Fund notes that about 50% of SSA's exports and 15% of its annual output come from nonrenewable natural resources. Unfortunately, the region's excessive reliance on non-renewable energy sources raises carbon emissions, creates extreme weather, and in turn damages homes and businesses; and it is often the trigger that tips the vulnerable into poverty (Baloch *et al.*, 2020; Khan *et al.*, 2019; World Bank, 2015). Specifically, SSA contributes about 2% of the world's emissions, and perhaps it is now responsible for a large chunk of the world's emissions today (Statista, 2022). This may hinder the actualization of the 2030 sustainable development agenda. Thus, to engender sustainable growth and development across SSA, there is a need for the structural transformation of the economy [1]—through innovation— towards a knowledge-based economy [2].

Consequently, in recent literature, scholars (see Schwab, 2016; Vaidya *et al.*, 2018; ElMassah and Mohieldin, 2020; Digaru, 2020; Wen and Zhu, 2021; Metu *et al.*, 2021; Abbas *et al.*, 2023; Chen *et al.*, 2023; Caldarola *et al.*, 2023) have argued that the structural transformation of the economy aided by the innovative technologies such as information and communication technology (ICT) and the fourth industrial revolution technologies [3] (4IR hereafter) can aid the achievement of the sustainable development agenda by the year 2030 through various channels. First, technologies and their innovative applications, for instance, can play a significant role in facilitating access to loans, restructuring tax systems and aid resilient recovery and growth (Schwab, 2016; Metu *et al.*, 2021), thereby, raising global income levels and improving the quality of life for populations around the world. Second, the authors assert that the application of innovative technologies can help to curb the excessive utilization of non-renewable energy, reduce carbon emissions, stop damage to home and businesses, and ultimately engender sustainable development (ElMassah and Mohieldin, 2020). Unfortunately, despite the importance of technology in promoting sustainable development, sub-Saharan Africa lags other regions on several indicators essential for technological revolution and structural transformation, specifically, in infrastructure, technology access and education (see Figure A1 in the Appendix).

Although there have been a few attempts (see Schwab, 2016; Vaidya *et al.*, 2018; ElMassah and Mohieldin, 2020; Digaru, 2020; Signé and Ndung'u, 2020; Wen and Zhu, 2021; Metu *et al.*, 2021) to examine the effects of structural transformation and/or technological innovations on sustainable development, however, these studies suffer some significant shortcomings. One, the evidence presented thus far is limited and largely anecdotal, with most of the previous evidence on the relationship between innovations/structural transformation and SDGs based on survey and simple correlational study. Two, most of the existing studies have mostly focused on process and/or production engineering, system integration aspects of innovations, while the economic effects of these technologies have not been adequately investigated. Three, another important limitation of the existing studies is that extant studies have adopted a single metric approach, focusing on only one of the 17 SDGs per time. However, this single metric approach may not fully capture the full complexities in SDGs. Lastly, previous studies have not considered the transmission channels from structural transformation to sustainable development in SSA.

By addressing these gaps, we provide evidence-based strategies that will inform robust policy formulation on the structural transformation of sub-Saharan Africa's economy for inclusive and sustainable development.

The rest of the paper is organized as follows. Section 2 presents the review of literature. Section 3 describes the data and Methodology. Section 4 presents the empirical findings, and Section 5 concludes the paper.

2. Literature review

The literature reviewed has been summarized in Table 1.

3. Theoretical framework, methodology and model specification

3.1 Theoretical framework

The study is premised on two relevant theories. They are Arthur Lewis Structural Change theory (sometimes referred to as the dual economic theory) and the compensation theory of technological change (CTTC). Arthur Lewis theory of structural change documented in his work "Lewis's theory of economic development" tries to explain the growth of a developing country in terms of labour transition between two sectors. The theory focuses on labour being transferred from traditional activity to a modern capitalist sector under conditions of unlimited supply of labour (Gollin, 2014). To put it in a clear context, Lewis's structural change theory primarily focused on the mechanism by which underdeveloped economies transform their domestic economic structures from a heavy emphasis on traditional subsistence agriculture to a more modern, more urbanized and more industrially diverse manufacturing and service economy. Thus, according to Arthur Lewis's structural change theory, underdeveloped economies can only achieve sustainable development only if they undergo a structural transformation. However, Arthur Lewis recognizes that technology is crucial to the structural transformation of developing economies. Thus, we incorporated the compensation theory of technological change into the framework. The theory acknowledges that technological innovation may create some disruptions such as unemployment at the initial stage, however, it can compensate for the initial disruption through various compensation mechanisms. For example, technology innovation may create additional employment in the capital goods sector, which may help to increase productivity and economic growth, and engender sustainable development. In the alterative, the compensation mechanism may manifest through reduction in prices resulting from a decrease in the cost of production, and creation of new demand for product and employment, which may ultimately foster sustainable development (see Metu *et al.*, 2021).

3.2 Methodology

3.2.1 Materials and method. The study analysed the role of structural transformation in engendering sustainable growth and development in 18 SSA countries (due to data unavailability) over the period 1990–2018. For the list of 18 countries, see Table A1 in the Appendix. Secondary data on ICT (proxied by mobile cellular subscription, fixed telephone subscriptions, and ICT goods imports), economic complexity [4], and economic transformation are used to measure structural transformation. Economic complexity assesses the current state of a country's productive knowledge. The idea is that countries that can sustain a diverse range of productive know-how, including sophisticated, unique know-how would foster sustainable growth and development. Economic transformation is measured by output growth *(gross value added at current basic prices) across various sectors, namely, agriculture* [5], *mining* [6], *manufacturing* [7], *utilities* [8], *construction* [9], *services* [10], *real estate* [11])) [12].

Sustainable development is captured by a robust measure of sustainable development (*which considers life expectancy, expected and mean years of schooling, GNI per capita, CO2 emissions, and material footprint*). The study also adopts a more robust measure of sustainable development (*which considers life expectancy, expected and mean years of schooling, GNI per capita, CO2 emissions, and material footprint*). The control variables used in the study are the inflation rate used to capture macroeconomic fluctuations in the economy; and per capital gross domestic product (*pGDP*) to measure of economic development. Trade openness can also influence sustainable development by influencing carbon emissions through scale, composition, and technology effects. For instance, if the combined technology and

Table 1. A summary of review of literature on structural transformation and SDGs

Author(s) and date	Topic	Estimation strategy	Findings
Structural transformation			
Tasneem and Khan (2024)	Growth and structural transformation—options for Pakistan	Computable General Equilibrium (CGE) model	The results show that structural transformation towards promising sectors (manufacturing and services) has a positive impact on the macro-economic variables as well as at the household level in Pakistan
Caldarola *et al.* (2023)	Mobile internet, skills, and structural transformation in Rwanda	OLS and 2SLS	The study found that an increase in mobile internet increases employment opportunities and contributes to changes in the composition of the labour market, education, and migration in Rwanda
Abbas *et al.* (2023)	Structural transformation, urbanization, and remittances in developing countries: A panel VAR analysis	Vector Autoregressive (VAR) Model	The study reported that there is a two-way causal relationship between structural transformation and urbanization, structural transformation, and GDP growth
Fereira and Cateia (2023)	Trade reform, infrastructure investment, and structural transformation in Africa: Evidence from Guinea-Bissau	Dynamic Computable General Equilibrium model	The study found that structural transformation reduces inequality over time
Chen *et al.* (2023)	Do structural transformation and urbanization assist in enhancing sustainable energy technologies innovations? Evidence from ASEAN countries	Methods of Moments Quantile Regression	The findings show that structural transformation, urbanization, and renewable energy consumption significantly derive sustainable energy technology innovations
Ghosh *et al.* (2023)	Does economic structure matter for income inequality?	System-GMM (generalized method of moments)	The authors found that structural transformation improves income distribution
Zhao *et al.* (2022)	Does structural transformation in economy impact inequality in renewable energy productivity? Implications for sustainable development	CS-ARDL	The study shows that structural transformation helps to reduce the inequality in renewable energy productivity
Ali and Gninigué (2022)	Global value chains participation and structural transformation in Africa Are we advocating environmental protection?	Second-generation panel data	The study found that structural transformation influences the relationship between global value chain and environmental pollution

(*continued*)

Table 1. Continued

Author(s) and date	Topic	Estimation strategy	Findings
Grainger-Brown *et al.* (2022)	Exploring urban transformation to inform the implementation of the Sustainable Development Goals	A Systematic Qualitative Review	The authors note that urban transformation can be a tool to design a new transformative pathway to achieve SDGs in cities
Wang *et al.* (2022)	Has the Sustainable Development Planning Policy Promoted the Green Transformation in China's Resource-based Cities?	Synthetic Method	The authors note that the implementation of the SDP policy in China has a weak positive promotion effect on the overall transformation and development of resource-based cities
Haldar and Sethi (2022)	Effect of sectoral foreign aid allocation on growth and structural transformation in sub-Saharan Africa—Analysing the roles of institutional quality and human capital	Driscoll–Kraay Fixed-Effect estimators, Fixed-Effects Panel Threshold regression and Method of Moments Quantile regression	The authors found that the agricultural and social sectors do not aid structural transformation
Muazu (2020)	Effects of trade and financial integration on structural transformation in Africa: New evidence from a sample splitting approach	Threshold Analysis	The study reported that the there is an optimal level above which trade openness and financial integration slows down structural transformation
López and Yoon (2020)	Sustainable development: Structural transformation and the consumer demand	Dynamic equilibrium	The findings reveal that a consumers' composition effect plays a critical role in the structural transformation process
Atolia *et al.* (2020)	Rethinking development policy: What remains of structural. Transformation?	A Systematic Review	The review indicates that the manufacturing sector, which has been beneficial for most advanced economies for decades, may be incapable of delivering similar benefits to low-income countries
Cardinale and Scazzieri (2019)	Explaining structural change: actions and transformations	A Review	
Vu (2017)	Structural change and economic growth: Empirical evidence and policy insights from Asian economies	Generalized Method of Moments (GMM)	The result indicates that effective structural change (ESC) can be an important indicator for monitoring the impacts of structural reforms
Innovative technologies and sustainable development			
Vaidya *et al.* (2018)	Industry 4.0— A Glimpse	A Systematic Review	The study notes that Industry 4.0 allows smart, efficient, effective, production at reasonable cost

(*continued*)

Table 1. Continued

Author(s) and date	Topic	Estimation strategy	Findings
Wen and Zhu (2021)	China's industrial revolution: A new perspective	A Simple Analysis	The author notes that the lack of industrialization in any nation is due to the lack of a mass market
Metu *et al.* (2021)	The Fourth Industrial Revolution and Employment in Sub-Saharan Africa: The Role of Education	System GMM	The result shows that 4IR exert a positive effect on industry labor employment in SSA
Digaru (2020)	The Main Goals of the Fourth Industrial Revolution. Renewable Energy Perspectives	A Simple Analysis	The authors note that the 4IR has the potential to increase revenue and raise standard of living
ElMassah and Mohieldin (2020)	Digital transformation and localizing the Sustainable Development Goals (SDGs)	A Simple Correlational Study	The study found that digital transformation boosts localization of sustainable development
Armoo *et al.* (2020)	The fourth industrial revolution: a game-changer for the tourism and maritime industries	A Qualitative Approach	The authors assert that the integration of the floating dry dock with 3D printing technology can make Jamaica a more economically viable country
Bhattacharyya and Mitra (2020)	Fourth industrial revolution and India's "employment problem"	Fixed Effects (FE), Random Effects (RE), and OLS estimation Techniques	The authors found that innovation does not seem to enhance the performance index in a very significant manner across industry groups considered in the study
Erer and Erer (2020)	Industry 4.0 and its Role on Labour Market: A Comparative Analysis of Turkey and European Countries	A Simple Correlational Study	The authors concluded that Turkey have a higher risk at automation than European countries
Demirbağ and Yildirim (2018)	Industry 4.0: Literature Review and Thematic Analysis	A Review	The review shows that empirical methods are rare, with majority of the studies utilizing qualitative methods such as case studies
Ghobakhloo (2020)	Industry 4.0, digitization, and opportunities for sustainability	Interpretive Structural Modelling Technique	The results indicate that sophisticated precedence relationships exist among various sustainability functions of Industry 4.0
Ghobakhloo *et al.* (2021)	Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants	A Bibliometric and Systematic Review	The findings reveal that Industry 4.0 transformation could address pressing issues of sustainable development goals, particularly manufacturing-economic development

(*continued*)

Table 1. Continued

Author(s) and date	Topic	Estimation strategy	Findings
Stock *et al.* (2018)	Industry 4.0 as Enabler for Sustainable Development: A Qualitative Assessment of its Ecological and Social Potential	A Qualitative Assessment Approach	The assessment uncovers that the value creation might positively contribute to a sustainable development in many instances
Dantas *et al.* (2020)	How the combination of circular economy and industry 4.0 can contribute towards achieving the Sustainable Development Goals	A systematic Literature Review	The authors note that the Circular economy- Industry 4.0 nexus is pivotal in the endeavours to achieve the SDGs

Source(s): Created by authors

composition effects (oriented towards clean goods) outweigh the scale effect, trade openness will improve environmental quality, and thus, sustainable development; and vice-versa (Fakher, 2019). Institutional quality (captured by the quality of government index) is used to capture the institutional environment. It is important to consider the quality of the institutional environment to reinforce the need for state and institutional capacity to drive and support innovation and create an enabling business environment, especially for developing countries who lack a comprehensive legal framework and institutional capacity to drive and support innovation for sustainable development. The measurement and sources of data are shown in Table 2.

3.2.2 Model specification. The study models the relationship between structural transformation and sustainable development in line with extant studies. This is shown in Equation (1):

$$sd_t = \tau + \alpha(ST)_t + X_t'\beta + \varepsilon_t \tag{1}$$

where subscripts N is the time index, *sd* denote sustainable development (the measure considers life expectancy, expected and mean years of schooling, GNI per capita, CO2 emissions, and material footprint). ST denotes structural transformation (captured by a vector of variables, namely, (technology (measured by *mobile subscription per 100 users, fixed telephone subscription per 100 users, and ICT goods imports*)), economic transformation (*measured by sectoral output growth*)), and Knowledge (*captured by economic complexity*)). X_t captures other control variables that could influence sustainable development, in line with extant studies, such as, the quality of institutions (proxied by the ICRG's quality of government index, which is measured by the mean value of the ICRG variables on "Corruption", "Law and Order" and "Bureaucracy Quality"). The ICRG variables have been re-scaled from 0 to 1— the closer to 1, the higher values indicate higher quality of government [13]; economic growth, tertiary school enrolment ratio, and inflation rate, and ε_t is the error term.

3.2.3 Estimation technique. The baseline estimation technique is the traditional ordinary least square (OLS). However, the OLS estimate is limited, in that it does not account for the potential cross-sectional or temporal dependency in panel data models. Thus, the study also adopts Driscoll-Kraay covariance matrix estimator to account for every form of cross-sectional and temporal dependence in panel data, and in technology diffusion (see Caldarola *et al.*, 2023).

Table 2. Measurement and sources of variables

Variables	Definition/Measurement	Source
1. Structural transformation		
i. Technology	This is measured by mobile subscription per 100 users, fixed telephone subscription per 100 users, and ICT goods imports	WDI/International Telecommunication Union
ii economic transformation	This is measured by output growth (gross value added at current basic prices) across various sectors, namely, agriculture, mining, manufacturing, utilities, construction, services, and real estate	ETD
iii. Economic complexity	Economic complexity assesses the current state of a country's productive knowledge. A high ECI index implies a higher level of productive knowledge	Atlas Media databank
2. Sustainable development	This is measured by a single index which considers the following five indicators: life expectancy, education, income, material footprint, and CO2 emissions	Hickel (2020) Sustainable development database
3. Economic development	It is measured by per capita GDP	WDI
4. Quality of government	This is measured by the mean value of the ICRG variables on "Corruption", "Law and Order" and "Bureaucracy Quality". The closer to 1, the higher quality of government	ICRG Quality of Government Dataset
5. Trade openness	This is the degree to which nondomestic transactions (imports and exports) take place in a national economy	WDI
6. Level of technology preparedness and literacy	This is measured by school enrolment, tertiary (% gross)	WDI
7. Technology use	It is measured by the share of individuals using the internet	International Telecommunication Union
8. Inflation	It is measured by consumer prices	WDI
9. Physical capital	It is measured by gross capital formation	WDI

Note(s): WDI denotes World Bank Development Indicators, ETD is Economic transformation Dataset (de Vries *et al.*, 2021), ICRG is the International Country Risk Guide
Source(s): Created by authors

3.2.4 Cross sectional dependence test. Before estimating the cross-sectional and spatial-dependence consistent models, the study tests whether the error terms in the panel models are truly cross-sectionally independent since it is affirmed that panel data models are likely to show various forms of cross-sectional dependencies (see Driscoll and Kraay, 1998). The test is set under the null hypothesis (H_0) the errors are cross-sectional independent.

4. Empirical analysis

This section presents the results from empirical analysis and discusses the results in relation to existing studies and theory. First, we present the descriptive statistics of the data used in the study.

4.1 Descriptive statistics

Table 3 presents descriptive statistics. The data shows that the model is stable as indicated by the mean, median, minimum, and maximum values. For instance, the data shows that the mean

Table 3. Descriptive statistics of variables

Panel A	sus. dev	tech	know	transf	pGDP	quality o G	techpre	inf	gcf
Summary statistics									
Mean	0.50	31.43	−0.77	10.62	7.01	0.45	7.58	11.14	22.60
Median	0.50	7.49	−0.77	10.77	6.92	0.45	5.03	7.31	21.93
Max	0.71	161.19	0.36	15.27	9.27	0.89	41.59	183.31	58.18
Min	0.20	0.000	−2.33	5.15	5.24	0.09	0.32	−9.61	0.00
std. dev.	0.10	40.96	0.50	2.36	0.97	0.11	8.25	16.19	9.10
Skewness	−0.22	1.24	−0.29	0.02	0.39	0.64	1.92	5.70	0.31
Kurtosis	2.80	3.54	3.24	2.12	2.25	4.68	6.89	50.15	4.64
Observations	489	521	406	522	522	435	347	485	484
Panel B									
sus. dev.									
tech		1.000							
know		0.359	1.000						
transf		−0.010	−0.125	1.000					
pGDP		0.627	0.492	−0.246	1.000				
quality o G		0.070	0.437	−0.361	0.395	1.000			
techpre		0.855	0.332	−0.141	0.816	0.203	1.000		
inf		−0.212	−0.190	−0.053	−0.140	0.183	−0.200	1.000	
gcf		0.339	0.107	0.034	0.251	0.028	0.315	−0.056	1.000

Note(s): Table 2 presents the descriptive statistics for the variables used in the study. The study covers 18 sub-Saharan African countries over the period 1990–2018. sus. dev. tech, know, transf, pGDP, quality o G, techpre, inf, and gcf denote sustainable development, technology (captured by mobile subscription), knowledge (measured by economic complexity), transformation (measured by logarithm of financial services), quality of government, technology preparedness (measured by school enrolment, tertiary (% gross), inflation, and gross capital formation, respectively

Source(s): Created by authors

and median values are close, which denotes a symmetric distribution, low variability, and a high level of consistency.

Table 4 presents the result of the multicollinearity test. By rule of thumb, the decision rule is that there is multicollinearity among variables when the variance inflation factor (VIF) is above 4.0. The result in Table 4, column 1 shows that there is multicollinearity among the measures of transformation (*agriculture, mining, manufacturing, utilities, construction, services, and real estate*), and technology (*mobile subscription per 100 users, fixed telephone subscription per 100 users, and ICT goods import*s). To sidestep this issue, we use each variable per time. The results in columns 3 and 5 show that the model is free from the problem of multicollinearity. Thus, we estimate the model using each of the proxies of transformation, and technology per time.

4.1.1 Unit root test. The study examined the order of stationarity of the variables. The result is presented in Table 5. The result shows that the variables are integrated either at levels, i.e. I (0) or at first difference, i.e. I(1).

4.1.2 Baseline regression. Table 6 presents the baseline model. The method of estimation is the ordinary least square (OLS). The result indicates across all specifications that knowledge, technology, and transformation contribute positively to sustainable development in SSA. However, given that many panel data models exhibit some form of cross-sectional and temporal dependence, we test for cross-sectional dependence in the model.

Table 4. Multicollinearity test

Variable	VIF 1	1/VIF 2	VIF 3	1/VIF 4	VIF 5	1/VIF 6
Agriculture	204.10	0.004	4.09	0.244	–	–
Manufacturing	154.12	0.006	–	–	–	–
Financial services	120.57	0.008	–	–	2.36	0.42
Utilities	69.59	0.014	–	–	–	–
Business services	55.42	0.018	–	–	–	–
Real estate	47.34	0.021	–	–	–	–
Construction	44.66	0.022	–	–	–	–
pGDP	18.32	0.054	–	–	–	–
School enrolment	13.96	0.071	–	–	4.13	0.24
Fixed tele	12.71	0.078	4.14	0.24	–	–
Mobile	10.06	0.099	–	–	4.24	0.23
Mining	8.99	0.11	–	–	–	–
Pop. using internet	7.73	0.12	3.66	0.27	–	–
Trade open	7.55	0.13	3.41	0.29	3.25	0.30
Complexity	3.80	0.26	1.96	0.51	1.72	0.58
QoG	3.53	0.28	1.90	0.52	1.88	0.53
gcf	3.00	0.33	1.46	0.68	1.47	0.67
ICT imports	2.57	0.38	–	–	–	–
Inflation	1.90	0.52	1.29	0.77	1.23	0.81
Mean VIF	*41.58*		*3.12*		*2.53*	

Note(s): VIF denotes Variance Inflation Factor
Source(s): Created by authors, authors computation

Table 5. Result of the panel unit root tests (individual effects)

Variables	LLC	Breitung	IPS	PP-Fisher	ADF-Fisher	Order
tech	−2.14***		−3.35***	74.80***	84.18***	I(1)
inf	−6.80***		−6.37***	108.30***	147.01***	I(0)
sus. dev.	−2.45***	–	−4.09***	78.74***	152.70***	I(1)
pGDP	−6.41***		−8.75***	149.25***	240.74***	I(1)
know	−1.99**		−2.77***	54.48***	85.02**	I(0)
transf	−5.35***		−8.85***	152.34***	304.63***	I(1)

Note(s): Table 4 shows the results of unit root tests under individual and linear trends
Source(s): Created by authors

4.2 Cross-sectional dependence

The results of the cross-section dependence tests show that the units are cross-sectionally dependent (see Tables 7 and 8). Thus, the OLS estimation may not be adequate.

In the presence of cross-sectional and temporal dependence, we re-examined the order of stationarity using second-generation CIPS and CADF panel unit root tests. The model is set under the null hypothesis of homogeneous non-stationarity. The results are presented in Table 9. The result is consistent with the result from the first-generation unit tests. The result shows that the variables are integrated either at levels, i.e. I(0) or at first difference, i.e. I(1))

The result in Table 10 is robust to different estimation techniques. The study finds that knowledge (proxied by economic complexity) exerts a positive and statistically significant impact of sustainable development in SSA (see column 1), indicating that knowledge is very vital for sustainable development in Africa. Similarly, we found that technology (mobile cellular subscription, and fixed telephone lines subscription) promotes sustainable

Table 6. OLS estimates

Variable sus. dev	Knowledge 1	Technology 2	3	4	Transformation 5	6	7	8	9	10	11
Complex	0.037***	–	–	–	–						
	(0.009)										
Mobile	–	0.0003***	–	–	–						
		(0.00009)									
Fixed tele	–	–	0.0018**	–	–						
			(0.0008)								
ICT imports	–	–	–	0.007***	–						
				(0.001)							
Agriculture	–	–	–	–	0.007***						
					(0.002)						
Mining	–	–	–	–	–	−0.004*					
						(0.0022)					
Manufacturing	–	–	–	–	–		0.0088***				
							(0.0022)				
Services	–	–	–	–	–			0.011***			
								(0.002)			
Utilities	–	–	–	–	–				0.011***		
									(0.002)		
Construction	–	–	–	–	–					0.009***	
										(0.002)	
Real estate	–	–	–	–	–						0.003*
											(0.002)
Inflation	0.001**	0.0009**	0.0006	0.0006	0.0004**	0.0003	0.0009**	0.0008*	0.0008**	0.0008*	0.0007*
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0001)	(0.0004)	(0.0005)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
gcf	0.0003	0.0001	0.001*	0.001*	0.0005	0.001*	0.0007	0.0003	0.001**	0.0001	0.0006
	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
pGDP	0.062***	0.066***	0.066***	0.066***	0.081***	0.076***	0.075***	0.070***	0.079***	0.074***	0.074***
	(0.006)	(0.005)	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)

(*continued*)

Table 6. Continued

Variable	Knowledge	Technology			Transformation						
sus. dev	1	2	3	4	5	6	7	8	9	10	11
Trade	−0.0001	−0.00001	−0.0001	−0.0001	0.0004**	−0.0002	0.0004**	0.0005***	0.0005***	0.0005***	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
Pop/internet	–	–	–	–	–						
QoG	–	–	–	–	–						
School enrol	–	–	–	–	–						
Constant	0.091**	0.010	0.011	0.085**	−0.208***	0.004	−0.185***	−0.166***	−0.242***	−0.180	−0.098**
	(0.047)	(0.036)	(0.041)	(0.04)	(0.059)	(0.041)	(0.051)	(0.042)	(0.0455)	(0.046)	(0.047)
Adjusted R^2	0.4701	0.4975	0.4824	0.4152	0.4997	0.4809	0.4964	0.5103	0.5647	0.5023	0.4807
F-statistics	55.82	75.45	71.27	37.92	74.30	70.84	75.33	79.57	97.52	77.11	70.78
Prob. *F*-statistics	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note(s): Sus. dev, complex, mobile, fixed tele, services, gcf, pGDP, trade, pop/internet, QoG, school enrol are sustainable development, economic complexity, mobile cellular subscription, fixed telephone subscription, financial services, gross capital formation, share of population using the internet, quality of government, and school enrolment, respectively. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source(s): Created by authors

Table 7. Panel cross-section dependence tests (variable)

Variable	Breusch-Pagan LM	Pesaran scaled LM	Bias-corr. scaled LM	Pesaran CD
sus. dev.	2515.688***(0.0000)	134.03***(0.0000)	133.71***(0.000)	28.91***(0.0000)
inf	557.17***(0.0000)	22.07***(0.0000)	21.75**(0.0000)	16.65**(0.0000)
tech	4139.87***(0.0000)	226.88***(0.0000)	226.56***(0.0000)	64.30***(0.0162)
know	365.71***(0.0000)	14.82***(0.0000)	14.50****(0.0000)	2.80***(0.0000)

Note(s): The cross-section dependence test is set under the null hypothesis of cross-section independence, CD ~ N (0,1) *p*-values close to zero indicate data are correlated across panel groups. $***p < 0.01$, $**p < 0.05$, $*p < 0.10$. Abbreviations: CSD, cross-sectional dependence; LM, Lagrange multiplier
Source(s): Created by authors

Table 8. Panel cross-section dependence tests in the model (regression)

Test	Results
1.Breusch-Pagan LM	867.07***(0.0000)
2. Pesaran Scaled LM	56.48***(0.0000)
4. Pesaran (2004) CD	21.35***(0.0000)

Note(s): $***p < 0.01$, $**p < 0.05$, $*p < 0.10$
Source(s): Created by authors

Table 9. Results of panel unit root tests in presence of cross-section dependence

	CIPS[a] Level	CADF[b]	CIPS[a] 1st difference	CADF[b]
sus. dev.	–	4.64	–	−2.52***
transf	2.14***	−1.90	–	−2.53***
pGDP	−1.98	−1.86	−4.38***	−3.285***
Know	–	−1.66**		
Tech	–	−4.17***		

Note(s): [a]H_0 (homogeneous non-stationary): bi = 0 for all I whereas [b] the null hypothesis assumes all series are non-stationary in a heterogeneous panel with cross-sectional dependence. $***p < 0.01$, $**p < 0.05$, $*p < 0.10$
Source(s): Created by authors

development (see columns 2 and 3). The study aligns with the findings of Dantas *et al.* (2020) and Ghobakhloo *et al.* (2021) [14][15]. Similarly, the result is consistent with the findings of Caldarola *et al.* (2023) who reported that an increase in mobile internet increases employment opportunities and contributes to changes in the composition of the labour market, education, and migration in Rwanda. However, we do not find that ICT imports engender sustainable development. The result is also consistent with the submission of the Nigerian Communication Commission that the achievement of the 2030 sustainable development agenda in SSA may be dependent on broadband availability and technology infrastructure (Olaoye and Zerihun, 2023). The Commission notes further that the security, economic, and educational development of Nigeria, and the region in general, may be contingent on the availability of state-based broadband structure and framework. The result is also corroborated by the central bank of Nigeria in its July 2022 report, that technology and innovation are crucial for positive economic transformation, output growth and sustainable development (Central Bank of Nigeria, 2022).

Table 10. Driscoll-Kraay estimates (adjusted for fixed effects)

Variable	Knowledge	Technology			Transformation							
sus. dev	1	2	3	4	5	6	7	8	9	10	11	12
Complexity	0.034***	–	–	–	–							0.024***
	(0.01)											(0.008)
Mobile	–	−0.0002*	–	–	–							0.0001
		(0.0001)										(0.0001)
Fixed tele	–	–	−0.006***	–	–							
			(0.001)									
ICT imports	–	–	–	0.0003	–							
				(0.001)								
Agriculture	–	–	–	–	0.142***							
					(0.018)							
Mining	–	–	–	–	–	0.050***						
						(0.004)						
Manufacturing	–	–	–	–	–		0.054***					
							(0.014)					
Services	–	–	–	–	–			0.0359***				0.085***
								(0.009)				(0.0102)
Utilities	–	–	–	–	–				0.015			
									(0.018)			
Construction	–	–	–	–	–					0.075***		
										(0.005)		
Real estate	–	–	–	–	–						0.039	
											(0.023)	
Inflation	−0.003	−0.0003	−0.00003	0.0003*	0.0005**	0.0004	0.00001	−0.00005	−0.0002	0.0003	−0.00007*	0.0002
	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0001)	(0.0002)	(0.0002)
gcf	0.002***	0.002**	0.001**	0.001***	0.001**	0.0008	0.002**	0.001**	0.002***	0.001***	0.002***	−0.0007***
	(0.0008)	(0.0009)	(0.0001)	(0.0004)	(0.0006)	(0.0005)	(0.0009)	(0.0009)	(0.0008)	(0.0005)	(0.0009)	(0.0002)
pGDP	0.135***	0.208***	0.207***	0.175***	0.042*	0.095***	0.091***	0.072*	0.145***	−0.013***	0.093**	0.018
	(0.011)	(0.022)	(0.011)	(0.007)	(0.023)	(0.014)	(0.014)	(0.035)	(0.023)	(0.004)	(0.044)	(0.028)
Trade	−0.0001	−0.00001	−0.00002***	−0.0001	−0.0001	−0.0002	−0.00003	−0.00002	0.0002	−0.00003	0.0001	−0.0004**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Pop/internet	–	–	–	–	–							−0.0002
												(0.0003)

(*continued*)

Table 10. Continued

Variable	Knowledge	Technology			Transformation							
sus. dev	1	2	3	4	5	6	7	8	9	10	11	12
QoG	–	–	–	–	–							0.09***
												(0.035)
School enrol	–	–	–	–	–							−0.004***
												(0.001)
Constant	−0.486***	−1.04***	−0.997***	−0.789**	−1.59***	−0.760	−0.852***	−0.447***	−0.762***	−0.275	−0.670***	−0.560***
	(0.080)	(0.153)	(0.073)	(0.062)	(0.100)	(0.062)	(0.103)	(0.154)	(0.080)	(0.062)	(0.089)	(0.135)
Within R^2	0.5013	0.4375	0.5195	0.5102	0.5838	0.6002	0.4813	0.4892	0.4907	0.5516	0.4741	0.8710
F-statistics	489.15	355.50	222.71	419.54	597.16	579.06	709.43	474.70	399.64	472.60	523.16	1038.91
Prob. *F*-statistics	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note(s): Sus. dev, complex, mobile, fixed tele, services, gcf, pGDP, trade, pop/internet, QoG, school enrol are sustainable development, economic complexity, mobile cellular subscription, fixed telephone subscription, financial services, gross capital formation, share of population using the internet, quality of government, and school enrolment, respectively. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$
Source(s): Created by authors

On the effect of economic transformation on sustainable development, the results show that all the economic transformation variables, except the utilities and real estate sectors promote sustainable development in SSA (see columns 5 to 11). This implies the rapid development of the services, manufacturing, agriculture, construction, and mining sectors can aid sustainable development in SSA. The results also align with the World Bank report (2023) that the rapid development of some sectors, particularly the services sector, driven by rapid growth and application of information and communication technologies (ICTs) has been the driving force behind the post-pandemic recovery in some parts of Africa. We also found that economic development (*captured by per capital GDP*) and capital (measured by gross capital formation) are important drivers of sustainable development in SSA. However, trade openness does not contribute to sustainable development in SSA. This might be that the combined scale effect in trade outweighs the combined technology and composition effects (oriented towards clean goods) in SSA. That is, the ICT component in total trade activities in SSA is not sufficient to engender sustainable development. This may also explain the insignificant impact of ICT goods import (a measure of ICT) on sustainable development (see column 4).

4.2.1 The role of technology preparedness and technology use. The results presented in Table 10 (column 12) show that quality of government exerts a positive and statistically significant effect of sustainable development, indicating that improvements in the quality of government in SSA will foster sustainable development. However, the level of technology preparedness (measured by tertiary school enrolment) exerts a negative and statistically significant effect on sustainable development in SSA, while technology use (proxied the share of population using the internet) has no statistically significant effect on sustainable development in SSA, indicating that SSA may not be ready to harness the gains of the ongoing technological revolution. This might mean that the number of people enrolled in tertiary school education, and the share of the population with access to internet may be too small to help drive the sustainable development agenda in SSA.

In summary, the results emanating from the empirical research indicate that the structural transformation of the SSA economy will aid the actualization of the sustainable development agenda in SSA. The results align with a recent study by Tasneem and Khan (2024) who found that structural transformation towards promising sectors (manufacturing and services) has a positive impact on the macro-economic variables as well as at the household level in Pakistan.

5. Conclusions, policy recommendations, and suggestions for further studies

The study investigated the link between structural transformation (measured by knowledge, technology, and economic transformation) and sustainable development in SSA. The study adopted a cross-sectional and spatial-consistent model to account for every form of cross-sectional and temporal dependence in panel data, and more specifically, in technology diffusion. The study finds that knowledge (proxied by economic complexity) exerts a positive and statistically significant impact of sustainable development in SSA. Similarly, we found that technology (mobile cellular subscription, and fixed telephone lines subscription) promotes sustainable development. The results show that all the economic transformation variables, except the utilities and real estate sectors promote sustainable development in SSA. This implies the rapid development of the services, manufacturing, agriculture, construction, and mining sectors can aid sustainable development in SSA. The results also align with the World Bank report (2023) that the rapid development of some sectors, particularly the services sector, driven by rapid growth in information and communication technologies (ICTs) has been the driving force behind the post-pandemic recovery in some parts of Africa. We also found that economic development (*captured by per capital GDP*) and capital (measured by gross capital formation) are important drivers of sustainable development in SSA. However, trade openness does not contribute to sustainable development in SSA.

Based on the empirical findings, the study recommends the following:

One, government and policymakers across SSA should invest more in technology and knowledge-acquisition programmes to foster sustainable development in SSA.

Two, governments across SSA should provide state-based broadband and eco-friendly technologies to foster sustainable development.

Three, governments across SSA should ensure that ICT-based products constitute a larger component of their imports.

Four, governments should make education (particularly, at the tertiary level) affordable and accessible to all to improve the level of technological preparedness that will aid the structural transformation of SSA economies.

Five, governments across SSA should invest more in ICT and mobile cellular infrastructure or create an enabling environment that promotes digitization and the development of financial technology in the manufacturing, mining, construction, agriculture, and services sector (often referred to as the knowledge economy) since the knowledge economy can enhance green and quality growth and promote sustainable development in SSA.

The study examined the effect of structural transformation on sustainable development in SSA. One limitation of the study is that it did not consider the potential non-linear relationship in the model. However, this is not the focus of the study. Future research can investigate the optimal level of technology and knowledge that engenders sustainable development.

Notes

1. Danquah *et al.* (2024) defined structural transformation as the shift from an agrarian economy to a more industrialized economy as well as the redistribution of income to poor households.
2. The knowledge economy (captured by the services sector) can enhance green and quality growth, and promote sustainable development (Olaoye and Zerihun, 2023).
3. Schwab (2016) defines the 4IR as the fusion of technologies that blurred the lines between the physical, digital, and biological spheres.
4. Economic complexity assesses the current state of a country’s productive knowledge. The idea is that countries that can sustain a diverse range of productive know-how, including sophisticated, unique know-how would foster growth and development.
5. Agriculture sector comprises Agriculture, forestry, and fishing.
6. Mining includes mining and quarrying.
7. Manufacturing sector comprises of all manufacturing-related activities.
8. The sector comprises electricity, gas, steam, and air conditioning supply; water supply; sewerage, waste management and remediation activities.
9. Construction refers to all activities relating to construction.
10. It includes all financial and insurance activities.
11. All Real estate activities.
12. https://www.rug.nl/ggdc/structuralchange/etd/
13. Krueger and Maleckova (2003) and Choi (2010) argue that sound institutions (captured by corruption, bureaucratic quality, and law and order) promote sustainable development, while a deficient rule of law, high level of corruption, and low bureaucratic quality hinder sustainable development.
14. The authors affirmed that innovative technologies enhance sustainable development.

References

Abbas, S.A., Selvanathan, S. and Selvanathan, E.A. (2023), “Structural transformation, urbanization, and remittances in developing countries: a panel VAR analysis”, *Economic Analysis and Policy*, Vol. 79, pp. 55-69, doi: 10.1016/j.eap.2023.06.010.

Ali, E. and Gninigué, M. (2022), "Global value chains participation and structural transformation in Africa: are we advocating environmental protection?", *Journal of Cleaner Production*, Vol. 366, 132914, doi: 10.1016/j.jclepro.2022.132914.

Armoo, A.K., Franklyn-Green, L.-G. and Braham, A.J. (2020), "The fourth industrial revolution: a game-changer for the tourism and maritime industries", *Worldwide Hospitality and Tourism Themes*, Vol. 12 No. 1, pp. 13-23, doi: 10.1108/whatt-10-2019-0063.

Atolia, M., Loungani, P., Marquis, M. and Papageorgiou, C. (2020), "Rethinking development policy: what remains of structural transformation?", *World Development*, Vol. 128, 104834, doi: 10.1016/j.worlddev.2019.104834.

Baloch, M.A., Danish, Khan, S.U., Ulucak, Z.S. and Ahmad, A. (2020), "Analyzing the relationship between poverty, income inequality, and CO2 emission in Sub-Saharan African countries", Vol. 740, 139867, doi: 10.1016/j.scitotenv.2020.139867.

Bhattacharyya, S. and Mitra, A. (2020), "Fourth industrial revolution and India's 'employment problem'", *International Journal of Social Economics*, Vol. 47 No. 7, pp. 851-866.

Caldarola, B., Grazzi, M., Occelli, M. and Sanfilippo, M. (2023), "Mobile internet, skills and structural transformation in Rwanda", *Research Policy*, Vol. 52 No. 10, 104871, doi: 10.1016/j.respol.2023.104871.

Cardinale, I. and Scazzieri, R. (2019), "Explaining structural change: actions and transformations", *Structural Change and Economic Dynamics*, Vol. 51, pp. 393-404, doi: 10.1016/j.strueco.2018.12.002.

Central Bank of Nigeria (2022), "Monetary policy committee: digitization, catalyst for accelerated growth", CBN Update, Vol. 4 No. 7, pp. 1-8, available at: https://www.cbn.gov.ng/out/2022/ccd/cbn%20update%202022%20july.pdf

Chen, N., Novy, D., Perroni, C. and Wong, H. (2023), "Urban-biased structural change", CEPR Discussion Paper 18522.

Choi, S.M. (2010), *Institutional foundations for economic growth (MPRA paper 42633)*, University Library of Munich.

Danquah, M., Ouattara, B., Ohemeng, W. and Barimah, A. (2024), "Urbanisation, climate change and structural transformation in Accra, Ghana", *ACRC Working Paper 2024-21, Manchester: African Cities Research Consortium*, The University of Manchester, available at: www.african-cities.org

Dantas, T.E.T., de-Souza, E.D., Destro, I.R., Hammes, G., Rodriguez, C.M.T. and Soares, S.R. (2020), "How the combination of circular economy and industry 4.0 can contribute towards achieving the sustainable development goals", *Sustainable Production and Consumption*. doi: 10.1016/j.spc.2020.10.005.

de Vries, G., Linda, A., Dorothea, D., Mareike, G., Calumn, H., Bente, J-T., Ahmet, I.K., Hagen, K., Emmanuel, M. and Pieter, W. (2021), "The economic transformation database (ETD): content, sources, and methods", WIDER Technical Note 2/2021, available at: https://www.wider.unu.edu/project/etd-–-economic-transformation-database. doi: 10.35188/UNU-WIDER/WTN/2021-2

Demirbağ, K.S. and Yildirim, N. (2018), "Industry 4.0: literature review and thematic analysis".

Digaru, L. (2020), "The main goals of the fourth industrial revolution: renewable energy perspective", *Procedia Manufacturing*, Vol. 46, pp. 397-410.

Driscoll, J.C. and Kraay, A.C. (1998), "Consistent covariance matrix estimation with spatially dependent panel data", *The Review of Economics and Statistics*, Vol. 80 No. 4, pp. 49-560, doi: 10.1162/003465398557825.

ElMassaha, S. and Mohieldin, M. (2020), "Digital transformation and localizing the sustainable development goals (SDGs)", *Ecological Economics*, Vol. 169, 106490, doi: 10.1016/j.ecolecon.2019.106490.

Erer, E. and Erer, D. (2020), "Industry 4.0 and its role on labour market: a comparative analysis of Turkey and European countries", *Agile Business Leadership Methods for Industry*, Vol. 4 No. 0, pp. 85-102, doi: 10.1108/978-1-80043-380-920201006.

Fakher, H.-A. (2019), "Investigating the determinant factors of environmental quality (based on ecological carbon footprint index)", *Environmental Science and Pollution Research*, Vol. 26 No. 10, pp. 10276-10291, doi: 10.1007/s11356-019-04452-3.

Fereira, S.B. and Cateia, J.V. (2023), "Trade reform, infrastructure investment, and structural transformation in Africa: evidence from Guinea-Bissau", *Emerging Markets Review*, Vol. 55, 101027, doi: 10.1016/j.ememar.2023.101027.

Ferreira, A., Moulang, C. and Hendro, B. (2010), "Environmental management accounting and innovation: an exploratory analysis", *Accounting, Auditing & Accountability Journal*, Vol. 23 No. 7, pp. 920-948, doi: 10.1108/09513571011080180.

Ghobakhloo, M. (2020), "Industry 4.0, digitization, and opportunities for sustainability", *Journal of Cleaner Production*, Vol. 252, 119869, doi: 10.1016/j.jclepro.2019.119869.

Ghobakhloo, M., Fathi, M., Iranmanesh, M., Maroufkhani, P. and Morales, M.E. (2021), "Industry 4.0 ten years on: a bibliometric and systematic review of concepts, sustainability value drivers, and success determinants", *Journal of Cleaner Production*, Vol. 302, 127052, doi: 10.1016/j.jclepro.2021.127052.

Ghosh, S., Doğan, B., Can, M., Shah, M.I. and Apergis, N. (2023), "Does economic structure matter for income inequality?", *Quality and Quantity*, Vol. 57 No. 3, pp. 2507-2527, doi: 10.1007/s11135-022-01462-1.

Gollin, D. (2014), "The Lewis model: a 60-year retrospective", *The Journal of Economic Perspectives*, Vol. 28 No. 3, pp. 71-88, doi: 10.1257/jep.28.3.71.

Grainger-Brown, J., Malekpour, S., Raven, R. and Taylor, E. (2022), "Exploring urban transformation to inform the implementation of the Sustainable Development Goals", *Cities*, Vol. 131, 103928, doi: 10.1016/j.cities.2022.103928.

Haldar, A. and Sethi, N. (2022), "Effect of sectoral foreign aid allocation on growth and structural transformation in sub-Saharan Africa—analysing the roles of institutional quality and human capital", *Economic Analysis and Policy*, Vol. 76, pp. 1010-1026, doi: 10.1016/j.eap.2022.10.009.

Hickel, J. (2020), "The sustainable development index: measuring the ecological efficiency of human development in the anthropocene", *Ecological Economics*, Vol. 167 C.

Khan, Z., Sisi, Z. and Siqun, Y. (2019), "Environmental regulations an option: asymmetry effect of environmental regulations on carbon emissions using non-linear ARDL energy sources", *Part A: Recovery, Utilization, and Environmental Effects*, Vol. 41 No. 2, pp. 137-155, doi: 10.101080/00036846.2021.1907289.

Krueger, A.B. and Maleckova, J. (2003), "Education, poverty and terrorism: is there a causal connection?", *Journal of Economic Perspectives*, Vol. 17 No. 4, pp. 119-144.

López, R.E. and Yoon, S.W. (2020), "Sustainable development: structural transformation and consumer demand", *Structural Change and Economic Dynamics*, Vol. 52, pp. 22-38, doi: 10.1016/j.strueco.2019.09.011.

Metu, A.G., Madichie, C.V., Ulua, C.K. and Nzeribe, G.E. (2021), "The fourth industrial revolution and employment in Sub-Saharan Africa: the role of education", *Journal of African Development*, Vol. 21 No. 1, pp. 116-137.

Muazu, I. (2020), "Effects of trade and financial integration on structural transformation in Africa: new evidence from a sample splitting approach", *Physica A: Statistical Mechanics and its Applications*, Vol. 556, 124841, doi: 10.1016/j.physa.2020.124841.

Olaoye, O.O. and Zerihun, M.F. (2023), "Financial inclusion and poverty reduction in Nigeria: the role of information and communication technology (ICT)", *African Journal of Economic and Management Studies*, ISSN 2040-0705, doi: 10.1108/AJEMS-12-2022-0488.

Pesaran, M.H. (2004), "General diagnostic tests for cross section dependence in panels", *Cambridge Working Papers in Economics 0435*, Faculty of Economics, University of Cambridge.

Schwab, K. (2016), *The Fourth Industrial Revolution: What it Means, How to Respond*, World Economic Forum, available at: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond

Signé, L. and Ndung'u, N. (2020), "Capturing the fourth industrial revolution—a regional and national agenda", Brookings Foresight Africa, available at: https://www.brookings.edu/wp-content/uploads/2020/01/ForesightAfrica2020_Chapter5_20200110.pdf

Statista (2022), "Africa's share in global carbon dioxide (CO2) emissions", available at: https://www.statista.com/statistics/1287508/africa-share-in-global-co2-emissions/

Stock, T., Obenaus, M., Kunz, S. and Holger, K. (2018), "Title: Industry 4.0 as enabler for sustainable development: a qualitative assessment of its ecological and social potential", *Process Safety and Environmental Protection*, Vol. 118, pp. 254-267, doi: 10.1016/j.psep.2018.06.026.

Tasneem, F. and Khan, M.A. (2024), "Growth and structural transformation – options for Pakistan", *Research in Globalization*, Vol. 8, 100190, doi: 10.1016/j.resglo.2023.100190.

Vaidya, S., Ambad, P. and Bhosle, S. (2018), "Industry 4.0—a glimpse", *Procedia Manufacturing*, Vol. 20, pp. 233-238, doi: 10.1016/j.promfg.2018.02.034.

Vu, K.M. (2017), "Structural change and economic growth: empirical evidence and policy insights from Asian economies", *Structural Change and Economic Dynamics*, Vol. 41, pp. 64-77, doi: 10.1016/j.strueco.2017.04.002.

Wang, Y., Chen, H., Long, R., Sun, Q., Jiang, S. and Liu, B. (2022), "Has the sustainable development planning policy promoted the green transformation in China's resource-based cities?", *Resources, Conservation and Recycling*, Vol. 180, 106181, doi: 10.1016/j.resconrec.2022.106181.

Wen, Y. and Zhu, X. (2021), "Structural change and aggregate employment fluctuations in China", *International Economic Review*, Department of Economics, University of Pennsylvania and Osaka University Institute of Social and Economic Research Association, Vol. 62 No. 1, pp. 65-100.

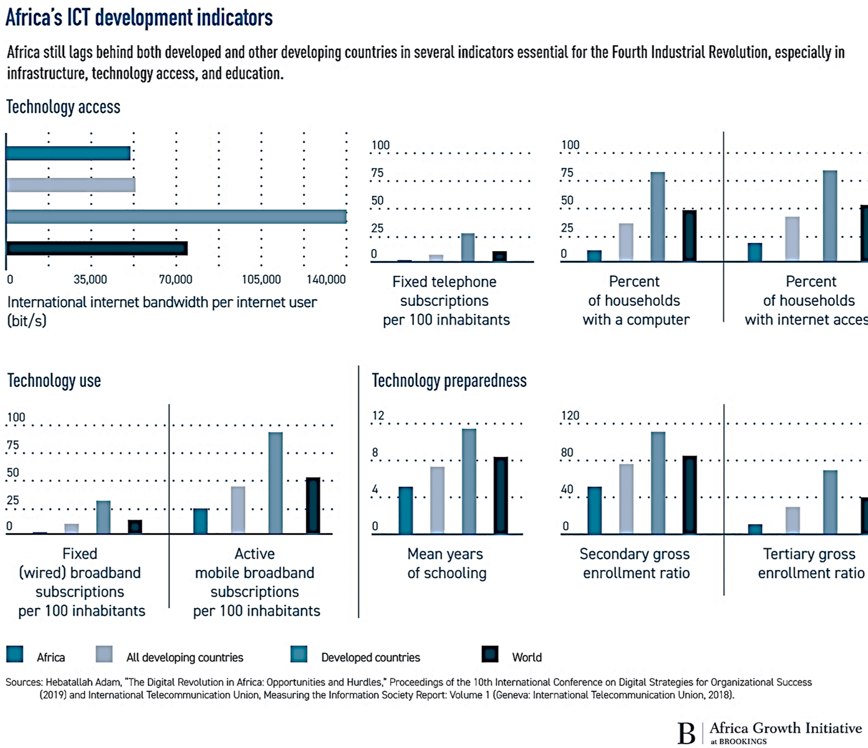
World Bank (2015), "Climate change complicates efforts to end poverty", available at: https://www.worldbank.org/en/news/feature/2015/02/06/climate-change-complicates-efforts-end-poverty

Zhao, J., Sinha, A., Inuwa, N., Wang, Y., Murshed, M. and Abbasi, K.R. (2022), "Does structural transformation in the economy impact inequality in renewable energy productivity? Implications for sustainable development", *Renewable Energy*, Vol. 189, pp. 853-864, doi: 10.1016/j.renene.2022.03.050.

Further reading

OECD (2023), "Telecommunications database", *OECD Telecommunications, and Internet Statistics (database)*, doi: 10.1787/data-00170-en.

Appendix



Source(s): International Telecommunication Union

Figure A1. Africa's technology development indicator

Table A1. List of countries

	Africa
1	Botswana
2	Burkina Faso
3	Cameroon
4	Ethiopia
5	Ghana
6	Kenya
7	Lesotho
8	Malawi
9	Mauritius
10	Mozambique
11	Namibia
12	Nigeria
13	Rwanda
14	Senegal
15	South Africa
16	Tanzania
17	Uganda
18	Zambia

Source(s): https://www.rug.nl/ggdc/structuralchange/etd/

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