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*DOI:*  
[10.1007/s10668-023-04355-x](https://doi.org/10.1007/s10668-023-04355-x)

*Publication date:*  
2024

*Licence:*  
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*Document Version*  
Publisher's PDF, also known as Version of record

[Link to publication in Discovery Research Portal](#)

*Citation for published version (APA):*  
Ahmad Bello, A., Hassan, A., Saint Akadiri, S., Onuogu, I. C., & Shuaibu Aliyu, U. (2024). Towards ICT diffusion and trade liberalisation on inclusive growth in Sub-Saharan Africa. *Environment, Development and Sustainability*. Advance online publication. <https://doi.org/10.1007/s10668-023-04355-x>

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# Towards ICT diffusion and trade liberalisation on inclusive growth in Sub-Saharan Africa

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Received: 21 September 2022 / Accepted: 12 December 2023  
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## Abstract

While the debate over the nexus between trade liberalization and inclusive growth is progressively reaching some consensus in emerging and developing economies, the empirical findings are mixed for sub-Saharan African (SSA) countries. Some of the SSA countries experience rapid growth in information and communication technology (ICT) diffusion manifesting in increased green wealth via the invention of new ideas, access to wider markets like the African Continental Free Trade Area (AfCFTA), promoting accountability, social inclusion, and e-governance among others. The present study critically assesses how ICT diffusion modulates trade liberalization on inclusive growth throughout the 2005–2020 periods for 48 SSA countries. This study contributes empirically and methodologically to literature, specifically on the construction of the ICT index, inclusive growth index, and adoption of a better befitting econometric model. The study explores the direct impacts of ICT diffusion and trade liberalization, and their indirect impacts using an interaction term on inclusive growth. Contrary to the prior expectations, trade liberalization does not lead to inclusive growth in the SSA region, but ICT diffusion has a positive and significant impact on inclusive growth. However, the interaction term of ICT and trade liberalization improves inclusive growth. Therefore, the study advocates for policies that would build a knowledge-based human capital, stimulate innovation in socio-economic systems, and develop ICT infrastructure and its penetration among others, with the expectation that as AfCFTA takes effect, ICT diffusion will facilitate intra-regional trade, enhancing inclusive growth in the African region among other sound policy suggestions.

**Keywords** Inclusive growth · ICT diffusion · Trade liberalization · Sub-Saharan Africa · Panel study

**JEL Classification** F11 · F14

## 1 Introduction

Trade liberalization boosts growth and reduces overall inequality in emerging and developing nations (Dollar & Kraay, 2004; Gruber and Koutroumpis, 2011; Anand et al. 2013; Ward & Zheng, 2016, 2016b; Zahonogo, 2016; Kang et al., 2017; 2019; Arabiyat et al. 2020; Faizah et al. 2021; Osabohien et al., 2021). Thus, trade boosts productivity, encourages the spread of information and innovation, encourages the development of skills, broadens the choice of goods available to consumers, and lowers prices (Bachetta et al. 2021). While some studies have found that trade hinders socioeconomic development (Nourzad & Powell 2003; Dollar & Kraay, 2004; Razmi & Yavari, 2012; and Hartmann & Hidalgo, 2017), Others contend that trade leads to distorted economic structures that favour skilled labor and capital over unskilled labor, and this deepens the inequality gap (Melitz, 2003; Milanovic & Squire, 2005; Jawaid & Waheed 2017). A recent report by the International Monetary Fund (IMF) revealed that increases in inclusive growth are strongly connected to improvements in international trade, particularly in emerging and developing economies (Henceforth: EMDEs), because it lowers inequality, and enhances knowledge and technological diffusion (IMF, 2020). While the debate on the nexus between trade liberalization and inclusive growth is gradually reaching some consensus in EMDEs, studies on the synergy effects of trade liberalization and ICT diffusion on inclusive growth are rare to find especially for Sub-Saharan Africa (SSA).

Since the early 1990s, the SSA region has been experiencing steady economic growth (Albiman and Sulong, 2017; Obeng, et al., 2021). Available statistical data from the United Nations (2020) shows that the region continuously achieved steady positive economic growth in 2016, 2017, and 2019 at 1.3%, 2.6%, and 2.7%, respectively. Despite this episode of steady growth, the region achieved in recent years, the levels of poverty rate and hunger are still so prevalent in the region (Usman et al., 2022). Several countries in the SSA region are lagging in achieving inclusive growth, where many of their citizens live below the poverty line and the continent is facing the worst food insecurity in the world (Aliyu et al., 2021), with around one in every three persons facing severe food insecurity (UNCAT, 2021). The SSA region is one of the most socially and economically disadvantaged regions with the highest levels of inequality in the world today (Ravallion and Chen, 2019). Following the Coronavirus pandemic (COVID-19) outbreak, the region slumped into a deep recession, contracted by 1.9% in 2020 down from the projected growth of 3.2% (World Bank, 202; IMF, 2020).

Some of the SSA countries such as South Africa, Nigeria, Gabon, Mauritius, Namibia, Cape Verde, and Seychelles experience rapid growth in ICT diffusion manifesting in increasing shared prosperity. ICT diffusion generates green wealth via the invention of new ideas, and access to wider markets like the AfCFTA which facilitates access to information and knowledge enhances social networking, simplifies administrative procedures, and promotes accountability, e-governance and social inclusion (see, Sassi and Goaid 2013; Tchamyou 2017; Palvia et al. 2018; Donou-Adonsou 2019; Asongu et al. 2019; Mengesha and Garfield, 2019; Rondović et al., 2019;). The 2020 World Bank report further revealed that the \$450 billion in potential economic benefits from the implementation of AfCFTA would be driven by \$292 billion in trade liberalisation measures that cut red tape and improve customs operations. With this massive potential income gain from AfCFTA, can the spread of ICT have a beneficial synergistic effect on fostering inclusive growth in SSA nations? This is the main research question, the current study addresses using panel data of 48 SSA countries over the periods of 2005–2020.

The study critically assesses how ICT diffusion modulates trade liberalization on inclusive growth. The interaction between the trade openness index and ICT diffusion could be explained within the context of AfCFTA. ICT diffusion facilitates wider access to African markets and helps to deliver the targets of a trading block. The result is fostering shared prosperity via the generation of employment opportunities, more access to knowledge, efficient medical services, and social inclusion among others.

The current study adds to existing knowledge in numerous important ways. To begin, the research employs a composite measure of ICT and a composite measure of inclusive growth to empirically assess the influence of ICT and trade liberalizations on inclusive growth. Second, this study scrutinizes the role of ICT in attaining inclusive growth, given the necessity of trade freedom in delivering digital tools or equipment for inclusive development. Third, to generate reliable and efficient estimates, the research work applies the robust panel data econometric methodologies on the most recent accessible data set. Thus, this research contributes to a better understanding of how trade liberalization and ICT contribute to inclusive growth in SSA.

The remainder of the study is structured as follows: The theoretical foundations underpinning the research and empirical literature are provided in Sect. 2. Section 3 presents the data and methodology for the study. In Sect. 4, the empirical data are presented and discussed with references to previous research. Section 5 concludes the study by deriving conclusions and policy implications from the main findings.

## 2 Review of related literature

### 2.1 Theoretical framework

The theoretical framework underpinning this current research is drawn from two creeks of economic ideas—the Heckscher–Ohlin trade proposition (i.e., theoretic basis of trade liberalization), and the Sustainable Livelihoods Approach (SLA) of economic growth. The Heckscher–Ohlin denotes the connection between trade liberalization and economic growth (see Acharya, 2015; Lederman, 2013). The basis of this theory hinges on the fact that the extent to which countries are opened in terms of trade among countries has a significant role to play in stimulating inclusive growth among countries of the world, evidence of which is seen in African, Asian, and Middle East countries. The SLA on the other hand creates varying connections among, institutions, livelihood assets, livelihood outcome, and economic policies (see Messer & Townsley 2003). It is a sharing method built on the assumption that people, firms, and nations have abilities to develop their situations, businesses, and economies at large, provided they have access (which trade openness can enhance) to assets (both physical and human assets). It is on this premise and the SLA framework's flexibility in analyzing inclusive growth that trade liberalization is incorporated into the model (see Lederman, 2013).

The connection between trade liberalization and inclusive growth was first introduced in the early works of neoclassical economists on the trade model of Haberler, Heckscher, and Ohlin and further developed by Samuelson (1949, 1948) and Stolper and Samuelson's (1941) idea of trade. A well-developed and open economy can induce inclusive growth via the effective integration of such economy into world economies, which would facilitate the efficient distribution of scarce resources while compensating or minimizing any adverse effects trade liberalization might have on such opened economies. Aside the relevance of

ICT in stimulating trade among countries, ICT is also significant in trade and service sector, most specifically in tourism, processing, administrative and manufacturing industries (see Egoeze et al., 2018; Pohekar 2018; Bethapudi, 2013; Farkhondezhadeh et al., 2013; Taisch et al., 2012; Tewari & Misra, 2012; Fumagali et al. 2008; Peansupap & Walker, 2006). In SSA regions, several factors including structural, political, socio-cultural, economic, and administrative bottlenecks impede trade development and its attendant growth-stimulating impacts, but ICT diffusion can be employed to stimulate and enhance operational proficiency and address some of these bottlenecks. This resonates well within the works of several researchers including, Yushkoya (2014); Latif et al., (2017); Nath and Liu (2017); Rodriguez-Crespo and Martinez-Zarzoso (2019). These researchers argued that ICT diffusion would reduce trade costs, enhance trade development in developed and developing economies and more crucial than access and trade-related skills for some services.

Theories underpin the idea that ICT and trade liberalization are key to ensuring inclusive growth. ICT enhances trade liberalization through digital trading at a global scale, whereas trade liberalisation facilitates penetration of ICT goods between countries. However, discussions around the synergy effects of trade liberalization and ICT on inclusive growth remain a theoretical gap.

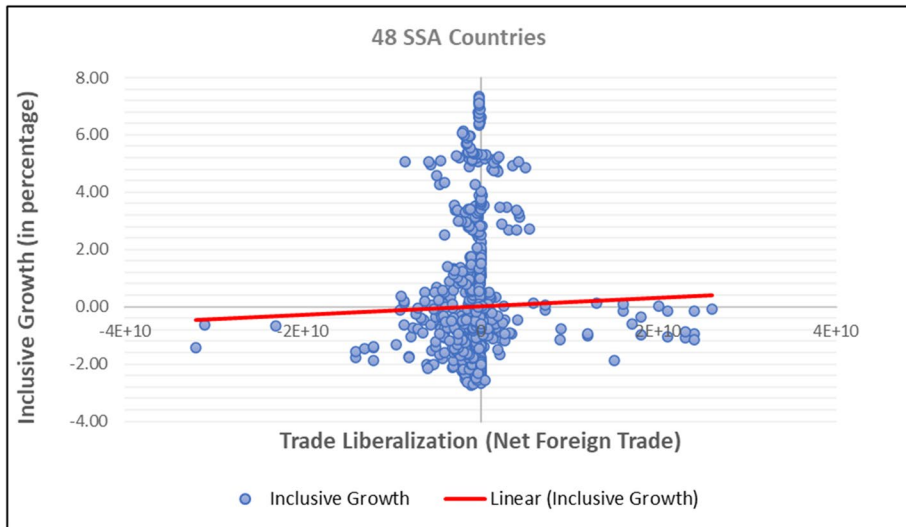
The theoretical ideas discussed provided the foundation for the propositions on which this current study is based. First, the study investigates whether ICT diffusion promotes inclusive growth or not in SSA. Second, it also analyzes whether the impact of trade openness on inclusive growth is ambiguous or not in the region. Finally, the study scrutinizes whether the interaction of trade liberalization and ICT impacts on inclusive growth for the sampled region.

## 2.2 Trade impact on inclusive growth

The trade impact on inclusive growth is seldom direct but often is reported in a two-step argument where trade is seen to be the driver of growth which will consequently promote inclusive growth through decreasing inequality and poverty, financial inclusion, raising employment and human development index. This is otherwise referred to as the indirect impact of trade on inclusive growth. Hence, trade-growth nexus literature is also as important as those of trade-inclusive ones Fig. 1.

From the literature, it appears that there is a consensus on the indirect channels rather than the direct ones. For example, the empirical work of Zahonogo, (2016) with the help of Pooled Mean Group estimation technique studied 42 SSA, and even though he acknowledged a threshold after which the impact of openness declines, he maintains that, on the whole, trade is a positive addition to growth in the SSA. Similarly, Dollar and Kraay (2004) conducted a cross-country analysis of 137 developing countries and opined that fluctuations in trade dimensions are connected to faster economic growth. Similarly, Kong et al. (2020) finds a significant positive relationship between trade to growth in chi china. Amna Intisar et al. (2020) revealed a mixed finding, in western Asia, the study finds a bidirectional causal connection amongst openness to trade and growth performance; however, southern Asia only showed a unidirectional relationship.

Looking at Table 1, which summarizes the literature on the trade-inclusive growth nexus, several variables are used to capture inclusive growth, such as inequality using Gini coefficient, poverty rates, human development index, rural employment, etc. On inequality, Urata and Narjoko (2017) find trade to be a contributing factor in closing the



**Fig. 1** Trade liberalization and inclusive growth in 48 Sub-Saharan African countries, 2005–2020

within-country income inequality in the developing economies. Usman et al. (2023) and Arabiyat et al. (2020) observed a positive relationship between trade liberalization and inclusive growth. The global works of (Dollar & Kraay, 2004; Kang et al., 2017) find openness to be positively impactful to inequality particularly in developing economies and Korea, respectively. Poverty-wise, the poverty rate in India and China have reduced tremendously following years of increased trade (Mitra 2016). Rachman (2018) shares the same opinion on India and Asian countries' poverty levels as he opined that trade decreases poverty rates through employment. However, the work of Osei (2020) summarizes it all, where he used 29 out of 35 indicators of IG listed by the Asian Development Bank (ADB) to form a Principal Component variable for IG across 46 African countries from 1995 to 2016 and concluded that trade indeed spurs IG.

### 2.3 ICT diffusion impact on inclusive growth

The contribution of ICT diffusion to the economy is multifaceted. Pepper and Garrity (2015) assert that ICT diffusion impacts the economy in several ways: ICTs increase productivity by reorganizing how goods and services are produced and distributed in the economy; ICT-related firms create beneficial employment opportunities and make other beneficial contributions to the overall economy. ICTs also directly increase GDP through increased production of ICT-related goods and services as well as the continuing development of all ICT-related sectors. All these have direct ramifications on inclusive growth measured by poverty and inequality levels. However, widespread adoption of ICT, particularly for fixed telephone lines and the Internet, can be detrimental to a nation's economic development if it is not accompanied by equivalent structural changes (Albiman and Sulong, 2017).

Empirical research on the impact of ICT diffusion on inclusive growth otherwise known as pro-poor growth which in so many instances is measured by poverty levels or inequality

**Table 1** Synopsis of existing studies related to trade impacts on inclusive growth

Reference	Country/Region	Methodology	Findings
Arabiyat et al. (2020)	Jordan	FMOLS	Openness positively impacts on inclusive growth
Osei (2020)	46 African Countries	Spatial Tobit Panel Generalised Method of Moment (STPGMM)	Trade positively impacts inclusive growth
Osobohien et al. (2021)	15 ECOWAS	2SLS	Trade may increase inclusive growth by embracing liberalization policies
Kang et al. (2017)	Korea	OLS	Trade promotes Inclusiveness
Dollar and Kraay, (2004)	Global	System GMM	Trade policies promote faster growth and lower levels of poverty in poor nations
IMF, (2020)	Global	Content analysis	Trade lowers poverty
Anand et al. (2013)	Emerging markets	Panel regression analysis	Trade openness fostering greater inclusiveness
Mitra (2016)	Global	Content analysis	Trade spurs inclusiveness in China, India, and Developing economies

indices has shown remarkable improvement in the decline of poverty rate particularly amongst developing economies (Pepper & Garrity, 2015).

Table 2 below shows a synopsis of works conducted across the globe on the link between ICT and inclusive growth. Analysis of the literature reviewed shows that, the works largely employed a large variety of ICT goods and services as proxies for ICT. These variables range from internet access fixed and mobile phone usage (Adeleye & Eboagu, 2019), ICT investment, and internet penetration as well as (Albiman and Sulong, 2017); to internet-enabled services such as e-health, e-commerce, and mobile banking as seen in the work of Tuyisabe et al., (2018) conducted in Rwanda. On the other hand, while few studies used an inclusive growth index such as seen in (Ejemeyovwi & Osabuohien, 2020; Ofori & Asongu, 2021) majority of the studies viewed IG as a pro-poor growth, hence, measured it using the GINI index, poverty and Human capital development see (Faizah et al., 2021; Oshota, 2019; Tsurai & Chimbo, 2021).

In a study conducted among poor households in East Africa, (May et al. 2014) established that households with access to ICT access experience a raise in their income levels in other words, ICT usage narrows the income gap between people of low- and high-income brackets. In a similar study conducted in rural areas of Tanzanian, ICT investment in the form of mobile phone usage and Internet access reduced poverty incidence (Diga, 2013). Oshota (2019) opined that ICT suppresses poverty by boosting growth through the provision of economic and social infrastructures (transportation, electricity, communication, housing, health, and education).

Adeleye and Eboagu (2019) finds ICT adoption to be a significant positive changer for achieving inclusive growth in Africa. Despite its negative interaction effect on trade, it is intriguing to note that it does not have a significant impact to undermine the positive influence of trade on economic growth. In addition, it is worth mentioning that the impact of both trade and ICT adoption differs across various sub-regions of African continent. This may not be unconnected with the different levels of income brackets of African countries as ICT penetration is seen to be more efficacious in higher income nations than lower income nations or regions (Gruber & Koutroumpis 2011).

Contrastingly, Mohammed and Sulong (2017) found that fixed telephone lines have long-run, large, and nonlinear negative impacts on both richer and lower-income countries' economic growth, but became positive for lower-income countries when the analysis was disaggregated. However, the authors maintained that the mobile phone is the best ICT technology capable of triggering economic growth and development in the SSA region, hence, should be prioritized. On the issue of between groups difference of the ICT-growth nexus Farhadi et al. (2012) which employed GMM across 159 countries argued that the estimated coefficients of the ICT use index is higher in high-income countries than in lower-income groups Fig. 2.

In summary, it appears from the literature that ICT infrastructure and services have most often than not been found to be a source of improving IG through reduced poverty levels, inequality, income gap and raising income levels of low-income households, regions, and countries.

### 3 Data and methods

#### 3.1 Data and variables

The current study utilises a panel dataset for 48 SSA nations spanning from 2005 to 2020. The start year of 2005 was chosen to enable greater inclusion of more sample countries



**Table 2** Summary of literature on the impact of ICT on inclusive growth

Reference	Country/Region	Methodology	Findings
Ofori & Asongu (2021)	sub-Saharan Africa	OLS and Dynamic System GMM	ICT diffusion induces IG
Ejemeyovwi and Osabuohien (2020)	15 West African countries	System GMM	Mobile phone technology has no significant effect on inclusive growth
Gruber & Koutroumpis (2011, 2016)	192 countries	3SLS GMM	Mobile technology impacts growth
Mohammed and Sulong (2017)	SSA	Pedroni cointegration	ICT enhances growth
Farhadi et al. (2012)	159 countries over	GMM	A positive correlation between the real GDP per capita growth rate and the ICT use index
Tuyisabe et al. (2018)	Rwanda	OLS	ICT use increases growth
Adeleye and Eboagu (2019)	54 African countries	System GMM	ICT spurs growth
Ward and Zheng (2016)	China	Dynamic system GMM panel	ICT increases growth
Tsaurai and Chimbo (2021)	11 transitional economies	Dynamic (GMM)	Internet usage is negatively related to inequality
Faizah et al. (2021)	Indonesia	2SLS	The correlation between ICT infrastructure and the lessening of social disparities was notably evident
Ofori & Asongu (2021)	42 SSA countries	System GMM	ICT diffusion and related factors (ICT usage, access, and skills) lead to inclusive growth in SSA
Oshota (2019)	Nigeria	ECM	ICT does not reduce poverty

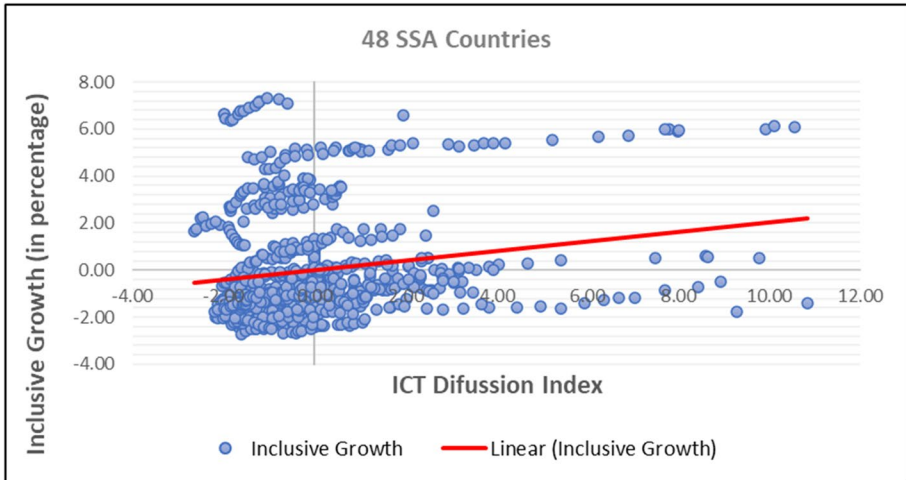
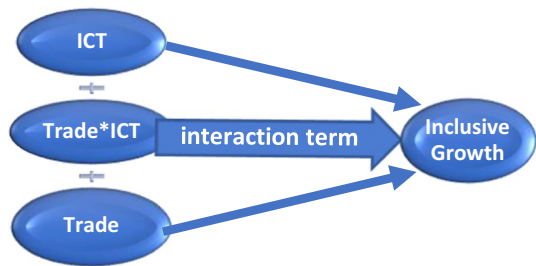


Fig. 2 ICT diffusion and inclusive growth

Fig. 3 Schematic of the ICT, Trade, and Inclusive Growth



because of the unavailability of certain data on the ICT indicators before 2005 in some of the SSA countries. The paper scrutinizes the impact of openness to trade on inclusive growth as controlled by ICT diffusion, and this is described in Fig. 3 below:

The three main variables this current study focuses on are ICT, inclusive growth, and trade openness. ICT and inclusive growth are defined by indexes (see Tables 3 and 4) while the trade openness is measured as net foreign trade in goods and services. The study employs principal component analysis (PCA) to develop a comprehensive measure of inclusive growth, as proposed by the Asian Development Bank (ADB 2013).

Equally, in consonance with the interpretation of the international telecommunication union (ITU) of ICT variables, the study develops an index for ICT diffusion. While foreign direct investment (FDI) is measured by net FDI inflows as a percentage of GDP, the inflation rate is measured based on indexes of consumer prices (2010=100), the unit of measurement for employment vulnerability is based on the total family contribution and workers' accounts as a share of employment and, social protection coverage and labor engagements measured as a percentage of the population establish the control variables of the study. The choice of the study's variables is pioneered by extant literature. In the extended literature, both employment vulnerability and inflation exert adverse on shared prosperity, whereas FDI and social inclusion induce inclusive growth (Ofori & Asongu 2021; Mlachila et al., 2017; Asongu &

**Table 3** ICT indicators and unit of measurement

ICT indicators	Measurement unit
internet servers that are secured	Per 1 million people
people who use the internet	%of the population
Subscriptions for mobile phones	Per hundred people
Dedicated broadband subscription plans	Per hundred people
Fixed telephone subscription plans	Per hundred people
Years of average secondary school enrolment	Mean enrolment in years
Enrolment in tertiary education	Gross enrolment
Enrolment in secondary school education	Gender parity

*Source:* WDI Database (2022) and Bello et al. (2023)

**Table 4** Inclusive growth indicators and their unit of measurements

Inclusive growth indicators	Measurement unit	Source
International poverty headcount	US\$1.90	PED, 2022
People that utilise basic sanitation services	% of the total population	WDI, 2022
Gross domestic product (GDP) per capita	US\$'2017 PPP	WDI, 2022
Effectiveness of institutions for social protection	From low (1) to high (6)	CPIA, 2022
Effectiveness of institutions for social inclusion	From low (1) to high (6)	CPIA, 2022
Electricity access	Total population	CPIA, 2022
Availability of clean fuels and cooking technologies that use clean cooking fuels and technologies	As percentage of total population	WDI, 2022
Gini coefficient index	% of income distribution	WDI, 2022
Rule of law	Estimate	WDI, 2022
Government spending on healthcare	Percentage of GDP	WDI, 2022
Government spending on education	Percentage of GDP	WDI, 2022
Index of human capital	Scale of 0–1	WDI, 2022
Total labour force participation rate	As % of total population ages 15–64	WDI, 2022
Public and media freedom	Public institutions and associations	WDI, 2022

Nwachukwu, 2017). Database of development indicators from the World Bank (WDI, 2022) is the main source of the data used in this study. Table 3 describes all the variables and their measurement units in this study.

### 3.2 Model and methodology

The study adopts different estimation methods to investigate the static and dynamic interactive effect of trade and ICT on inclusive growth. These different regressions and estimation methods produce different results.

### 3.2.1 Static models

The study develops a static regression model to show inclusive growth as a linear function trade, ICT and the interaction term between trade and ICT as follows:

$$IGR_{it} = \beta_0 + \beta_1 TRAD + \beta_2 ICT + \beta_3 TRAD * ICT + \beta_4 X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where IGR., TRAD and ICT present the inclusive growth index, trade openness, and ICT index as explained previously. The additional X is a vector of control variables which includes FDI, CPI, VEM, and SOP (see Table 5).  $\beta_0$  shows a constant term while i and t represent the countries and the time.  $\mu_i$  and  $\varepsilon_{it}$  are the unobserved time-invariant factors and the error terms.

OLS is used to estimate Eq. (1) which assumes that the regressors are not correlated with the composite error term ( $\mu_i + \varepsilon_{it}$ ). This is only true when it is assume that the model contains all the variables that affect both the regressors and the regressand, which empirical studies prove impractical (Leszczensky & Wolbring, 2019). The endogeneity problem arises from OLS results that are heterogeneity biased as OLS assumptions fail to hold (Wooldridge, 2012).

This study makes use of fixed and random effects estimators to estimate Eq. (1). The assumption of the unobserved time-invariant factors ( $\mu_i$ ) correlating with the regressors makes the two estimators differ from each other. While fixed effects estimators assume that  $\mu_i$  correlates with the regressors, random effects estimators do not.  $\mu_i$  captures all the time-invariant unobserved heterogeneity by correlating with the regressors and the fixed effects estimators are devoid of bias arising from that, contrary to fixed effect and random effect estimators.

Dynamic features of the inclusive growth and reverse causality between it and its determinants may also cause endogeneity in the model. Biased estimates in fixed and random effects estimators are the results of this reverse causality. These estimators assume strict exogeneity and correlation between the regressors and the error terms. However reverse causality between inclusive growth and its regressors (trade openness and ICT) falsifies this assumption, which makes the models' estimates biased (Leszczensky & Wolbring, 2019).

A correlation between the present and past values of the regressand defines dynamic causality, a problem that requires serious attention. Equation (1) above represents a regression model that does not embody a lagged regressand and whose parameter estimates could

**Table 5** Variables descriptions and measurement units

Variable name	Variables' description	Measurement unit	Sources
<i>IGR</i>	Inclusive growth index	PCA constructed Index	WDI, 2022
<i>ICT</i>	ICT index	PCA constructed Index	WDI, 2022
<i>TRAD</i>	Trade openness	Net trade in goods and services of BOP in current US\$	WDI, 2022
<i>FDI</i>	Foreign direct investment	Net inflows as a % of GDP	WDI, 2022
<i>CPI</i>	Inflation, consumer price index	Annual percentage	WDI, 2022
<i>VEM</i>	Vulnerable employment	% of total employment of the modeled ILO estimate	WDI, 2022
<i>SOP</i>	Social protection	% of the population covered by social protection and labor programs	WDI, 2022

PCA is an acronym for principal component analysis

be inconsistent due to a potential correlation between lagged regressands and other regressors. Given that economic linkages are dynamic, appropriate methods should be used to estimate a dynamic panel model (Baltagi, 200).

### 3.2.2 Dynamic panel model

The dynamic panel model is specified as follows:

$$\text{IGR}_{it} = \beta_1 \text{igr}_{it-1} + \beta_2 \text{TRAD}_{it-1} + \beta_3 \text{ICT}_{it-1} + \beta_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where  $i = 1, 2, \dots, N$ , where  $N$  denotes the number of countries,  $t$ ,  $t-1$  signifies the present year and the year before, and IGR, trad, and ICT indicate inclusive growth, trade openness, and ICT diffusion. FDI, inflation, vulnerable employment, and social protection make up the vector of controls ( $X$ ).  $\mu_i$  and  $\varepsilon_{it}$  are the unobserved time-invariant factors and the error terms.

The term representing the interaction between FDI and ICT diffusion can be found in Eq. (2):

$$\text{IGR}_{it} = \beta_1 \text{IGR}_{it-1} + \beta_2 \text{TRAD}_{it-1} + \beta_3 \text{ICT}_{it-1} + \beta_4 \text{TRAD}_{it-1} * \text{ICT}_{it-1} + \beta_5 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

The GMM method is used to estimate the preceding Eqs. (1–3). As a method of estimation, we use the system GMM. To assess and compare the performance of the two estimated models, a robustness check was conducted. For all the GMM estimations performed with the STATA statistical software, the `xtpdgmm` command is utilized. The number of instruments in the GMM system dramatically increases as the number of regressors and periods increases (Roodman, 2009). The orthogonal option combats any loss in the dataset, while the first differences magnify gaps in an unbalanced panel dataset.

There are two types of specification tests for GMM models: Hansen tests and higher-order serial correlation. On first-differenced error terms, a second-order serial correlations test is conducted; No any second-order serial correlation is reported when the error term is not serially correlated. However, if the internal instruments are not valid due to endogenous lagged variables, the null hypothesis is rejected. To assess the instrument validity, the second-order serial correlation test is combined with the Hansen test, also referred to as the over-identification test. Two diagnostic tests can be used to identify weak instruments: the Kleibergen-Paap LM test and the Kleibergen-Paap F-test. The `ivreg2` command with the `gmm2s` option is used in computing the test statistics for the joint null hypothesis of the specified models in this study. The objective is to ascertain whether the instruments are unaffected by the level and first-differenced equations. It is important to note that the `ivreg2` command, which is a two-step GMM, produces the same coefficients as the `xtpdgmm` command.

## 4 Result and discussions

### 4.1 Pre-estimation results

#### 4.1.1 ICT diffusion index

This study departs from a large body of prior research by doing something novel: using principal component analysis (PCA) on a set of twelve indicators based on the International Communication Union classification (ICU) to create a composite index for ICT diffusion (Table 3).

There are prerequisites for PCA, all of which are met by this research. In addition, the study has also conducted additional diagnostic tests to ensure that (i) an adequate sample of ICT covariates. (ii) How strongly these covariates are correlated. (iii) The strength of these indicators' partial and overall intercorrelations. To aid in the selection of these indicators, Appendix 1 illustrates covariates with strong correlations. Bartlett Chi ( $\chi^2$ ) statistic of 1061.52 and corresponding  $p$ -value confirms significant intercorrelations between these indicators, as indicated by the test. The overall and partial intercorrelations between the indicators are displayed in Table 6 based on the Kaiser–Meyer–Olkin (KMO) statistics. KMO statistics over 0.5 show that the sample used to calculate the ICT diffusion index is appropriate.

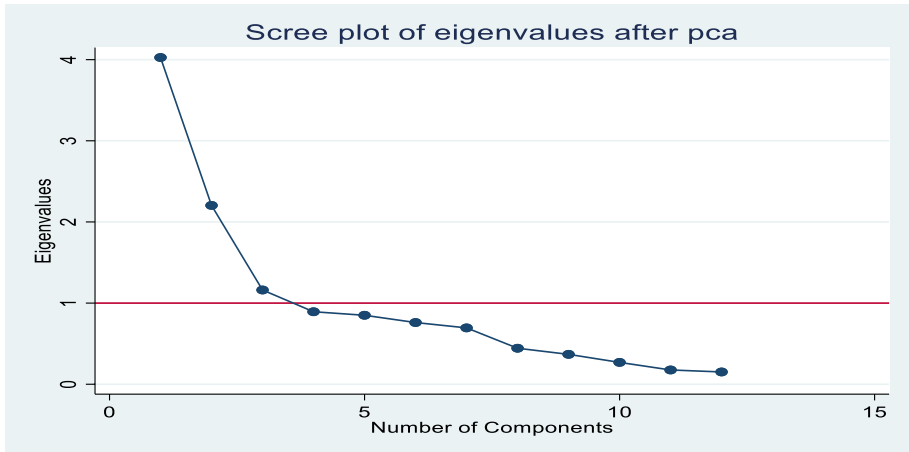
Since each indicator has a distinctive scale and the model passes the basic testing, the indicators are normalized to obtain a zero mean and a standard deviation of one (Jolliffe, 2002). Table 5 similarly displays the difference, proportion, cumulative, and eigenvalues of these factors. According to the Kaiser rule of eigenvalues, which was accepted by Ofori and Asongu (2021) and Tchamyou (2019), the study retains three components whose eigenvalues are greater than one (1) in creating the composite ICT index. In the dataset, the three (3) retained components provide substantial information (61.6%). Both Table 7 and Fig. 3 back up what has been said thus far.

#### 4.1.2 Inclusive growth index

In the previous section, a detail description was made in the procedure for determining an ICT diffusion composite index. In this study, an inclusive growth index was developed using the principal component analysis based on the identification of multiple variables that define inclusive growth in developing countries following the recommendations of the Asian Development Bank (ADB, 2013). Indicators used in the construction of the inclusive growth index are reported in Table 4, note that the indicators used are similar to the ones

**Table 6** Principal component and eigenvalue (ICT diffusion)

Component	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	All
Eigenvalue	5.04	2.15	1.18	1.03	0.58	0.76	0.69	0.44	0.36	0.26	0.17	0.15	–
Difference	1.82	104	0.26	0.04	0.08	0.06	0.25	0.07	0.09	0.09	0.02		–
Proportion	0.33	0.18	0.09	0.07	0.07	0.06	0.05	0.03	0.02	0.02	0.01	0.01	–
Cumulative	0.33	0.51	0.61	0.69	0.76	0.82	0.88	0.91	0.95	0.97	0.98	1.0000	–
KMO stat	–	–	–	–	–	–	–	–	–	–	–	–	0.74



**Fig. 4** Scree plot of Principal Components of ICT diffusion

used by Bello et al. (2022), who examined how foreign direct investment and ICT diffusion could work together to promote inclusive growth in Sub-Saharan Africa.

Similar to the ICT index, the inclusive growth index likewise passes all preliminary testing. Appendix 2 illustrates the significant association between the covariates. This analysis supports the statistically significant finding that overall covariates are associated.

Chi ( $\chi^2$ ) statistic value of 564.85. Also, the sampling adequacy in generating the index is confirmed by the 0.8078 KMO statistic as reported in Table 7. Due to the different scales of the inclusive growth indicators, the current study normalizes them to have a mean of zero and a standard deviation of one. To construct a composite inclusive growth index, four components with eigenvalues greater than one (1) are retained. When combined, the retained components explain 78.5% of the data's information. Figure 4 illustrates a scree plot of inclusive growth components by Table 7.

## 5 Summary statistics

The summary of the variables' statistics is shown in Table 8.  $-1.041$ ,  $-7.988$ , and  $-1.181$  are the mean values for inclusive growth, trade, and ICT, respectively. Average values for FDI, inflation, vulnerable employment, and social protection are 4.888, 9.400, 69.613, and 26.405, respectively. Inflation and social protection are the most widely distributed variables and have the highest values too. Strong positive and negative correlations between the dependent and independent variables are displayed in the correlation matrix provided in Appendix 1.

### 5.1 Estimation results

Table 9 displays the results of the static models represented by Eq. (1): pooled-OLS, fixed effects, and random effects estimators. We conduct Breusch–Pagan and Hausman tests to decide on the most consistent and efficient estimators among them. The results of the

**Table 7** Principal components and eigenvalues (Inclusive growth index)

Component	Eigen value	Difference	Proportion	Cumulative	KMO statistic
PC1	5.04	2.88	0.42	0.42	0.90
PC2	2.15	0.96	0.17	0.59	0.88
PC3	1.18	0.14	0.09	0.69	0.60
PC4	1.03	0.44	0.08	0.78	0.86
PC5	0.58	0.10	0.04	0.83	0.49
PC6	0.76	0.08	0.04	0.87	0.83
PC7	0.69	0.02	0.03	0.90	0.86
PC8	0.44	0.11	0.03	0.93	0.88
PC9	0.36	0.05	0.02	0.95	0.71
PC10	0.26	0.01	0.01	0.97	0.71
PC11	0.17	0.06	0.0	0.99	0.68
PC12	0.15	–	0.00	1.00	0.84
Overall	–	–	–	–	0.80

KMO is Kaiser–Meyer–Olkin

**Table 8** Summary statistics

Variables	Obs	Mean	Stand. dev	Min	Max
<i>IGR</i>	767	–1.041	2.25	–2.75	7.33
<i>TRAD</i>	638	–7.98	4.63	–3.20	2.60
<i>ICT</i>	752	–1.18	2.01	–2.66	10.85
<i>FDI</i>	739	4.89	8.52	–11.20	103.34
<i>INFL</i>	704	9.40	29.34	–8.98	557.20
<i>VUL_EMPL</i>	705	69.61	21.72	8.83	94.46
<i>SOC_PROT</i>	421	26.40	29.07	–114.30	105.53

*Stand. dev.* means standard deviation. *Min.* denotes minimum while *max.* implies maximum

Breusch–Pagan LM test reveal a significant  $p$ -value which implies that the random individual effects are valid and have non-zero variances (Baltagi, 2005). By implication, the study gets biased estimates from pooled OLS estimation of Eq. (1). Using a robust Hausman test, the study compares fixed effects and random effects estimators to find an efficient and reliable estimator. The results of this test show a significant  $p$ -value which rejects the null hypothesis of random effects. Therefore, a fixed-effects estimator is suggested as a consistent and efficient estimator Table 9.

The results of the estimation of fixed effects are shown in Table 9 and suggest that while ICT has a positive significant effect on inclusive growth, trade openness has a greater negative significant effect. The control variables in the model indicate that vulnerable employment negatively affects inclusive growth while social protection positively influences this shared growth. According to the findings, trade openness does not promote shared prosperity, whereas ICT diffusion promotes inclusive economic growth in Sub-Saharan Africa.

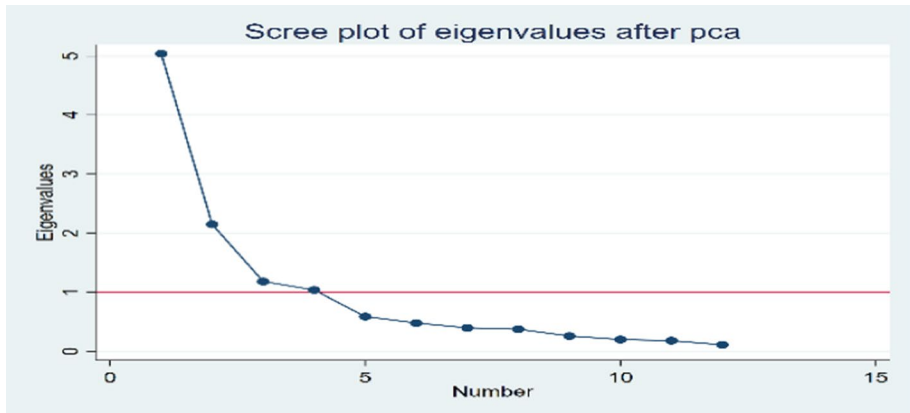
On the other hand, strict exogeneity of the regressors is a prerequisite to a consistent fixed effects estimator. The study employs the Wooldridge test to check the exogeneity of these regressors in Eq. (1). The results of the test reveal a significant  $p$ -value (0.00) and



**Table 9** Estimation results of the dynamic panel models

Variables	Pooled-OLS	Fixed effects	Random effects	One-step difference GMM	One-step difference GMM
<i>IQR</i>				0.712*** (0.035)	0.69*** (0.03)
<i>ICT</i>	0.05*** (0.02)	0.154*** (0.012)	0.137*** (0.012)	0.034*** (0.011)	0.05*** (0.014)
<i>TRAD</i>	2.07** (0.98)	-5.820*** (0.211)	2.911** (0.826)	-2.822*** (0.011)	-5.20*** (1.63)
<i>TRAD*ICT</i>					3.74* (1.10)
<i>FDI</i>	0.01* (0.00)	0.12 (0.01)	0.00 (0.00)	0.01*** (0.00)	0.01*** (0.00)
<i>INFL</i>	-0.03*** (0.01)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
<i>VUL_UNEMPL</i>	-0.08*** (0.00)	-0.04*** (0.01)	-0.05*** (0.00)	-0.02*** (0.00)	-0.02*** (0.00)
<i>SOC_PROT</i>	0.00** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00 (0.00)	0.00 (0.00)
<i>CONSTANT</i>	5.77*** (0.16)	2.86*** (0.29)	3.77*** (0.28)	1.07*** (0.24)	1.11 (0.20)
Observations	367	367	367	346	346
<i>R</i> -squared	0.90	0.84	0.88	-	-
Year dummies	yes	yes	yes	-	-
Post-estimation diagnostics:					
Breusch-Pagan LM test	-	-	0.00	-	-
Hausman ( <i>p</i> -value)	-	0.00	-	-	-
Wooldridge ( <i>p</i> -value)	-	0.00	-	-	-
Hansen-Sargan ( <i>p</i> -value)	-	-	-	0.29	0.49
AR(1)	-	-	-	0.00	0.00
AR(2)	-	-	-	0.54	0.78

The parenthesis contains the robust standard errors at \*\*\* (0.01), \*\* (0.05), & \* (0.10) significant levels



**Fig. 5** Scree plot of Principal Components of Inclusive Growth

reject the null hypothesis of no first-order serial correlation. This violates the assumption of the fixed effects model that the regressors are strictly exogenous and confirms a correlation between future values of the regressors and the error term. Thus, the parameter estimates of the fixed effects model are biased and inconsistent Fig. 5.

Existing literature suggests that GMM accounts for unobserved heterogeneity and avoids biased estimates when the dependent variable has a time lag (Nickell, 1981). The study follows the recommendations of (Kiviet, 2020) and (Kripfganz, 2019) to conduct model specification exploration as a prerequisite for obtaining an efficient and consistent GMM estimator. The model specification process seeks to classify all relevant regressors included in the model as per economic theory, as strictly exogenous, endogenous, or predetermined. The lack of correlation between regressors and error terms (time-variant) defines a variable as strictly exogenous, whereas the opposite is true for endogenous variables. Predetermined variables are those that are potentially correlated with past values but not with present or future values of time-variant error terms Table 9.

In contrast, this study employs a one-step difference GMM estimator after an exhaustive model search. The model passes all post-estimation diagnostics and fits the data quite well. In the fourth column of Table 9 are the results of the GMM baseline model. Results indicate that a 1% increase in ICT results in a 0.03% increase in inclusive growth. This represents a small but significant impact of ICT on Sub-Saharan Africa's shared prosperity. This finding supports the first hypothesis and is consistent with the findings of previous studies. Most existing studies contend that ICT diffusion facilitates common people's access to vast economic opportunities by making information more accessible, thereby increasing inclusion in economic prosperity (Adeleye et al., 2021; Ofori & Asongu, 2021).

Contrary to the a priori expectations, trade openness does not promote inclusive growth in the region. The results of the study's baseline model indicate that a 1% rise in trade openness results in a  $-2.822$  decline in inclusive growth. By implication, trade openness in the region worsens shared prosperity and validates the second hypothesis. Documented evidence also shows that as trade openness expands, inequality rises in many developing and emerging economies (Bauer & Boussard, 2021; Ravallion, 2018). Many countries around the world, including advanced ones, attribute rising trade openness to the loss of manufacturing jobs and economic deprivation of the poor (IMF, 2021). Sub-Saharan Africa does poorly in terms of sharing the benefits of trade openness. Many of the countries in

the region have a balance of payments deficits (Ozdeser et al. 2021). The region has the world's lowest intra-regional trade and the highest trade with countries outside its domain (Usman et al., 2022). In terms of modern technology, infrastructure development, and capital base, countries like China who are the biggest region's trading partners have a competitive advantage. Jobs are lost in the value chain of this trade, undermining shared prosperity in the region.

Equation (3) was used to investigate the synergy effect of ICT and trade openness on inclusive growth. The results of this interaction effect are shown in the last column of Table 9 and show that, while trade openness hinders inclusive growth, ICT diffusion positively influences trade openness, and the synergy effect can promote shared prosperity in the region. The findings of the study as revealed by the model with the interaction term, show that an interaction effect of ICT on trade openness can cause a 3.741% improvement in inclusive growth, thereby validating the third hypothesis.

The results of the control variables show that there is little difference between the two models—baseline and interaction. According to the baseline model, a 1% increase in FDI raises shared prosperity by 0.014%, while a 1% rise in vulnerable employment lessens shared prosperity by  $-0.016\%$ . The interaction model shows the same signs for both. A 1% increase in FDI raises inclusive growth by 0.011%, while the latter falls by  $-0.015\%$  as vulnerable employment increases by 1%. FDI promotes shared prosperity, whereas vulnerable employment hinders it. Institutions that are designed to prevent, control, and respond to crises that threaten the well-being of the poor and vulnerable can have significant effects on fostering growth for all segments of society. For long-term wealth accumulation and the development of the masses' capacity to prepare for, endure, or adapt to socio-economic shocks, good macroeconomic planning and the creation of better economic employment options are essential. This is especially true given the negative impact that vulnerable employment has on inclusive growth. The results of the post-estimation tests show that AR (1) for both models is significant (0.00  $p$ -values), and AR (2) is also significant with 0.537 and 0.782  $p$ -values that are well above 0.1. The Hansen test results for both models show significant  $p$ -values of 0.289 and 0.492. As a result, it can be concluded that the study's estimates are reliable and that the model fits the data well.

## 6 Conclusions

This study investigates the impact of trade openness on inclusive growth in Sub-Saharan Africa (SSA) because of its importance for sustainable development and shared prosperity in the region. However, factors like trade openness, ICT diffusion, foreign investment, and vulnerable employment have complex effects on the region's capacity for inclusive growth. Therefore, investigating these dynamics is crucial for informing effective policy. The study uses macro data from 2005–2020 and develops a composite ICT diffusion index with twelve indicators and PCA analysis. The validity of the ICT and inclusive growth indices is ensured through various tests. Static and dynamic models are employed to analyze the trade-ICT interaction on inclusive growth, with tests like Breusch–Pagan and Hausman determining the most reliable estimators. GMM estimation is recommended for the dynamic model to address unobserved heterogeneity and avoid biased estimates. Model

specification exploration is also done to ensure efficiency and consistency of the GMM estimator.

The study finds ICT diffusion has a positive but small impact on inclusive growth. Despite connectivity improvements, Africa's internet penetration remains below global average. It is recommended that policies enhancing ICT penetration be implemented, including ICT-focused curricula, addressing health/safety concerns, and employee training opportunities. Such policies can develop knowledge-based human capital, spur innovation, and build ICT infrastructure in the region.

ICT diffusion in Sub-Saharan Africa can potentially improve information access, overcome barriers, and create opportunities—enhancing education, healthcare, inclusion, and governance. However, lacking trade policies, regulations, and financial accessibility have hindered inclusive growth. The African Union's African Continental Free Trade Area (AfCFTA) aims to address this by creating a single market and trade policy, reducing tariffs, and deepening economic integration in Africa and abroad. Thus, enacting AfCFTA should be a policy priority to overcome barriers and enable inclusive growth.

The study reveals trade openness hampers inclusive growth, while ICT diffusion positively impacts trade openness, and their synergy promotes shared prosperity—suggesting ICT diffusion may mitigate trade openness' negative effects on inclusive growth. Digital technologies like e-commerce and digital trade can cut trade costs, enable interaction, overcome policy barriers, and boost global trade. A recent report predicts that the service sector's share of global trade will increase by 50% due to digital technologies (World Trade Report, 2019). As ICT adoption grows in Sub-Saharan Africa, AfCFTA implementation may facilitate regional trade and enhanced inclusive growth.

This study has some limitations, particularly in terms of investigating alternative transmission channels via which the variables under consideration, especially ICT diffusion influence and inclusive growth nexus. Furthermore, other important components of inclusive growth can be further explored and investigated by future research works. These recommendations are based on the caveat that the scope of the current study cannot fully address all aspects of the green-led growth and development agenda. To give policymakers a more focused country-oriented implication, future research should consider country-specific studies.

## Appendix

### Appendix 1 Correlation matrix of the variables

	igr	trad	ICT	FDI	info	Vul_empl	Soc_prot
igr	1.0000						
trad	0.0817	1.0000					
ICT	0.2757	-0.0778	1.0000				
FDI	-0.1729	-0.0637	-0.0202	1.0000			
infl	-0.2140	-0.0651	-0.0977	1.0000			
Vul_empl	-0.9439	-0.0439	-0.2386	0.1481	0.1627	1.0000	
Soc_prot	0.6136	-0.0421	0.1882	-0.0797	0.0088	-0.6288	1.0000

## Appendix 2 Correlation matrix for ICT index indicators

	1	2	3	4	5	6	7	8	9	10	11	12	Bartlett Test
Secured internet servers (per 1 million people)	1.0000												
Secure internet servers	0.0931	1.0000											
Individuals using the internet (% of the population)	0.2635***	0.2641***	1.0000										
Mobile cellular subscriptions	0.1910**	0.2196***	0.7985***	1.0000									
Mobile cellular subscriptions (per 100 people)	0.3088***	-0.0133	0.2587***	0.2769***	1.0000								
Fixed broadband subscriptions (per 100 people)	0.0417	0.4702***	0.5752***	0.4696***	-0.0530	1.0000							
Fixed broadband subscriptions	0.4892***	0.0255	0.3849***	0.3607***	0.5089***	0.1599**	1.0000						
Fixed telephone subscriptions	0.3114***	0.0023	0.1917***	0.2174***	0.4298***	0.0576	0.6882***						

	1	2	3	4	5	6	7	8	9	10	11	12	Bartlett Test
Fixed telephone subscriptions (per 100 people)	0.0318	0.2149***	0.5004***	0.4175***	-0.1053	0.7621***	0.1387	0.1670**	1.0000				
Secondary school education (Gender parity)	-0.1237*	0.0622	-0.3164***	-0.0785	-0.1636**	0.1298**	-0.1802**	-0.2243***	0.0549	1.0000			
Mean secondary school enrolment in years	0.1610**	0.1078	0.5814***	0.5617***	0.2045***	0.5080***	0.3117***	0.2823***	0.5893***	-0.1227	1.0000		
Tertiary school enrolment (Gross)	0.0540	0.0463	0.2142***	0.1822***	0.1511*	0.1418**	0.1422**	0.1381*	0.2475***	-0.1917***	0.3524***	1.0000	
Chi ( $X^2$ ) statistic													1061.522***
Chi ( $X^2$ ) $p$ -value													0.0000

### Appendix 3 Correlation matrix for inclusive growth index indicators

	1	2	3	4	5	6	7	8	9	10	11	12	Bartlett Test
Sanitation	1.0000												
Electricity access	1.0000	1.0000											
Gini index	0.7170***	0.1926***	1.0000										
Education expenditure	0.2985***	0.1847***	0.3081***	1.0000									
Human capital index	0.2292***	0.1265***	0.0397	0.4631***	1.0000								
Health expenditure	-0.0992*	0.2686***	0.3108***	0.5473***	-0.1153***	1.0000							
Labor	0.4314***	-0.5664***	-0.1169**	-0.0343***	0.0525***	-0.0986*	1.0000						
Clean fuel access	-0.4955***	0.7561***	0.3006***	0.2725***	-0.0575	0.4897***	-0.5245***	1.0000					
Social protection	0.7754***	-0.4349***	-0.4535***	-0.0530	0.2016***	-0.3039***	0.4355***	-0.5848***	1.0000				
Rule of law	-0.5147***	0.4631***	0.2405***	0.5895***	0.0443	0.5600***	-0.1331**	0.5383***	-0.0748*				
Voice and accountability	0.4966***	0.3226***	0.0295	0.5492***	0.0278	0.5090***	-0.1175**	0.3426***	0.0200	0.8000***	1.0000		
GDP per capita	0.2795***	0.6720***	0.2488***	0.0867*	-0.11143***	0.2752***	-0.4790***	0.7102***	-0.6768***	0.3489***	0.1694	1.0000	
Chi ( <i>statistics</i> )													1061.522***
Chi ( <i>p - values</i> )													0.0000

**Authors' contribution** AH collected data and analyzed the data. AAB and IJO wrote the introduction and literature review. USA worked on the first draft of the literature review and SSA wrote the conclusion and policy suggestion, ARI worked on study development and proofreading.

**Funding** Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK). This research does not receive any funding.

**Data availability** Corresponding authors can provide data used in the study on appropriate request.

## Declarations

**Conflict of interest** The authors confirm that there is no conflict of interest for this paper submission.

**Consent for publication** NA.

**Ethics approval** NA.

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