Telecommunications Policy 49 (2025) 102936

Contents lists available at ScienceDirect

Telecommunications Policy

journal homepage: www.elsevier.com/locate/telpol

Assessing digitalization and the economy: A dynamic recursive CGE modelling approach

David Iheke Okorie [a,b,c,d,*], Adeniran Adedeji [c], Chinedu Ifionu [c]

[a] Hangzhou City University, The University of Waikato Joint Institute, Hangzhou, China
[b] University of Waikato, Management School, School of Accounting, Finance and Economics, Hamilton, New Zealand
[c] Centre for the Study of the Economies of Africa (CSEA), Abuja, Nigeria
[d] SD Consulting Agency (SCA), Lagos, Nigeria

ARTICLE INFO

Keywords:
Digitalization
Dynamic CGE
Macroeconomics
Simulation
Policy evaluation

ABSTRACT

Advanced economies continue to adopt and embed digitalization into their everyday activities. One may ponder; how does a significant digitalization upgrade affect developing economies? To answer this question and highlight the economic & environmental effects of digitalization in a developing economy, this study adopts the singly-country dynamic Energy and Environment Integrated computable general equilibrium model (EEICGE) with a 5-year gradual digitalization policy plan design in Nigeria, a developing economy. The shock simulation comparative statics show digitalization-driven investment opportunities in Nigeria and reveal that digitalization increases productivity and national output levels while leading to a substantial decline in the general price levels in the Nigerian economy. It further strengthens Nigeria's international trade revenue and makes its goods and services cheaper in the international (market) communities. Digitalization of the Nigerian economy also results in a structural shift and decline in on-site labour equilibrium demand/supply that is substituted mainly with capital (machines) but increases online entrepreneurial labour services such as online training sessions/classes, content creations like comedy skits, online sells & delivery services, online skill acquisition sessions etc., aimed at increasing agents' labour income. Thus, digitalization increases the economic agents' consumption, income, and welfare while availing the rich household cohorts, firms, and governments the chance to take advantage of the digitalization-driven investment opportunities financed through decreases in consumption budgets. In the end, this study presents pieces of evidence that favour and support substantial digitalization upgrades in developing economies like Nigeria.

1. Introduction

1.1. Motivation

The internet, digitalization and digital technologies have become necessities and embedded into various aspects of everyday life in most (advanced) economies which have substantial impacts on their economies (Zhang, Shinozuka, et al., 2021a, 2021b; Myovella et al., 2020; Mentsiev et al., 2020; Lubin & Esty, 2014; etc). Digitalization plays a key role in clean energy developments (Chen, 2022).

* Corresponding author. Hangzhou City University, The University of Waikato Joint Institute, Hangzhou, China
E-mail address: okorie.davidiheke@gmail.com (D.I. Okorie).

https://doi.org/10.1016/j.telpol.2025.102936
Received 1 October 2024; Received in revised form 19 February 2025; Accepted 20 February 2025
Available online 25 February 2025

As such, the potential of digitalization cannot be over-emphasized (Seele & Lock, 2017). Conversely, recent developments like Artificial Intelligence (AI) and Blockchain are relatively underutilized in most developing and underdeveloped economies. Also, some digitalization policies have adversely affected businesses in underdeveloped and developing economies (Anyim, 2021; Iyatse & Adepetun, 2021). To adequately utilize and optimize digitalization and its technologies in developing and underdeveloped countries, a significant level of digitalization is required. Calibration tools like the Computable General Equilibrium (CGE) models have been adopted to study an economy-wide effect of digitalization in an economy (Lim et al., 2021) against conventional estimation tools (Abendin et al., 2022). Existing studies have either presented the challenges of digitalization or supported digitalization in an economy due to its positive effects on the economy. However, they fail to show how an improved and upgraded level of digitalization affects a developing and/or underdeveloped economy. As such, this study contributes to the body of literature by proposing and adopting a dynamic CGE model to assess the economy-wide implications of a substantial upgrade in digitalization for a developing economy, Nigeria. While most CGE models do not incorporate the energy and environmental blocks into their model, some CGE models like the GTAP-E (Burniaux & Truong, 2022) and AIM/CGE V2.0 (Fujimori et al., 2017) do. However, these models treat energy inputs as independent intermediate inputs with capital and labour. Conversely, the proposed CGE model, in this study, recognizes the fact that energy use, in production processes, is dependent on (physical) capital (Okorie, 2021) and as such, energy is modelled as a nested intermediate input with capital relative to the labour factor input. Secondly, electricity and fossil fuels are modelled as suitable close substitutes in the production of goods and services (value added). That is, this proposed model allows businesses to decide and substitute fossil fuel intermediate inputs with electricity intermediate inputs towards sustainable practices and reduction in carbon emissions. These highlight some of the model contributions of this study.

Digitalization and its aggregate effects on economic welfare continue to drive research interests in the opportunities as well as challenges it presents to Public and Private interests. This becomes more pertinent in the international context of increased interest in sustainable development and climatic concerns. The global digital transformation of governing processes and entire industries has resulted in leaders giving precedence to digital adoption and application in pursuit of optimal outcomes. The Gartner 2018 CIO Agenda Industry Insights ranked digital business or transformation a top three business priority Gartner (2017).In the past few decades, digitalization has resulted in evolutions to mechanical processes, manufacturing, transportation, methods of payments and transacting, information gathering and dissemination, agriculture and communication. The consensus is that there exists a positive correlation between digital activity and economic growth. Countries investing in and promoting digitalization are expected to grow – directly through ICTs, and indirectly when ICTs support other industries (Mentsiev et al., 2020). What is less certain is the measure of impact digital technologies and industries have on GDP growth and general economic activity. The Association of Southeast Asian Nations (ASEAN) are undergoing talks on a Digital Masterplan for 2025 to improve economic integration and promote inclusive and sustainable growth for the region. Lim et al. (2021) ran a computable general equilibrium analysis and found that Singapore's digital economy agreements (DEAs) as they currently exist when modelled for ASEAN countries as a region, will improve inter-regional trade by an average of 7.27 percent. The DEAs are also expected to positively impact the ICT sector with downstream benefits for the business services and financial sectors which are estimated to increase their output by an average of 6.78 percent.

There are both positive and negative consequences of digitalization but also "incalculable" potential to help bridge the sustainability gap (Lubin & Esty, 2014) or reduce the negative impact on people, a sort of "digital tragedy of the commons" (Nagle, 2018, pp. 19–60). Most arguments make cases for the positive impact that digitalization has on green-house gas (GHG) emissions and efficiency in production. The introduction of ICT services and digitalization limits wastage and improves productivity which contributes to less pollution and GHG emissions, a reality that is expected to limit the acceleration of climate change going forward. For instance, Zhang, Shinozuka, et al. (2021) find that a targeted introduction of ICT into various aspects of production and added services in Japan should increase GDP growth in the Asian giant by an additional 1 percent and reduce GHG emissions by 4 percent. Chen (2022) posits that the digital economy is important for driving clean energy development and achieving sustainable development. The study also provides new ideas for building a digital economy and clean energy development in emerging-developing countries. Despite this, there remains little research on the relationship between digitalization and clean energy.

We are technologically, conceptually and politically at the beginning on all levels of leveraging the transformative potential of both sustainability and digitalization (Seele & Lock, 2017). This is relevant to the African context as the deficiencies in good governance and basic infrastructure limit the adoption of digitalization and digital technologies and thus, the measure of potential pay-off derived from widespread digitalization. However, Edward and Malecki (2007) highlight how challenging it may be to measure the impact of digital technologies on the economy in areas of wide adoption. Another aspect considers the causality of one over the other. Hernandez et al. (2016) outline this by pointing out that the economic impact of ICT infrastructure and internet adoption is caused by a third variable – where economic growth leads to internet adoption while internet adoption leads to economic growth. This relationship differs across space and time.

Most research on the subject is limited to OECD countries, Europe and the United States. Myovella et al. (2020) find that digitalization has a positive impact on economic growth in both OECD and SSA countries, but broadband internet and mobile telecommunications have varying impacts for OECD versus SSA countries. With a focus limited to OECD countries (Czernich et al., 2011), find a 0.9–1.5 percentage point increase for every 10 percent increase in broadband penetration. However, this was limited to broadband penetration and not the propagation of other digital tech like computers, smart phones and devices. The GDP share of the digital economy grew by 4.4 percent per annum from 2006 to 2016. Gillett et al. (2006) studied the impacts of broadband on economic activities in communities in the United States and outlined specific impacts on employment, number of businesses, industry mix etc. The study was limited in its scope and focused on earlier years of global adoption of digitalization. Also, in terms of employment, the digital economy accounted for 5.9 million jobs in 2016 –about 3.9 percent of the 150 million employed that year (Barefoot et al., 2018).

In an approach aimed at analyzing this impact for both developed and developing countries (Qiang et al., 2009), included 120 countries in their study. Results presented a 1.21 percent increase in GDP per capita growth in developed countries and a 1.38 percent increase for the same in developing countries. Abendin et al. (2022) focus on the impact digitalization had on bilateral trade in the ECOWAS from 2000 to 2018 by estimating an augmented gravity model to capture this effect using POLS, GLS and PPML estimators. The result was a significant positive relationship that recommends that economic agents in the region should pursue policies that promote digitalization in an effort aimed at enhancing bilateral trade. The argument holds for varying results at different levels of economic development and the adoption of digitalization. The opportunity exists for researchers to explain this disparity with empirical evidence, shedding light on development and rates of development in the context of the fourth revolution.

Scott (2012), working under the assumption that broadband internet should engender economic growth, attempts to provide an answer for whether internet access spurs GDP growth. The results show a 1.35 percent increase in GDP for every 10 percent increase in broadband penetration, suggesting broadband (as an aspect of digitalization) as a valuable investment for spurring economic growth. The assumption of agreed consensus on the positive relationship between digitalization and aggregate GDP may be premature. Meijers (2012) contends that internet use does not explain economic growth in a "fully" specified growth model. They however find that international trade variables are highly correlated with internet use and economic growth is a possible consequence of this specific impact on trade. More specifically, the study shows that the impact of trade on economic growth is about the same in both high- and low-income countries. However, the impact of internet use on trade is less pronounced in high-income countries than the case in non-high-income countries.

The physical nature of goods and products of sectors such as manufacturing, agriculture, transportation etc., make it easier to evaluate the impact these sectors have on the economy. The 'digital economy' is more difficult as it is largely non-physical and involves the provision of information, intangibles and services that help improve efficiencies in other sectors (Mentsiev et al., 2020). The bulk of the challenge in studies that aim to evaluate the impact of digitalization and the digital economy is that a single index cannot provide a comprehensive and accurate measure of the extent of the real development level of the digital economy (Li Y. et al., 2021). Nonetheless, the recognition of the value that digitalization brings to other sectors is acknowledged in policy and outcomes. In manufacturing, for example, digitalization and application of enabled technologies multiplies efficiency outcomes. China has introduced policies to force the upgrade of mechanical processes to a computerized control system and A.I. generation-capable by 2030, recognizing that digital innovation enables the total elimination or simplification of traditional mechanical transmission mechanisms, allowing for multifunctionality, flexibility and improved overall performance (Zhou, 2013).

1.2. Stylized digitalization facts in Nigeria and Africa, at large

There exist technical and legal deficiencies limiting the required level of digitalization on the African continent; however, the primary problem with widespread adoption is not isolated from the general economic and political shortcomings plaguing the continent. To carry out a robust study, researchers must consider the lack of widespread reach of digitalization on the continent and model accordingly. More recent developments like Artificial Intelligence (AI) and blockchain are relatively underutilized and show the potential for greater impact. The African adoption of digitalization leaves much room for improvement, relative to developed countries and its effect on the economy must be evaluated considering this fact. Much less broad macroeconomic evaluation has been done on the impact of digitalization and ICT adoption in developing countries in general and even much less of such analysis on the African continent.

Digitalization is a general-purpose technological application that has fundamentally altered the African economy and the way businesses, government institutions and individuals interact. Individuals have access to mobile banking services, social networks and alternate means of communication as well as interacting with businesses and governmental institutions i.e., e-commerce and internet-based public service access. The bulk of tech-based companies operating on the continent are either traditional banking services offering digital alternatives or fintech and financial inclusion services and thus, attract the most investment funding. Iddrisu and Chen (2022) find that digitalization positively impacts financial sector development, but digitalization conditioned on financial sector development does not promote economic growth in Africa. A lot more research is required on the continent on the subject matter to provide fair insights into the overall impact of digitalization as well as minor factors that may impact outcomes in varying sectors and across countries on the continent.

Digitalization and the introduction of the internet and digital technologies into varying aspects of everyday life is a relatively nascent development that only proliferated in the later part of the first decade of the millennium. Countries like South Africa and Northern African countries are relatively ahead of others in this regard. Nigeria, the largest economy on the continent only introduced supporting infrastructure in relatively recent years. Additionally, widespread adoption and reliability concerns remain a challenge across the country and more so in rural communities– factors that are to be considered for a robust analysis of the impact of digitalization on overall economic activity. The reality is similar or worse in most sub-Saharan African nations. Also, digitalization and the potential of automation portends offer a tool that is open to abuse in autocratic governments. For instance, the president of Nigeria drew the ire of businesses and open internet advocators when he ordered the shutdown of twitter (the social network) for punitive measures twitter activated upon his account's violation of their terms and conditions. This resulted in losses to several businesses amongst other unnecessary repercussions for about 7 months according to (Anyim, 2021; Iyatse & Adepetun, 2021). Autocratic governments like Sudan and Togo shut down the internet during elections to facilitate the rigging of the polls (Kohnert, 2021). Approaches to carrying out this study in the African context could vary by evaluating the impact on a continent-wide scale by categorizing countries into different levels of digital adoption and governance –advanced to less advanced states of adoption– and the degree of restiveness in countries prone to social and political crisis.

Fig. 1 shows the trend of the contributions of the Nigerian telecommunication industry. Particularly, these are the Telecommunication Contribution to Nominal Output (TCNQ) and Real Output (TCRQ). They are the ratios of the telecommunication sectors value added to the overall nominal and real outputs in Nigeria, sourced from the 2024 statistical bulletin of the Central Bank of Nigeria (CBN)[1]. Based on the information presented in Fig. 1, the Nigerian telecommunication sector's contribution has been rising continually and experiencing substantial sectorial growth over the years, especially in recent years. Based on these data, the telecommunication sector has remained the third largest contributor to the Nigerian national output in recent years. Similarly, based on the 2019 Social Accounting Matrix (SAM) of Nigeria adapted from Okorie and Wesseh (2024), Table 1 shows the intermediate (INDP) and final (FIDP) demand proportions of the domestic supply of telecommunication in Nigeria. The real estate sector, followed by the Finance & Insurance and Trade industries, aside from the telecommunication sector itself, are the leading telecommunication intensive and leading production process absorbers of the telecommunication services produced in Nigeria. In the same light, while the rich relatively consume more of the telecommunication domestic outputs, the level of the services consumed in the urban cities substantially outweighs that of the rural areas. Over time, the Nigerian government has made and implemented a series of competitive policies towards achieving the short- and medium-term telecommunication objectives and goals in Nigeria.

These policies include industry privatization, de-regularization, restructuring & reforms, etc. Recently in 2024, the Nigerian government introduced a 5% excise duty on telecommunication services. This policy was initially introduced in 2022 but suspended in 2023 following backlash from the populace due to the current situation of the economy (Okamgba, 2024a). Generally, these policies are geared towards further improvements and developments in the Nigerian telecommunication industry.

1.2.1. Households and individuals

There is little evidence on the quantitative impact of digital and ICT technologies on poverty levels and their alleviation (Hernandez et al., 2016). However, the prevalent consensus is that digital development provides a wide range of opportunities for individual empowerment which implies a positive effect on potential welfare. Adera et al. (2014) found that poor households gaining access to ICT witnessed some improvement in their poverty status whilst other poor households became poorer in a study carried out in East and Southern Africa. Most studies on digitalization focus on the impact of internet access and communication technologies on individual and household welfare. Notwithstanding, aggregating the overall benefits of digitalization and the digital economy on individual welfare and activities should prove a better measure of digitalization's impact on the smaller agents in an economy.

Another point of interest when debating welfare structures and outcomes is the assessment of inequality and mitigation strategies applied to society. Yin and Choi (2023) examine the effect of digitalization on income inequality by working with panel data from G20 countries from 2002 through 2018. The study finds that the interaction of digitalization with foreign direct investment and trade openness resulted in bridging the inequality gap. Outcomes were less pronounced in high-income countries than in their lesser-income counterparts. On the contrary, tentative evidence exists that suggests that the impact of ICT on wealth inequality is negative (Njangang et al., 2022).

Digitalization presents added efficiency and productivity potential for individuals. The internet allows for easier knowledge acquisition and access to otherwise esoteric knowledge and data. Communication is impacted, transportation challenges are limited, and transactions are concluded quicker and over far greater distances, thus positively shocking the volatility of transactions. Education delivery is made seamless and traditional challenges of reducing the cost and access to education, are in many cases, balanced out. Additionally, modern innovations like smart homes, digital integration of everyday appliances and the internet of things (IoT) all aid everyday activity and efficiency through implementation and time-saving advantages. These all account for added benefits to the human capital stock development within an economy (Scott, 2012).

Access to research tools and resources improves overall individual awareness and contribution to economic progress. Point of sale (POS) machines offer alternatives to settling transactions and improve the range of financial service offerings in the absence and unreliability of banking channels. The availability of mobile phones and value smartphones from China have enabled access at an unprecedented scale but also facilitated the ubiquity of digital services. Intuition suggests a positive relationship between digitalization for individual access and productivity, which implies a positive impact on GDP. However, some may argue in some cases that increased productivity decreases the number of available jobs (Gomez-Plana & Latorre, 2015). Researchers find little worth in considering the possible adverse effects increased productivity could have on employment levels. This is widely the case because digitalization, as the consensus enabler of productivity and the future of work, is here to stay, and the macro-view of indicators suggests that added benefits from digitalization make possible costs insignificant. To limit increases in unemployment, society needs to adapt the labour force to this inevitable future and only this retraining and reorientation of the population would allow for a timely absorption of the growing labour force into employment in the era of digitalization. Notwithstanding, the possible adverse effects of digitalization on employment have limited empirical confirmation. Overall, the fact remains that government and policymakers remain a crucial factor in addressing some of these issues (Loo & Ngan, 2012).

1.2.2. Firms and industry

Industrial production and operations are largely driven and facilitated by digital integration and the application of digital technologies. In the post-industrial age, the key facilitator of increased productivity has been digital integration into industrial processes.

[1] The entire 2024 Statistical Bulletin of the Central Bank of Nigeria can be accessed through https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.cbn.gov.ng%2FOut%2F2024%2FSTD%2F2024_Q2%2520Statistical%2520Bulletin%2520Tables.xlsx&wdOrigin=BROWSELINK.

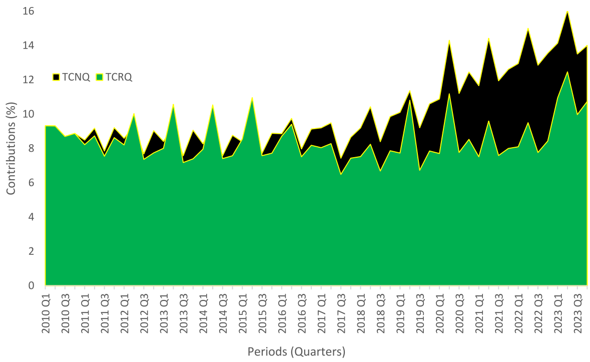

Fig. 1. The telecommunication sector's contribution in Nigeria.

Table 1
Telecommunication Sector flow in Nigeria.

Sectors	INDP	FIDP			
Trade	14.102	Poor		Rich	
Refined Oil	0.403	**Rural**	**Urban**	**Rural**	**Urban**
Other Industries	7.134	0.777	2.195	2.962	8.797
Other Utilities	2.056				
Finance & Insurance	17.524				
Transportation	0.272				
Telecommunication	19.026				
Art-Ent-Recreation	1.900				
Real Estate	19.278				
Education	0.060				
Health	0.036				
Other Services	3.476				

INDP is the Intermediate Demand Proportion for Telecommunication domestic Supply while FIDP is the Final Demand Proportion for Telecommunication domestic Supply.

Digitalization helps firms improve efficiency as well as streamline operations for greater and improved service delivery. Cost-reduction benefits from digitalization and ICT applications continue to positively impact the operations of firms and industries. Additionally, firms in the digital space continue to be one of the primary attractors of startup funds and tech investments on the African continent, growing much-needed foreign exchange depth and direct investments in the economy. The result is increased employment in the space and multiplier effects on the output of the economy. The degree of structural change noticeable as a result of digitalization is more pronounced in developed countries than is the case in developing countries, owing largely to infrastructural and policy weaknesses that limit reliable and widespread adoption. Infrastructural weaknesses (broadband, electricity, transportation) must be addressed for developing countries to gain major market share in global online and digital service provision (Matthess & Kunkel, 2020).

The ICT sector in Africa continues to grow exponentially whilst mobile technologies have generated 1.7 million direct jobs as well as contributed $144 billion in economic value. Also, the ubiquity of information that digitalization enables has limited information asymmetry concerns in financial systems and beyond. The result of this is added efficiency, greater certainty and a more competitive market for firms (Ndung'u & Signé, 2020). Under the assumption that digitalization optimizes operations, and in the era of clean energy, pollution and waste reduction, digital transformation of production and economic activity in general is essential. The digital economy has a significant positive contribution to green total factor energy efficiency and helps improve economic growth level, urbanization level, R&D input level and human capital (Zhang, Shinozuka, et al., 2021).

Zvereva (2019) examine the impact of digitalization on welfare in developed and developing countries. Like the results already presented, findings confirm a positive impact of digitalization in developed countries due to high levels of digital inclusivity, public and private investment, and digital literacy and trust. The study was unable to confirm the impact of digitalization on welfare, the consequence of a low level of state involvement in digitalization development and the non-flexible institutional environment. In both public and private sectors, digitalization facilitates innovation, efficiency, transparency, etc. However, limited infrastructure, insufficient stakeholder engagement, user education and training are challenges that limit the realization of the ideal benefits of digitalization (Ayakwah et al., 2021).

1.2.3. Government and good governance

Econometric studies have found evidence of a strong positive relationship between ICT investments and GDP growth, illustrating the importance of ICTs for development, both in the commercial and public sectors (Ndou, 2004). Regarding government and good governance. Digitalization offers opportunities to broaden transparency, limit corruption and encourage accountability. However, a governing body is only as good as it wants to be. Digitalization offers the opportunity for a reduction in the cost of governance. Whether or not savings and efficiency gains are applied appropriately to re-allocate resources in a manner that maximizes economic benefits remains the prerogative of the ruling class. Mobile technologies and services have contributed $15.6 billion to the public sector through taxation, improving state fiscal position for a few countries in the sub-Saharan context (Ndung'u & Signé, 2020).

The development of a national identification system and its integration into other aspects of governance should help improve overall data interoperability and thus, aid the execution of governmental responsibilities in Nigeria. The deployment of smart systems had the potential to markedly impact the levels of trust in electioneering processes in sub-Saharan Africa, but setbacks largely owing to human deficiencies limited positive outcomes. Government has a huge part to play by providing an infrastructural and legal enabling environment for easier adoption of digitalization and facilitating the interface between stakeholders in the industry for improved data interoperability and 'digital connectedness'. Adopting strategies for improved digital connectedness significantly impacts positive structural change at a faster pace in SSA than is the case in other developing regions (Da Piedade, 2022).

Wandaogo (2022) finds that a government's use of information and communication technologies (ICT) improves its effectiveness in both developing and developed countries. However, this effect is stronger in developed than in developing countries. Results highlight the fact that governments could fully benefit from digitalization by adopting policies that promote access to and use of ICT at all levels of the economy– government MDAs, businesses and individuals. In addition to adoption, the government must enable sustainability by investing and supporting required infrastructure as well as adopting a legal framework that is fairly "open" and guarantees stakeholder privacy. For the continent to realize the true potential and transformational power of digitalization, these interrelated conditions for an enabling environment must be initiated, otherwise solutions and services will be limited in their potential or short-lived (Baumüller & Addom, 2020). The challenge here to governments, policy makers and stakeholders is to shape technological change in this era of digital transformation in a way that impacts positively broader groups of people and effectively meets the needs and interests of economies and society (Qureshi, 2022).

Developing countries on the African continent trace most digital development and the rapid growth of digital services to the entrance of multinational enterprises (MNEs) in the telecommunications space. The capital-intensive nature of the industry and relatively high license fees limited entrants to foreign companies with the financial muscle to invest in the space. Overall contributions are applauded for the foreign direct investments (FDI), but less appreciated are the subsequent benefits to employment and society. The implications for foreign versus domestic operator dominance in the telecommunications sector are open to debate, but telecommunications investments originating from foreign sources result in increased employment and improved digital economy development (Gomez-Plana & Latorre, 2015). Results are not expected to differ in the African context or Nigeria in particular.

The proliferation of digitalization in Nigeria is the culmination of a few factors aligning at the right time. A major point of inflexion can be traced to the 2001 deregulation of the telecommunications market, the entrance of major telecommunications companies and the ubiquity of smartphones and smart devices. The result was a significant increase in private investment in the sector and a consequent increase in foreign direct investment (FDI). Only three years after deregulation, investments in the space had increased by about $6 billion, 120 times more than investments before deregulation. Also, initiatives introduced by the government of the day like a five-fold decrease in import duties on telecommunication equipment resulted in significant dividends that have continued to yield to date (Ologunde et al., 2006). The primary objective of such initiatives was to rapidly grow the nation's telecommunications infrastructure for a more competitive market and democratize access to quality telecommunications services (Ndukwe, 2011). The sector has grown to become a significant contributor to GDP, equity market capitalization and employment. Ancillary benefits to this include the significant growth in subscribers and thus the portion of the populace with potential access to the internet and unlimited information and data. The underlying outcome of unlimited access to data and information via the internet may translate to added benefits for the quality and equality of life across households.

Progress in the sector across the continent hardly varies, as similar growth and added benefits have become the norm in most African countries. The sector plays the key facilitator in the adoption of digitalization on the continent evidenced in the relationship between a relatively thriving telecoms sector and digitalization. In other cases, innovation hubs are recognized as key institutions in developing digitalization and digital-based companies. These hubs provide an entry point for investors and opportunities for networking and mentoring as well as deploy publicly accessible small-scale workshops offering digital fabrication (Baumüller & Addom, 2020). However, their offerings like many in the digital space are facilitated by the telecoms sector in Africa. Lagos, Nigeria; Cape Town, South Africa; and Nairobi, Kenya, are among the cities that host the most hubs. More than 50 percent of all hubs involve public or corporate partnerships, including with mobile network operators such as MTN, Orange, or Vodafone, as well as IT companies such as Nokia or Microsoft (Giuliani & Ajadi, 2019).

Measuring the impact of the proliferation of telecommunications on economic performance is multifaceted and not limited to the sectoral contribution to GDP but must account for the technical support and added efficiency services provided to other sectors. Without this factor accounted for, only a limited evaluation of the contribution of the sector would be represented.

The challenge when it comes to evaluating the impact of the sector on GDP growth is quantifying the indirect impact through its facilitating other sectors and economic activity in general. Babatunde (2013) tests the causal and reciprocal relationships between investment in telecommunications and GDP during the transitional period between 1985 and 2003 in addition to the impact of the reforms on the performance of the firms in the telecommunications sector. The study finds a strong and positive relationship between economic reform and firms' revenue and profit. The regression analysis shows that the telecommunications sector is statistically insignificant in explaining the GDP. Also, the impact of investment in telecommunications was found to be an insignificant predictor of GDP and vice versa even when the investment lagged by one year. Telecommunication brings clear benefits to economies and facilitates overall economic activity. However, to analyze telecom benefits to the economy in the context of digitalization, the direct impact of the sector on GDP must be evaluated in addition to the indirect benefits it provides for individual and business development and productivity.

2. Literature review

Digital technology is a key input required for pursuing economic objectives and initiatives in the era of the fourth revolution. More specifically, digitalization and its exponential impact on productivity, when properly applied, optimizes most functions. The very concept of a digitally driven future adopts wide consensus amongst most progress-driven world leaders. Nevertheless, methods of adoption and application vary, and these discrepancies are reflected in the country-specific importance of digitalization and the degree to which it impacts economic growth. In trying to analyze the positive and negative impact of digitalization in developing countries (Myovella et al., 2020), employ panel data from 74 countries using generalized methods of moments (GMM) estimators. They find that digitalization has a positive contribution to economic growth overall. The impact of telecommunications is higher in SSA than it is in OECD countries. However, the effect of the internet is minimal in SSA versus OECD. They posit that less advanced tech creates more opportunities in the least developed countries because of the greater room for improvement and suggest that governments increase investments in ICT and supporting infrastructure to spur more pronounced economic benefits from digitalization. The dataset consisted of 41 SSA and 33 OECD countries over 11 years only, from 2006 to 2016. In a case like Nigeria, this period is relevant, but perhaps expanding the years from 2004 to the present may offer more robust results for one of the best enablers of mobile internet penetration in the region (Kohnert, 2021).

An AIM/CGE-enabled study by Zhang, Shinozuka, et al. (2021) adopted a dynamic national CGE model to quantitatively analyze the future impacts of ICT services used in Japan on economic growth and GHG emissions until 2030. They find that the spread of ICT services and artificial intelligence-based applications reduces emissions and increases output by improving efficiencies in logistics and manufacturing whilst enabling labour-saving measures. The model is calibrated using the 2005 Input-Output (IO) tables for Japan and for future projections from 2016 through 2030, basic preconditions such as population change, expected GDP growth and changes in power supply configuration were adjusted based on Japan's intended nationally determined contributions. To represent ICT services, 36 kinds of ICT services varying from six determined industry categories (finance, public services, manufacturing, distribution and services, medical & agriculture and Infrastructure) were identified and divided into two distinct groups. The first group includes ICT services that are already common and in widespread use and the second group consists of services such as AI and IoT that have growing importance in some industries and life applications. Overall efficiency gains and supposed increased productivity would be expected with digitalization. The application of these innovations to varying aspects of economic function should put downward pressure on prices. However, the downward pressure on inflation directly attributed to the adoption of cost-efficient technologies has yet to appear in the statistics (Charbonneau et al., 2017). Also, Csonto et al. (2019), find that digitalization has on average, a negative impact on inflation. The study finds that a one percent increase in a specified digitalization factor results in a 0.006 percent reduction in inflation. The study arrives at these results by investigating inflation dynamics in a sample of 36 advanced and developing countries from 2000 to 2017.

Lim et al. (2021) assess the potential impact of the DEA by utilizing a CGE model and employing the Global Trade Analysis Project (GTAP) model with standard closures. In addition to disaggregating ASEAN members, other regions are specified in their disaggregation. China is included as a separate country for its deep integration into the ASEAN regional value chains in the global production network. EU & USA are also separated as they have a significant presence in global trade whilst 101 remaining regions are placed into the rest of world (ROW) category. Sixty-five sectors are aggregated into 15 broad sectors, where industries that are identified to be impacted by the DEAs to a larger extent have been identified and disaggregated. As such, the wholesale & retail trade, information & communications, financial services, and business services sectors have been separated. The main measurements used to assess the impacts of the DEAs were industrial output, value-added, employment and trade. They conduct a counter-factual analysis on the potential gains of a broader ASEAN-wide DEA which seeks to integrate the nations. Similarly, some studies have adopted the Input-Output (IO) table model, upon which the CGE models are built, to analyze the effects of the telecommunication industry in different economies. For example, using the IO table model, Xing et al. (2011) showed that the service sector featured a relatively higher demand-side convergence compared to the manufacturing sector in China. The telecommunication sector is one of the highly linked industries in India based on the findings from the IO table approach (Karonnon & Rajeev, 2023). Yu-Kyoung (2012) used the IO table model to systematically show the linkages between the telecommunication and transportation industries in Korea. Rohman and Bohlin (2010) also analyzed the contributions of the telecommunication sector of the European countries based on the IO table model and characterized its evolution and periodic fluctuations.

Zhang, Shinozuka, et al. (2021) employ a fixed-effects model to empirically examine the impact of the digital economy on green total factor energy efficiency using panel data from 30 provincial-level administrative regions in China. Years included in the study ranged from 2006 to 2018 and non-linear effects of the digital economy are tested using a panel threshold model that effectively divides the sample into multiple intervals and evaluates variable relationships within each interval based on data characteristics. The digital economy is measured by Li et al. (2021) with a specified digital economy index decomposed into 3 dimensions as follows: information development, internet development and digital transaction development. A linear weighting method is applied to calculate the digital economy index and for the comparison among indicators, the threshold method in the linear dimensionless method is employed to standardize the data. Czernich et al. (2011) limited their study to 25 OECD countries in trying to estimate the effect that broadband infrastructure had on economic growth. Their "instrumental variable model derives its non-linear first stage from a logistic diffusion model where pre-existing voice telephony and cable TV networks predict maximum broadband penetration". Results were robust to country and year-fixed effects and controlled for linear second-stage effects, predicting broadband penetration but not diffusion of contemporaneous technologies like mobile telephony and computers. Habibi and Zabardast (2020) observed that

ICT is positively associated with economic growth by analyzing panel data from 10 Middle Eastern and 24 OECD countries. The years included in the study ranged from the year 2000 through to 2017 with OLS fixed-effect and GMM methods applied.

Barefoot et al. (2018) estimate the real contribution of the "digital economy" to the GDP of the United States on behalf of the BEA. Estimates are constructed with a supply-use framework. BEA develops a conceptual definition of the digital economy. Identified specific goods and service categories within this supply-use framework with relevance to measuring the digital economy and then industries responsible for these goods and services. BEA then estimated output, value-added, employment, compensation, and other variables for these industries. BEA defines the digital economy primarily in terms of the Internet and related information and communications technologies (ICT). BEA also includes in its definition (1) the digital-enabling infrastructure needed for a computer network to exist and operate, (2) the digital transactions that take place using that system ("e-commerce"), and (3) the content that the digital economy users create and access ("digital media"). BEA focuses on goods and services that are primarily digital but also highlights the challenges that come with estimating the economic contribution of "partially-digital" goods and services and the opportunity it presents for future research.

In juxtaposing developed country effects versus developing countries (Qiang et al., 2009), settled for an econometric regression over 6 variables, varying over 120 countries. Data was collected for the years 1980 through 2007 with GDP being the dependent variable. Dummy variables were employed to account for regional variations. Numerous factors account for economic growth, so it is of added value modelling in a manner that accounts for this fact and isolates the relative impact of digitalization or related technologies. Looking at the relationship between the telecommunications sector and GDP growth (Babatunde, 2013), is limited in scope and methods. The study employed a regression analysis in evaluating the causal relationship between investments in telecoms and GDP from 1985 through 2003. These years are limited in the context of digitalization's impact on GDP on the African continent as adoption was largely limited and novel at the time.

Rather than focus on the impact of digitalization on aggregate output, some focus on more specific economic indicators like bilateral trade. For example Abendin et al. (2022), limit their analysis to the impact digitalization had on bilateral trade in the ECOWAS from 2000 to 2018 by estimating an augmented gravity model to capture this effect using POLS, GLS and PPML estimators. The result was a significant positive correlation. Iddrisu and Chen (2022) analyzed economic growth in Africa and limited focus to the role of digitalization and financial sector development. They employed country-level data from 36 African countries over 2 decades (2000–2020) and used fixed effect, random effect and the Hausman-Taylor estimation techniques in their analysis. Findings were relatively original and should provide insights for researchers as well as policy makers. On the part of policymakers and public officials, many tout the opportunities that digitalization may offer to limit corruption and promote transparency. Zumofen et al. (2022) help support this argument by finding that implementing new technologies in the Republic of Benin has limited abuse and corruption whilst improving state-to-citizen relationships in the long run.

Gomez-Plana and Latorre (2015) simulate with the aid of a CGE model, the impact of operations of multinational enterprises in the ICT sector of the Spanish economy from 2005 to 2013. They find no threat to employment emanating from more MNEs operating in the ICT sectors but find that regardless of wage flexibility, FDI in the sector reduced unemployment levels. The study uses the institutional sector accounts from the Spanish National Statistics institute (Instituto Nacional de Estadistica) to build the Social Accounting Matrix (SAM) rather than the Input-Output symmetric table available for the Spanish economy, for the year 2005. Others find valid evidence of the destruction of jobs amongst low-skilled workers in particular as this subset becomes less relevant for lacking the skills required to be productive in the era of digital domination. Balsmeier and Woerter (2019) find that increased investment in digitalization increases the employment of high-skilled workers and reduces the employment of low-skilled workers albeit at a minute net positive effect.

Sampling a panel dataset for 45 developed and developing countries, Njangang et al. (2022) analyzed the effect of digitization on wealth inequality between 2000 and 2017. To represent information and communication technology, these three indicators from the World Bank World Development Indicators (WDI) were used as follows: mobile phone penetration rate, internet penetration rate and ICT service exports as a percentage of service exports. Adopting a Generalized Method of Moments (GMM) estimation, they show that ICT has on average a positive and significant effect on wealth inequality which is measured by billionaire wealth to GDP. In addition, they find that improving democratic systems in both developed and developing nations helps alleviate the adverse effects of ICT on wealth inequality. Wen et al. (2022) employ panel data of Chinese manufacturing enterprises from 2008 to 2019 and find that digitalization and environmental regulation can significantly improve total factor productivity.

Wandaogo (2022) used panel data from 138 countries between 2006 and 2016 and found results suggesting that a government's use of ICT improves its effectiveness in both developing and developed countries. Results are robust after several tests (reverse causality, dynamic effect, sensitivity analysis, heterogeneities, and alternative measurements). Zvereva (2019) in studying the impact of digitalization on welfare in developed and developing countries, based their methodology on building a balanced panel regression. Employing Tuft University's Digital Evolution Index of fifty countries for the years 2008, 2013 and 2017. Wang and Xu (2023) found that digitalization has an enhancing effect on public health in developing countries and a greater effect in Africa by analyzing panel data from 81 developing countries between 2002 and 2019. The two-pronged study explored the significance of the enhancing effect digitalization has on public health as well as whether digitalization can enhance public health by bridging the income gap and reducing income inequality. Nevertheless, the potential for digitalization cuts across sectors and its inevitability in IR 4.0 means we have to adapt our ways of live to these innovations and these innovations to our ways of living. For example, Hilty and Bieser (2017) find that ICT has the potential to avoid up to 3.37 times more greenhouse gas (GHG) emissions than the amount of emissions caused by the production, operation and disposal of ICT devices and infrastructures used in Switzerland in 2025. The capabilities of digitalization in promoting emergency response systems, enhancing food and water security, improving power infrastructure performance, enabling citizen engagement and participatory adaptation measures and minimizing the impacts of climatic hazards are boundless. There are numerous opportunities offered by digitalization in support of climate change adaptation initiatives and dealing with social-ecological challenges (Balogun et al., 2020).

Existing studies have made tremendous efforts in analyzing and discussing the effects of improving the telecommunication sector in an economy using different approaches that are not limited to the IO table, and CGE model. However, these studies have focused mainly on the impact of the telecommunication sector on economic growth and its linkages to other industries in an economy. Conversely, a couple of studies have employed the CGE model to evaluate the economy-wide effects of the telecommunication industry in an economy (Lim et al., 2021; Zhang, Shinozuka, et al., 2021). Particularly, this current study builds on assessing the economic and environmental effects of increased investment in the telecommunication sector using a different CGE modelling assumption in the production design. The AIM/CGE model, adopted by Zhang, Shinozuka, et al. (2021), models output as a function of value-added, energy aggregates, intermediate inputs, and non-energy related GHG (greenhouse gases) while the GTAP model, adopted by (Lim et al. (2021), models output as a function of factor inputs, energy (electricity & non-electricity) and intermediate inputs. However, the EEICGE model models output as a function of value-added and intermediate inputs. The value added is a function of labour factor inputs and the nested energy-capital inputs. Then, the energy-capital is a function of energy and capital factor inputs. This modelling structure follows the argument that energy use is a capital-dependent intermediate input of production processes (Okorie, 2021). Secondly, the energy intermediate inputs are modelled as substitute inputs against the conventional practice of modelling the energy inputs as complementary inputs. This way, the model allows for the energy input choices of the industries between renewable and fossil-based energies. Last, but not least, the household economic agents are disaggregated to better reflect the different segmentations within the households. These are some of the differences and contributions this study makes to the body of existing studies in this spectrum.

3. Empirical strategy

3.1. The EEICGE model

Typically, a CGE model is a system of equations that summarises the optimization behaviours of economic agents and the relationships existing among them, in a closed or open economy. That is to say that a CGE model captures the flow of nominal and real resources among the different sectors or industries of an economy as shown in Fig. 2. CGE models can either be static or dynamic depending on the time design or structure. This study takes a novel approach towards investigating the impact of digitalization on an economy. As such, this study adopts a Computable General Equilibrium (CGE) model to capture the economic impact of digitalization in Nigeria. Particularly, this study adopts the Energy & Environment Integrated CGE (EEICGE) proposed by Okorie and Lin (2024). In their study, the single-country static EEICGE model (EEICGE V1.0) is developed and extended (EEICGE V2.0) in Okorie and Wesseh (2024). However, the single-country (recursive) dynamic EEICGE model version (EEICGE V3.0) is applied in this study. The EEICGE models, in addition, capture the energy and environmental aspects of the economy. Therefore, it can capture not only the economic impact of digitalization but also the energy and environmental impacts of digitalization in an economy. Unlike other CGE models that capture the energy and environmental relations,[3] the EEICGE models particularly follow and extend Okorie's (2021; 2017) argument that energy use is a capital-dependent intermediate input of production processes and not an independent primary or intermediate input as captured in other CGE models. The EEICGE model has nine (9) blocks. They include production, domestic demand, prices, income & savings, supply & international trade, energy & environment, real, national output and market clearing blocks.

$$U_{ht} = \prod_i \left(C_{i,h,t} - C_{i,h,t}^{min}\right)^{\gamma_{i,h}} \tag{1}$$

$$\sum_i P_{i,t} C_{i,h,t} = CB_{h,t} \tag{2}$$

$$P_{i,t} C_{i,h,t} = P_{i,t} C_{i,h,t}^{min} + \gamma_{i,h} CB_{h,t} - \sum_i \gamma_{i,h} P_{i,t} C_{i,h,t}^{min} \tag{3}$$

The households maximize utility, the Stone-Geary utility function, in equation (1) subject to the expenditure constraints in equation (2). Solving the constraints optimization problem and imposing the condition that $1 = \sum_i \gamma_{i,h}$ yields the utility optimization consumption demand function in equation (3). U_{ht} represents household h utility behaviour at time t. $C_{i,h,t}$ is the household h consumption of goods and services i at time t. $C_{i,h,t}^{min}$ is a minimum consumption level of goods and services i for household h at time t. $P_{i,t}$ is the market price, including taxes and margins, of goods and services i at time t. $CB_{h,t}$ is the consumption budget of household h at time t, which is the net of the household income after savings and transfer payments. The parameter $\gamma_{i,h}$ is the marginal consumption share of goods and services i at time t. The Stone-Geary utility function is a quasi-homothetic extension of the basic Cobb-Douglas utility function that captures the Linear Expenditure System (LES) that allows the consumers to first meet their basic subsistence needs or requirements through a basket of fixed minimum quantities of goods and services (non-homothetic component) and then, allocate the spending of any additional income based on their discretionary needs (homothetic component). Moreover, as income changes, the budget share on the non-homothetic component changes while that of the homothetic component remains fixed (Burfisher, 2017).

[3] Examples includes GTAP-E by Burniaux and Truong (2022), AIM/CGE V2.0 by Fujimori et al. (2017), etc.

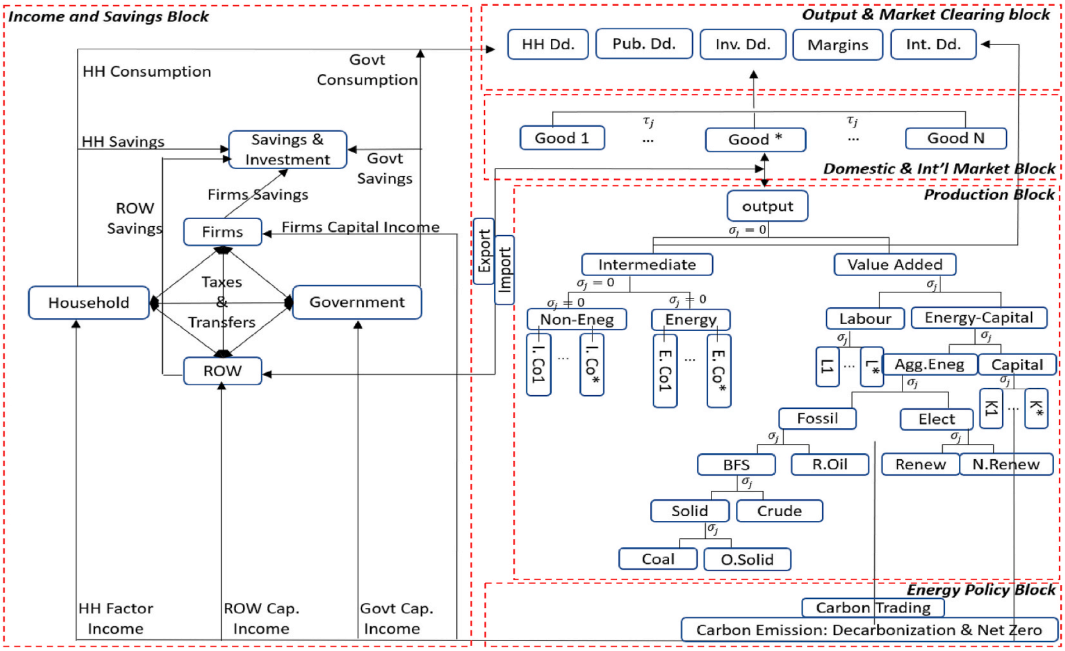

Fig. 2. EEICGE schema.[12].

$$\sum_j P_{j,i,t}Q_{j,i,t} - \left(W_{l,t}\sum_j L_{l,j,t} + \sum_j R_{k,j,t}K_{k,j,t}\right) \tag{4}$$

$$\overline{Q}_{j,t} = \beta_j^Q\left(\sum_i \beta_{j,i}^Q Q_{j,i,t}^{\rho_j^Q}\right)^{\left(\rho_j^Q\right)^{-1}} \tag{5}$$

$$Q_{j,i,t} = \frac{Q_{j,t}}{\left(\beta_j^Q\right)^{\sigma_j^Q+1}}\left(\frac{P_{j,i,t}}{\beta_{j,i}^Q P_{j,t}}\right)^{\sigma_j^Q} \tag{6}$$

Similarly, the firms maximize profits in equation (4) subject to their output function or production technology in equation (5). This optimization exercise yields the supply function (for all outputs above the minimum average variable cost) in equation (6). This result in equation (6) is the same if the firms maximize the production function subject to their cost function or minimize the cost function subject to their production technology. $P_{j,i,t}$ is the basic price of industry j output of goods and services i at time t while $Q_{j,i,t}$ is industry j output of goods and services i at time t. To produce these outputs, a heterogeneous l labour factor inputs $L_{l,j,t}$ and heterogenous k capital factor inputs are employed by industry j at time t. These heterogenous l labour inputs are unskilled, semi-skilled, and skilled labour while that of k capital are physical machines and lands. While these heterogenous capital inputs receive different rental rates, $R_{k,j,t}$, labour receives the minimum wage rate for each heterogenous labour type l, $W_{l,t}$. These costs are incurred to produce the pre-determined profit-maximizing quantity $\overline{Q}_{j,t}$ for industry j at time t which is a constant elasticity transformation function of other individual industry j output of goods and services i at time t, $Q_{j,i,t}^{\rho_j^Q}$. This constant elasticity transformation function ensures that these individual outputs are not perfectly transformed from one output to another. $\beta_{j,i}^Q$ is the scale parameter for industry j output of goods and services i. $0 < \sigma_j^Q < \infty$ is the elasticity of transformation for industry j's output and it's a function of the elasticity parameter $1 < \rho_j^Q < \infty$.

$$VA_{jt} = A_j^{va}\left[\beta_j^{va}L_{jt}^{-\rho_j^{va}} + \left(1-\beta_j^{va}\right)EK_{jt}^{-\rho_j^{va}}\right]^{\left(\rho_j^{va}\right)^{-1}} \tag{7}$$

$$P_{jt}^{va}VA_{jt} = W_{jt}^L L_{jt} + R_{jt}^{ek}EK_{jt} \tag{8}$$

Value added for industry j at time t, VA_{jt}, is a constant elasticity of substitution function of the labour factor inputs and energy-capital nested factor input (Okorie, 2021) as shown in equation (7) and their prices and quantities satisfy equation (8). The nested energy-capital, EK_{jt}, is a constant elasticity of substitution function of both energy, E_{jt}, and capital factor input, K_{jt}, as shown in equation (9). Similarly, equation (10) is a constant elasticity of substitution function electricity, EL_{jt}, and fossil fuel, FO_{jt}.

$$EK_{jt} = A_j^{ek}\left[\beta_j^{ek} E_{jt}^{-\rho_j^{ek}} + \left(1-\beta_j^{ek}\right) K_{jt}^{-\rho_j^{ek}}\right]^{\left(\rho_j^{ek}\right)^{-1}} \tag{9}$$

$$E_{jt} = A_j^{e}\left[\beta_j^{e} EL_{jt}^{-\rho_j^{e}} + \left(1-\beta_j^{e}\right) FO_{jt}^{-\rho_j^{e}}\right]^{\left(\rho_j^{e}\right)^{-1}} \tag{10}$$

Equations (11) and (12) summarize the energy block of the dynamic EEICGE V.3.0 model. The carbon tax rate, CT_{ijt}, follows a value-added structure as shown in equation (11) while equation (12) is the carbon emission tax, CET_{jt}, with the industry emission coefficient, $\varnothing_j$. Among the conventional blocks is the Energy & Environment block. It captures the negative or undesired output of the use of energy (fossil and electricity) in the production processes. These are the Greenhouse Gas (GHG) emissions. The emission of GHG and other pollutants due to production activities harms both the environment and the lives (plants and animals) of the environment. Hence, an economy has to determine its Carbon Efficiency Rate (CER) or Carbon Abatement Rate[4] (CAR), which is the policy target level of carbon mitigation towards achieving decarbonization and net zero. For closure and to guarantee the Walras' law of no excess supply, attainment of a feasible solution, normal completion, and zero infeasibility, the EEICGE model assumes the labour market clears, the capital market clears, the investment market clears, domestic and international goods & services market clears.

$$CT_{ijt} = \varnothing_j E_{ijt} P_{jt}^{e} \tag{11}$$

$$CET_{jt} = \sum_i \varnothing_j CT_{ijt} E_{ijt} \tag{12}$$

Just like the stone-geary utility function, a concave but simpler utility function is adopted to measure the welfare level of the economic agents in the model. Two equivalent models are adopted, these are the comparative variation in equation (13) and the equivalent variation in equation (14). These welfare measures capture welfare lose or improvements, in monetary terms, due to policy changes. These measures of welfare are similar and equivalent and return approximately the same comparative statics in most cases. CV_{at} and EV_{at} are the comparative and equivalent variations for economic agent a at time t. C_{iat} is the economic agent $a's$ real consumption quantities of goods and services i at time t while Y_{at} is the economic agent a income at time t. The superscripts O and I represent the benchmark values and policy change values respectively. Generally, equations (1) – (14) is a summary of some of the blocks in the dynamic EEICGE V.3.0 model.

$$CV_{at} = \left(\frac{\sqrt[2]{\sum_i C_{iat}^{I}} - \sqrt[2]{\sum_i C_{iat}^{0}}}{\sqrt[2]{\sum_i C_{iat}^{I}}}\right) Y_{at}^{I} \tag{13}$$

$$EV_{at} = \left(\frac{\sqrt[2]{\sum_i C_{iat}^{I}} - \sqrt[2]{\sum_i C_{iat}^{0}}}{\sqrt[2]{\sum_i C_{iat}^{0}}}\right) Y_{at}^{0} \tag{14}$$

The EEICGE V.3.0 is a recursive dynamic model with theoretical dynamics that links one period with the other. As a dynamic recursive model, the system of equations that represent the economy is solved sequentially, one period at a time, from the first period to the next. As such, the values or outcomes of a period influence that of the preceding period. The link from one period to the other is captured in variables that grow at the same rate as the population growth rate and capital accumulation processes. Variables like the population index, labour supply, inventories, minimum non-homothetic consumption quantities, public current expenditures, categorized public investment, and current account balance grow at the same population growth rate to achieve a balanced growth path in the BAU (Business As Usual) scenario. On the other hand, the capital accumulation process follows the perpetual method where the next period's capital is the sum of the current period's capital investments and the net depreciated capital stock for each type of capital and all industries. The investment allocation follows the Tobin's-Q definition where the volume of each new type of capital to a sector is proportional to its existing capital stock but varies to the ratio of the capital's rental rate to its user costs (Lemelin & Decaluwe, 2007). The population year-on-year growth parameter is set to 2.41%, a 10% depreciation rate parameter and an 18% interest rate.[5] The value-added elasticity parameters for each sector follow the estimation results of Okorie (2021) for Nigeria using empirical data from 1960 to 2019 on an extended CES model. Okorie (2021) extended the basic CES model to a nested energy-CES model to capture

[4] The EEICGE model assumes a 10% CER or CAR (Iraoya et al., 2024; Okorie, 2025).

[5] See https://www.macrotrends.net/countries/NGA/nigeria/population-growth-rate for the choice of population growth. See https://taxsummaries.pwc.com/nigeria/corporate/deductions for the depreciation rate and for the interest rate, see https://www.reuters.com/markets/rates-bonds/nigerias-central-bank-raises-benchmark-lending-rate-18-2023-03-21 and https://www.cbn.gov.ng/rates/mnymktind.asp.

the role of energy use in production processes. Thereafter, the nested energy-CES model was linearized and estimated using the Indirect Least Squares (ILS) methods. Based on the estimation results, the production elasticities for Nigeria are calculated. The rest of the elasticity parameters follow Okorie and Wesseh (2024) while other model parameters are calibrated from the Nigerian SAM data. The dynamic recursive CGE modelling approach is somewhat different from the SAM multiplier analysis approach employed in Yeo et al. (2023) and Yeo and Jung (2024). Particularly for digitaization, the SAM multiplier approach requires that the SAM data explicitly incorporates the digitalization of capital assets and the flows information of these assets within the economy. To do this, digitalization of capital assets are treated as distinct production factors. Based on this, proportional allocations, by industries, of these digitalization capital assets are computed and multiplied by gross value-added of industrial physical capital. It is also assumed that returns on capital are equal in a balanced economic system. Conversely, the dynamic recursive CGE model approach makes no adjustments to the SAM based on the ICT sector (or any other sector) but models the economy-wide flow of resources among the industries and economic agents of an open economy using system of equations. This system of equations comprises both endogenous and exogeneous variables with calibrated parameters, population growth & dynamic equations that link one period to the other, and a capital accumulation process that follows the perpetual method with a Tobin-Q investment allocation definition. Policy shocks are then simulated on an exogeneous variable(s) while solving the resulting effects on the rest of the variables in the system and entire economy.

3.2. Scenario design

Being the most populous economy in Africa, Nigeria is faced with a rapidly growing demand for telecommunication services due to its growing population, expanding internet access, rising smart technologies, etc. Thus, the foreign and domestic telecommunication investment profile in Nigeria reached $732 billion in 2023 (Jaiyeola, 2024) and about 187 million broadband Nigerian subscriptions are forecasted in 2025 (Terraincore, 2024). This presents the Nigerian telecommunication sector in the light of an investment-worthy sector both for domestic and foreign investors. In the first quarter of 2024, foreign direct investment in the Nigerian telecommunication sector increased to $191 million (Okamgba, 2024b). These growths are handy given the rapidly growing reliance on the internet and AI for daily life activities. Despite all these investment increases, Africa is still behind other continents in terms of the domestic supply level of telecommunication services. To remedy this, this study investigates a 50% capital investment boost in the telecommunication sector that is spread across five (5) years.

The comparative statics of digitalization and its impacts on an economy are captured in the EEICGE V.3.0 model using a gradual fifty per cent (50%) capital investment shock in the Telecommunication sector. This investment is spread across five (5) years (2024–2028). In detail, the 50% shock is spread over the years through a 5% shock in the first year (2024), a 7% shock in the second year (2025), a 10% shock in the third year (2026), a 13% shock in the fourth year (2027), and a 15% shock in the fifth year (2028). Particularly, this scenario design represents or captures the needed investment opportunities in the Nigerian telecommunication sector (Okamgba, 2024b). In addition, this digitalization scenario design is in-line with the National Climate Change Policy (NCCP) and the Renewable Energy Master Plan (REMP) given the role of digitalization in clean and renewable energy developments (Chen, 2022). The NCCP and REMP seek to reduce greenhouse gas emissions and their adverse climate change effects through increased production and supply of renewable electricity energy by 2030. The benefits from digitalizing Nigeria spill over to other sectors to increase the demand and supply of renewable energy alternatives against fossil fuel energies in production processes. Thereby, concurrently achieving the NCCP and REMP goals. It is vital to state that this capital investment in the telecommunication sector is financed through external savings. Generally, the argument is that a substantial investment in the Nigerian telecommunication sector is necessary and sufficient towards upgrading and boosting the level of digitalization in Nigeria which necessitates imbibing smart technologies and AI into Nigeria's daily life activities and improving the quality of life.

3.3. Data

The data used in CGE models, such as the EEICGE V2.0, is the Social Accounting Matrix (SAM). SAM is an array of data points or values that capture the flow activities (expenses and receipts) among different agents, industries, sectors, etc. of an economy. This study adopts the Nigerian 2019 SAM from Okorie and Lin (2024) and Okorie and Wesseh (2024) for parameter calibration, shock simulation designs, and analysis of results. Furthermore, the cross-entropy balancing technique (Lee & Su, 2014) is adopted. This Nigerian SAM disaggregates the labour account into skilled and unskilled labour accounts while aggregating the capital accounts. The economic agents' accounts are disaggregated into rural (rich and poor) households, urban (rich and poor) households, businesses, government, and the rest of the world. This SAM does not capture different levels of government or different types of businesses. There are a total of twenty-two aggregated sectors. These are agriculture, crude, solid minerals, refined oil, food-beverage-tobacco, clothing, iron/metals/steel, other industries, fossil-based electricity, renewable-mix electricity, other utilities, construction/cement, trade, transportation, communications, arts-entertainment-recreation, finance-insurance, real estate, education, health, other services, and government. Except for the public sector, whose goods and services are consumed domestically, the rest of the sectors produce only one good or service that is either traded domestically or exported to the international market, or both. This explains the domestic and export goods & services accounts. Finally, the investment and inventory accounts are captured in this Nigerian SAM.

Fig. 3. Employment - primary factor inputs.

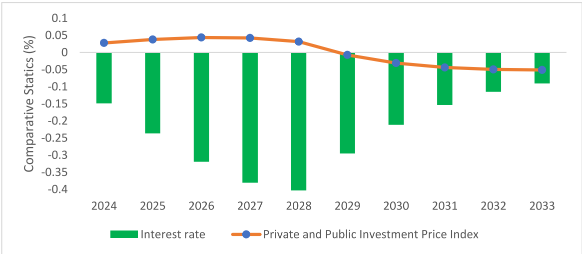

Fig. 4. Interest rate and investment prices.

4. Results and discussions

4.1. Economic impacts

4.1.1. National level effects

The information in Fig. 3 captures the comparative statics or percentage changes in the demand for capital and labour primary factor inputs due to digitalization in the Nigerian economy. Practically speaking, digitalization in the Nigerian economy opens a new door to enjoying technological benefits in businesses. Digitalization increases the demand for capital inputs (of new machines) for better ways of doing business in all sectors of the Nigerian economy. As such, every sector keys into the digitalization benefits for improving business activities ahead of production and sales. Similarly, the different categories of labour, skilled and unskilled labour, experience positive comparative statics which means an increase in employment and decreased unemployment due to digitalization. Digitalization in the Nigerian economy will result in increased employment (decreased unemployment). The increase in employment is relatively higher for skilled labour compared to unskilled labour supply. This is intuitively explained by the fact that capital, in the form of machines, requires or ought to be accompanied by skilled labour or operator services. It is equally important to point out that these increases in capital and labour inputs are sustained beyond 2028 which is the last year of the gradual digitalization progress.

The increases in capital translate to increases in investment for both private and public investors due to digitalization in the Nigerian economy. It is practically intuitive that digitalization drives immediate increases in private and public investments in Nigeria which also imply decreases in interest rates. The growth in public and private investment price indexes decreases to negatives in the preceding year after the end of the gradual digitalization scenario design. This is also true for the interest rates since the fall in the interest rate decreases after the end of the gradual digitalization design in Nigeria.

The rise and growth of the demand for capital & labour, increase in investments, and decreases in the level of interest rates spell increases in business outputs. This is mainly because all the sectors of the economy as these industries tend to take advantage of the digitalized economy. This is captured by a change in supply or shift in supply (curve) to create a new equilibrium at lower new equilibrium prices. This can also be explained by the fact that digitization increases outputs, reduces average costs of production, and thus decreases output prices. This transition is captured in Fig. 5 which depicts a fall in the overall level of output prices from all the industries or sectors of the Nigerian economy due to the digitalization policy design. Csonto et al. (2019) arrived at the same conclusion that digitalization has a significant negative impact on inflation through the estimation of the Phillips curve in 36 emerging and advanced economies of the world. This evidence is also supported by other related studies that investigate the role of digitalization on inflation or prices as shown in this study. As such, whether the aggregate price level index is measured using either the Consumer Price Index (CPI) or the Gross Domestic Product (GDP) Deflator confirms that digitalization substantially reduces inflation in an economy such as Nigeria.

Fig. 6 further confirms that digitalization increases the production of goods and services in an economy. Taking Nigeria for instance, the results show that digitalization drives the overall level of production in the Nigerian economy. Using the real national output as an indicator, both at basic and market prices shows that the level of economic growth in Nigeria has increased due to digitalization in Nigeria. This effect continues and is sustained even after the gradual digitalization scenario design as shown in Fig. 6.

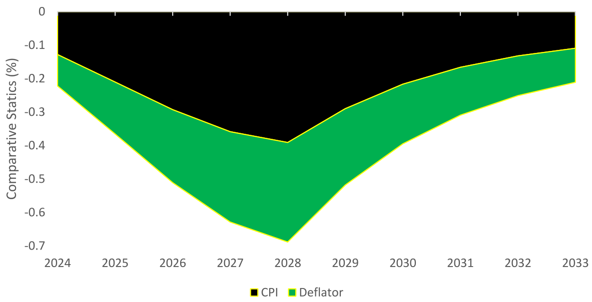

Fig. 5. Aggregate price indexes.

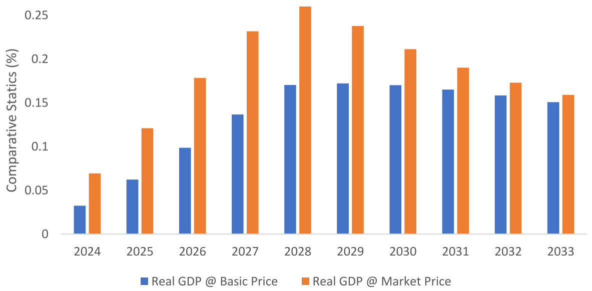

Fig. 6. Real domestic output.

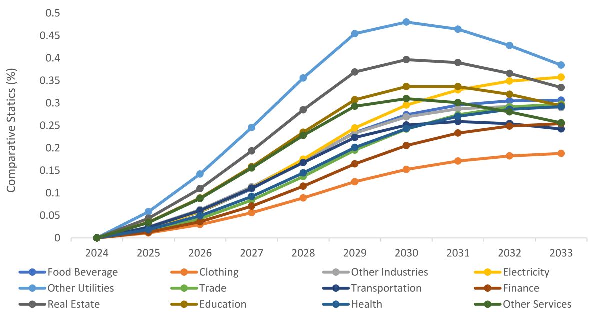

Fig. 7. Sectorial growth of digitalization.

4.1.2. Industrial level effects

Aside from the nationwide aggregate effects of digitalization in the Nigerian economy, there are industry-level or sectorial effects due to digitalization in the Nigerian economy. At first, Fig. 7 represents the quickness or rate at which other sectors or industries key into digitalization. From Fig. 7, the gradual digitalization design starts with the Telecommunication section in 2024. The next year, the rest of the sectors or industries adapt and key into digitalization for its benefits in promoting business activities. The level of digitalization grows for all the industries or sectors as shown in Fig. 7. Particularly, some key industries or sectors lead the promotion of digitalization in the various industries or sectors in Nigeria. As such, this growth in the sectorial level of digitalization is led by sectors like Utilities (others), Real Estate & Professional Services, Education, Services (others), and Electricity as shown in Fig. 7. These sectors champion the growth of digitalization in the Nigerian economy. Without a doubt, these sectors are best placed to optimize the benefits digitalization offers in an economy. Besides, the growth of digitalization in these industries continues to surge even after the end of the gradual digitalization scenario design in Nigeria.

Of course, the aggregate or national economic growth or increase in output levels has to be consistent and explained at the industrial or sectorial level. Fig. 8 shows steady growth in the level of domestically produced goods and services due to the digitalization policy design. This goes without saying that this increase in domestic output which is driven by digitalization is not only meant to meet domestic but global needs. To this end, international trade between Nigeria and the rest of the economies is strengthened due to digitalization in Nigeria. Specifically, the export of goods and services from Nigeria to the Rest of the World (ROW) continues to increase as the domestic output increases. This is intuitive and expected since the supply of these goods and services is not solely meant to meet domestic needs. Notwithstanding, the comparative statics show that the growth in the importation of goods and services into Nigeria from the ROW declined rapidly after the end of the gradual digitalization policy design in 2028. Based on the actual simulation results, the growth of the importation of goods and services into Nigeria became negative, although close to zero, from 2031 down to

2033.

Whilst the import prices are unaffected since they are prices that originate outside of the Nigerian economy, the export prices of goods and services from Nigeria decreased due to digitalization as shown in Fig. 9. This places Nigeria in a favourable, advantaged and competitive position with the rest of the economies of the world that produce similar products and offer similar services. Therefore, Nigerian products become cheaper in the international market relative to other close substitutes. Given the relative affordability of Nigerian products in the international market of goods and services, the Nigerian government increases its revenue from export taxes and import duties. It is also important to point out that the revenue of the government from the importation of goods and services into Nigeria increased more proportionally than its revenue from the exportation of goods and services from Nigeria. This can be explained by the fact that the importation prices are unaffected by the digitalization design or growth in Nigeria. As such, increases in importation, as shown in Fig. 8, directly translate into increases in the level of import duties revenue for the Nigerian government. However, since digitalization decreases the export prices of goods and services in Nigeria, the Nigerian government's revenue from export taxes is positive mainly because the growth in the export of goods and services from Nigeria outweighs the decrease in the export prices due to digitalization. In Fig. 9, these dynamics are captured by the higher comparative statics of import duties revenue over the export tax revenue of the Nigerian government. This is because, at constant import prices, important revenue only increases strictly due to the increases in importation due to digitalization. Conversely, the export tax revenue of the Nigerian government increases because the increase in exports is relatively more than the decrease in export prices. Moreover, over time, as importation into Nigeria falls and exportations from Nigeria rise, the revenue from export taxes starts to equal and outweigh the import duties revenues of the Nigerian government. This can be seen towards the end of the dynamic comparative statics in 2033. That is to say, given this gradual digitalization design in Nigeria, imports and exports are strengthened due to digitalization while Nigerian exports become relatively cheaper in the international market. Furthermore, the revenue of the Nigerian government is significantly increased via the increased import duties and export taxes. However, import duties lead the increases in the Nigerian government revenue until 2033 due to the sustained increases in the exportation of Nigerian products to the international community as a result of digitalization.

4.1.3. Agents level effects

Some of the microeconomic-level impacts of digitalization are discussed under this subheading. In the EEICGE model, Nigeria is modelled as an open economy to capture the true state of the economy. Thus, the economic agents extend beyond the Households, Firms, and Government to include the ROW. In addition, the household agents are disaggregated into urban and rural Nigerian households. Each of these household subgroups is further disaggregated into rich and poor Nigerian households. Firstly, Fig. 10 depicts the real consumption growth or comparative statics due to digitalization in the Nigerian economy. A look at the bar chart, in Fig. 10, clearly shows that the growth, in units of household consumption, is relatively higher for the poor cohort relative to the rich household cohorts for both rural and urban subgroups. This is very intuitive and suggests that the fall in the prices of goods and services avails poor households the opportunity to increase their consumption. On the other hand, the rich households also increased their real consumption but not so much as the poor households and channelled their increases in real income to investments (see Fig. 4) rather than consumption. This denotes that the rich households are quick and eager to take advantage of the increase in investment in the Nigerian economy owing to the digitalization policy rather than increase their real consumption more than necessary.

Suffice it to say that the digitalization effect is relatively more on the poor cohort because they are most likely newly introduced to digitalization technologies than their rich counterparts. As such, the poor cohorts seek to take greater advantage of digitalization relative to the rich that is presumably already used to digitalization. This also explains the reason behind the reduced real consumption for investments in the digitalization progress of the economy. On the other hand, the government's real consumption reduces for the first five years and increased afterwards until 2033. This is also intuitive since the government has to finance digitalization campaigns in the Nigerian economy until 2028. The results in Fig. 10 spell out the impacts or effects of digitalization on the consumption of (domestic) economic agents. The results support and provide shreds of evidence in the favour of digitalization of the Nigerian economy.

In an actual sense, Fig. 11 further shows that the rich households' cohort would reduce their nominal consumption budget for increases in investment relative to the poor household cohorts. Another striking fact is that the decrease in the rich household cohort's nominal consumption budgets only lasts through the five-year gradual digitalization plan (2024–2028) and a year after (2029). From 2030, the rich household cohorts start to increase their nominal consumption budgets until 2033. This goes to show that the period from 2024 to 2029 becomes the seed-sowing period for the rich. However, as their seeds germinate and bear fruits (i.e. returns from

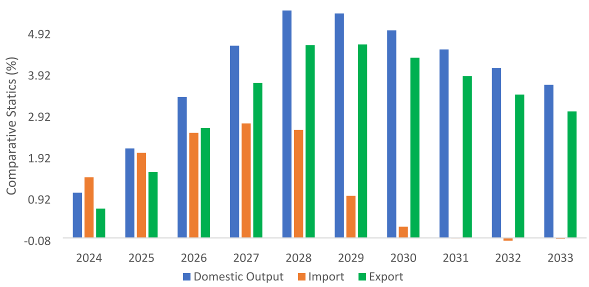

Fig. 8. Output and international trade.

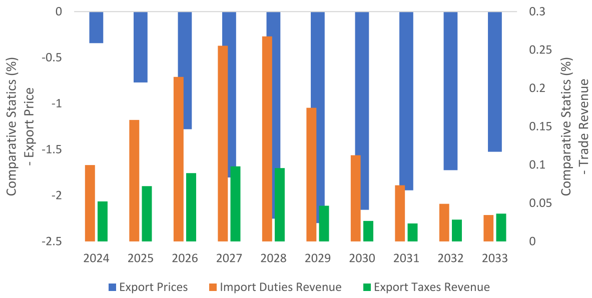

Fig. 9. International trade revenue & price.

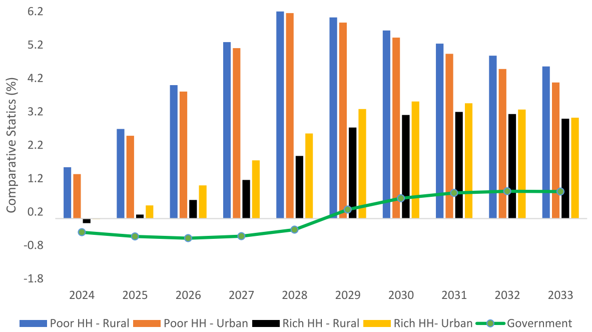

Fig. 10. Consumption (in units).

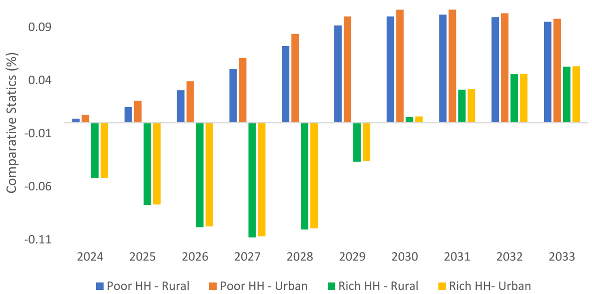

Fig. 11. Consumption budget/expenditure.

investments start to come in), the rich households are better positioned to increase their nominal budget consumption going forward. Also, these increases may very well surpass that of the poor household cohorts since the increases in the nominal consumption budget of the rich are additionally sustained by the returns on their preceding periods' investments.

That being said, it is equally important to point out that while the nominal budgets of the rich household cohorts decreased, their real consumption (Fig. 10) and real consumption budget (Fig. 12) increased due to the increases in their real income via the fall in the general price levels owing to the digitalization of the Nigerian economy. This practically suggests that the fall in the general price levels of goods and services outweighs the fall in the nominal consumption budget of the rich household cohorts as they seek to take advantage of the digitalization policy design in the Nigerian economy. Fig. 12 confirms that the real budget line of the (domestic) agents increased for all cohorts. In a nutshell, consumption increased for all households. However, the fall in aggregate prices results in increases in the real consumption budget of all households while only the nominal consumption budgets of the poor household cohorts increased and that of the rich decreased due to the increases in investment expenditure as the rich household cohorts seek to benefit from the digitalization-led investment opportunities.

The savings of all the domestic economic agents are presented in Fig. 13. Based on the results presented in Fig. 13, the poor household cohorts (urban and rural) increased their savings from the beginning to the end of the period. Conversely, the rich household cohorts (rural and urban), the firms, and governments initially sacrificed their savings for increases in their investment expenditure to take advantage of the digitalization-driven investment opportunities. For the government, their reduction in savings is explained by the increases in public investment expenditures and financing of the gradual digitalization investment program in the Nigerian economy. The rich household cohorts and the firms' decline in savings can be explained by the increases in private investment expenditure. After the gradual digitalization project, the savings for all the economic agents (households, firms, and government) increased and it was sponsored mainly by the returns on investments in the early periods of the study periods.

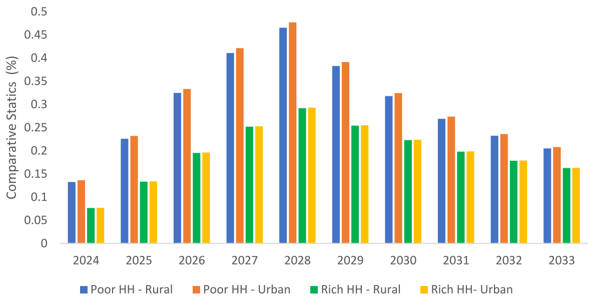

Fig. 12. Real consumption budget/expenditure.

So far, the results presented for the economic agents include consumption and savings. However, these two jointly define the income of the economic agents. As such, there is a need to also present the income of the economic agents. To this end, Fig. 14 presents the total income of the economic agents due to digitalization in the Nigerian economy. The income of the poor household cohorts (urban and rural) and the ROW increased throughout the study periods. However, that of the rich cohorts, firms and government decreased during the gradual digitalization investments periods and increased afterwards, given the increased economy's digitalization (re-)investments. That is to say that the rich households, firms, and governments increased and reinvested their incomes into the digitalization-led investment opportunities created in the economy. As such, the rich, firms and governments kept investing and reinvesting at the early stage or periods of the gradual digitalization package to increase their future earnings or incomes as shown in Fig. 14.

To better understand the state of the income of the economic agents through these study periods, Figs. 16 and 17 show the changes in capital and labour income of the economic agents due to the digitalization project respectively. Digitalization leads to a change in supply that shifts the capital supply curve to the right to create a new equilibrium that increases the equilibrium demand and supply for capital factor inputs (see Fig. 3) and decreases the price of capital, the rental rate of capital (see Fig. 15). As such, the capital income of the economic agents, which correlates positively with the rental rate of capital, also declined as shown in Fig. 16. Therefore, the fall in the capital income of the economic agents due to digitalization further explains the fall in the total income of the economic agents at the early stage of the gradual digitalization process. Hence, the rich household cohorts (urban and rural) financed their increases in investment (see Fig. 4) by decreasing their nominal consumption budgets (see Fig. 11) instead of their income (see Fig. 14).

On the other hand, as shown in Fig. 17, the labour income of the households (both rich, poor, rural, and urban) increased. This is practically intuitive because digitalization provides new online business platforms and opportunities. As such, more and more households tend to become self-employed entrepreneurs of online businesses such as creating online (comedy) content, online sells & delivery businesses, online stores, online training classes, etc. These then result in a leftward shift of the supply of labour for the conventional onsite real production of goods and services. As such, the equilibrium on-site labour supply and demand decreases (see Fig. 3) and increases the price of labour inputs (wage rates) as shown in Fig. 17. Based on the information represented in Fig. 15, it is clear that the growth in the wage rate of unskilled labour outweighs that of skilled labour. This is intuitive and evident in the fact that as labour supply shifts from the conventional onsite labour supply (as we know it) to online labour supply, specialized skills do not matter so much. In practice, it requires little or no skill to start and run most entrepreneurial online businesses. For instance, it requires very little or no specialized skillset to market products online via WhatsApp, Instagram, Facebook, Twitter, etc., chat with potential buyers, and deliver their orders to them. Another example is creating online content such as comedy skits. Long gone are the days one needs to acquire, at least, a degree in theatre art to be able to act or present roles in a script. Anybody can take on any assigned role(s) or script for an online comedy content creation skit. Besides, highly skilled labourers tend to shy away from or turn down such roles or opportunities, thereby, increasing the returns on labour (wage rates) for unskilled labour relatively more than their skilled labour counterparts.

Up to this stage, there have been different directional changes or comparative statics due to the gradual digitalization policy plan in

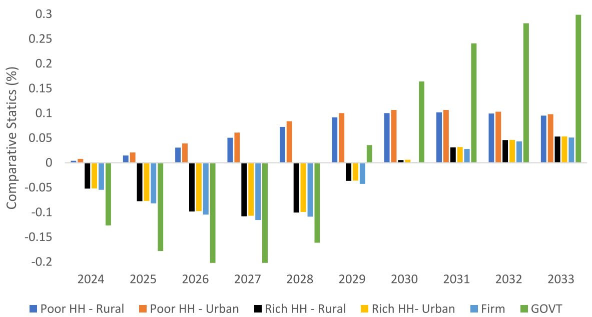

Fig. 13. Economic agents' savings.

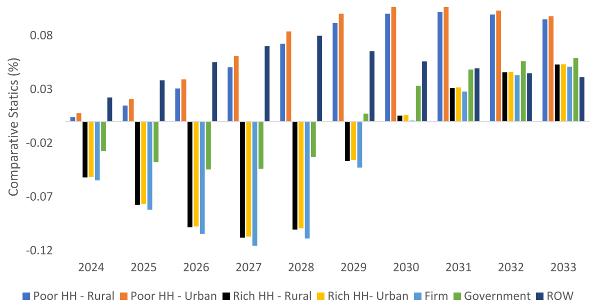

Fig. 14. Economic agents' income.

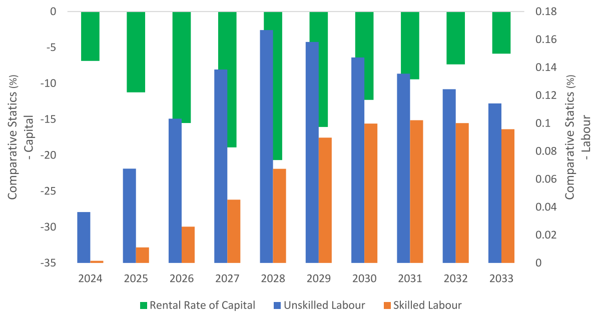

Fig. 15. Primary input prices.

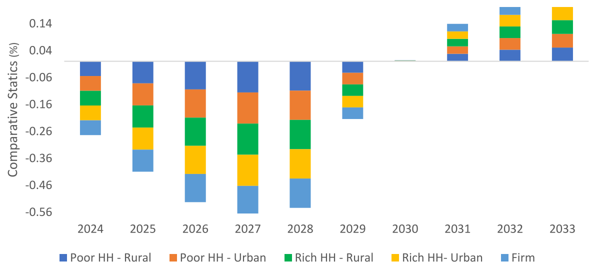

Figure 16: Economic Agents' Capital Income

Fig. 16. Economic agents' capital income.

Nigeria for the agents via consumption levels, consumption budgets, incomes (capital and labour), etc. It is, therefore, important to adopt an aggregate welfare measurement indicator for the agents which is capable of summarily dictating whether or not the economic agents are truly better off due to digitalization in Nigeria. Thus, the Hicksian Equivalent Variation (EV) is adopted to summarily measure the Nigerian agents, welfare given the gradual digitalization policy plan from 2024 to 2033. Fig. 18 presents the EV results for the study periods. Generally, the EV measures of welfare for the economic agents are all positive throughout the study periods. Positive EV welfare value translates to welfare improvements. As such, these positive welfare values from 2024 through 2033 signify that digitalization leaves the Nigerian economic agents well-off (or better-off) and not worse-off. Based on the results in Fig. 18, the urban household cohorts (rich and poor) are the happiest cohorts for the digitalization policy plan. This is mainly because settling in urban areas makes them better positioned to take diverse advantages of digitalization and the other several opportunities that come with digitalization. However, the EV welfare measure results also show that the government is not entirely well-off at the beginning of the gradual digitalization project until after 2028, the last year of the investment in digitalization. This is expected and mainly explained by the fact the government has to sacrifice some comfort to finance the gradual digitalization investment although the gradual 5-year digitalization investment plan. Moreover, the values in Fig. 18, are not percentage comparative statics but monetary values in billions of Nigerian Naira (₦). Typically and by definition, they represent the extra amount of money, in Nigerian Naira (₦), needed by the represented economic agents to maintain the post-digitalization level of utility at current prices. That is to say; without the digitalization policy plan, the represented Nigerian economic agents would need increases in their respective incomes, up to the values in Fig. 18, to maintain the same level of utility as implementing the gradual digitalization policy plan.

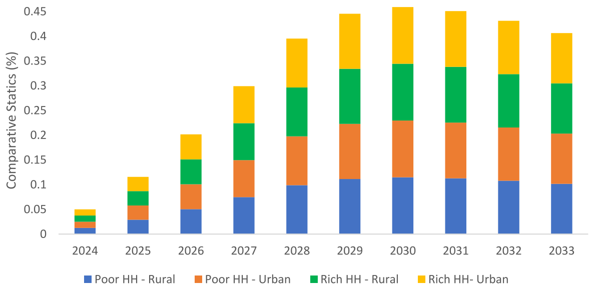

Fig. 17. Economic agents' labour income.

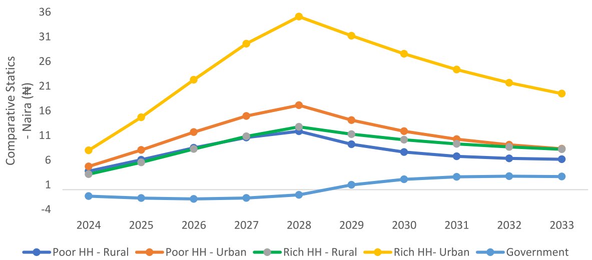

Fig. 18. Equivalent variation (EV) welfare measure.

4.2. *Energy and environmental impacts*

4.2.1. *Clean energy transitioning effects*

Digitalization has both economic and environmental effects on an economy. The environmental effect stems from the fact that while digitalization increases productivity and the national output level, it also increases the level of undesired output from productivity activities. These undesired outputs, in turn, adversely affect the environment. Hence, it is equally important to discuss the environmental effects of digitalization just like the economic effects. This undesired output is narrowed down to the emission of greenhouse gasses (mainly carbon dioxide) into the environment. The emission of carbon into the environment is dependent on the consumption of energy intermediate inputs. Despite the intrinsic difference between intermediate input energy consumption and demand, this study adopts energy demand as a proxy for energy consumption.

The total intermediate energy input demand is grouped into fossil fuel and electricity (renewable and non-renewable) as shown in Fig. 19. All through the gradual digitalization investment phase (2024–2028), there are significant increases in the consumption of electricity (renewable & non-renewable) energy input while that of fossil fuel substantially declined. This is a good outcome that champions the decarbonization and net-zero carbon emission prospects. In a nutshell, digitalization in the Nigerian economy is one of the leading drivers of the clean or renewable energy transitioning programme of Nigeria. The use of electricity as an alternative energy intermediate input for fossil fuel reduces carbon emissions. Moreover, a substantial portion of electricity is produced using fossil fuels. As such, this clean energy transitioning prospect, howbeit endogenously modelled in the EEICGE model, is not an end by itself but a means to an end.

Based on the results and findings in Fig. 19, it is evident that (significantly improved) digitalization can drive sustainable practices and thereby, have the potential to reduce carbon emissions at both the sectoral and economy aggregate levels. This implies that digitalization encourages increased demand for electricity and decreased demand for fossil fuels as intermediate inputs for production. As such, the industries gradually substitute their fossil fuel intermediate demands with electricity. These increased electricity demands translate into increased production and supply of electricity, produced from renewable and non-renewable energy sources. This substitution can lead to reduced carbon emissions during the production processes by the industries since less and less fossil fuels are

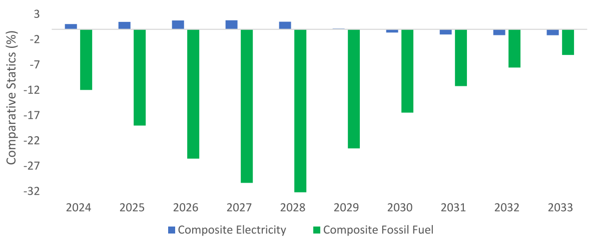

Fig. 19. Composite intermediate energy demand.

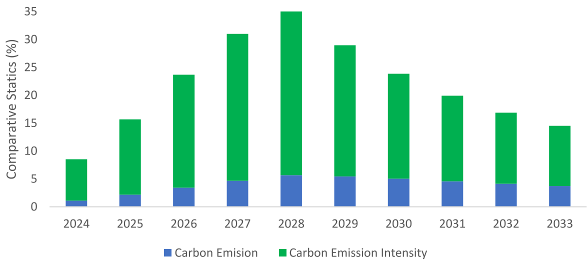

Fig. 20. Carbon emissions and intensities.

used during the production processes. On the aggregate level, Nigeria can experience a sustainable reduction in its level of carbon emissions. It is also important to mention that given that the fall in fossil fuel demands outweighs the fall in electricity demand after 2029, it is still the case that Nigeria can achieve reductions at both the sectoral and aggregate economy carbon emission levels. Based on the study results, there are heterogeneous effects of digitalization at the industrial level. That is, while some sectors experience decreases in their level of carbon emission, others have positive comparative statics. This confirms the possibilities of achieving sustainable practices for the industries and in turn, reducing greenhouse gas emissions in Nigeria.

4.2.2. Carbon emission and intensity effects

Fig. 20 summarily shows the level of carbon emission and carbon intensity due to the gradual digitalization in the Nigerian economy. The results show that digitalization increases the aggregate level of carbon emission in Nigeria. However, on a sectorial or industrial level, the changes in carbon emission due to digitalization vary and it's industry-specific. For instance, digitalization leads to decreases in carbon emissions for industries like Agriculture, Solid Minerals, Steel, Clothing, Electricity, Trade, Transportation, Finance, and Health but increases the emissions of industries like Oil & Gas Refining, Construction, Oil Extraction, etc. However, there is an overall increase in the aggregate level of carbon emission due to digitalization in the Nigerian economy. The same increase is also seen for carbon intensity due to digitalization. This suggests that the emission of greenhouse gasses (carbon) per production output increases due to digitalization. Even though the emissions of Nigeria and that of the African continent do not significantly contribute to the global level of emissions, this result is indicative of the fact that a lot still needs to be done to significantly reduce carbon emissions in Nigeria aside from digitalization.

Even when some industries experience reductions in carbon emissions due to their decreased intermediate demand for fossil fuels relative to electricity in production, at the aggregate level, Nigeria still has positive carbon emission comparative statics as shown in Fig. 20. However, it is important to point out that it could have been worse when all the industries increased their fossil fuel intermediate demands. Therefore, digitalization in Nigeria moves the economy closer to achieving its environmental and carbon abatement targets. Though Africa does not contribute substantially to the global carbon emission level, some African economies like Nigeria, pledge to take actions towards reducing their carbon emission level during the 2015 conference of the parties in Paris, France, the 2015 Paris Agreement[6] (Okorie & Wesseh, 2023). Particularly, Nigeria enacted the National Climate Change Policy (NCCP) plan to significantly reduce greenhouse gas emissions and socio-economic impacts of adverse climate change effects in Nigeria from 2021 to 2030. In terms of renewable energy plans, Nigeria enacted the Renewable Energy Master Plan (REMP) that seeks to increase the production and supply of renewable electricity from 13% to 36% of total electricity generation by 2030. Our results show that digitalization takes Nigeria forward towards the actualization of its energy policy, REMP, and the environmental & climate change policy, NCCP. Therefore, these results and findings confirm the role of digitalization in clean and renewable energy development just like the study by Chen (2022).

Concerning existing studies that examine the effects of digitalization using a general equilibrium model, this study confirms that digitalization increases the level of national output as shown by Zhang, Shinozuka, et al. (2021), Lim et al. (2021), Yeo et al. (2023), and Yeo & Jung (2024). However, while Zhang, Shinozuka, et al. (2021) show that digitalization leads to a reduction in carbon emissions in Japan, this study shows that the carbon emission comparative statics for Nigeria increases at a decreasing rate. This is mainly due to the different levels of renewable and fossil fuel energies in Japan and Nigeria. Similarly, the findings of this study agree with that of Xing et al. (2011) that digitalization strengthens the (consumption) demand of the economic agents and the aggregate demand of the economy. Furthermore, this study shows that digitalization improves international trade as shown by Lim et al. (2021). While Gomez-Plana and Latorre (2015) show that there are no threats to employment due to digitalization, this study confirms that this is true for labour and capital given the increased labour and capital income levels by the economic agents. In the same light, Balsmeier and Woerter (2019) and Yeo & Jung (2024) find that digitalization increases the employment of high-skilled workers but reduces the employment of low-skilled workers albeit at a minute net positive effect in Switzerland. On the contrary, this study also confirms that digitalization increases the employment of high-skilled labour or workers and that of the low-skilled workers in Nigeria, which agrees with the findings of Yeo et al. (2023). This difference mainly stems from the diverse levels of economic development in Switzerland and Nigeria.

[6] See the United Nations (UN) page about Climate Action: https://www.un.org/en/climatechange/paris-agreement.

Generally, two different approaches are used to perform sensitivity and robustness checks in a CGE model. These are the Monte Carlo and Range approaches. While the Monte Carlo approach assigns random values, the ran approach adopts a range or intervals to check the robustness of the model predictions on the parameter changes. In this study, the range approach is used to perform a couple of robustness and sensitivity checks by varying the CES substitution elasticities around the initial set elasticities (Okorie, 2017, 2021; Okorie & Lin, 2024; Okorie & Wesseh, 2024). Particularly, the elasticity parameters for each sector were changed (increased and decreased) by 5 percentage points (see Appendix). This guarantees that the factor inputs remain suitable substitutes. For each of the altered elasticity parameters, the study simulation designs were performed, and the comparative static results remain approximately equal to the original results both in magnitudes and directions. This reaffirms that the findings are reliable, robust and insensitive to the elasticity parameters.

5. Conclusions and policy implications

The impact of technologically driven change or digitalization has been analyzed over time from varying perspectives and with differing representations of an adequate measure of aggregate digital impact on an economy. The literature on the inevitable adoption of digitalization recognizes heterogeneity in the impact largely due to varying levels of adoption. For instance, the positive effect of digitalization on aggregate income levels is more pronounced in developing economies than is the case in more developed economies. This study has summarized the literature on the impact of digitalization and digital technology on economic indicators, GDP growth, trade, prices, energy efficiency and emissions. Whereas actual analysis investigated the impact of digitalization on an African economic leader (the Nigerian economy) with emphasis on the economic and environmental effects of digitalization. The integrated computation showed that digitalization results in mostly positive effects on the Nigerian economy despite the increases in unemployment resulting from the creative destruction of jobs by the digitalization of production processes with inputs such as machine-based technologies, the internet of things, artificial intelligence, robots and 3D printing. Government-supported investments to ensure widespread adoption of digitalization resulted in increased economic growth. Increased economic output also came at a digitalization-influenced reduction in cost, thus implying downward pressures on inflation and overall prices. The expected outcome of such realizations is a strengthening of the country's capability in multilateral trade with cheaper and competitive exports. Receipts from export taxes and increased import duties should result in a net positive effect on revenues for the government. This is because revenue losses from reductions in export prices are offset by increased volumes of exported goods and services.

The study also finds that digitalization leaves economic agents in a better position than not. Urban denizens (rich and poor) realize greater benefits of a national digitalization plan than do their rural counterparts. This is expected since infrastructural investments are usually concentrated in urban areas with a relatively denser and more lucrative market. A clean energy transition initiative that adopts electricity as an alternative energy input to fossil fuels should reduce carbon emissions. However, most electricity is generated using fossil fuels and may net out the clean energy gains from adopting electricity as a primary energy input. That notwithstanding, it is worth noting that the Nigerian electricity generation mix is largely dominated by natural gas-powered plants (a cleaner alternative to coal-powered plants) and hydroelectric dams and as such may preserve the benefits of such a transition. Digitalization results in reductions in emissions in most sectors of the economy but increases in emissions for both the crude oil mining & refining and construction industries. It is also noteworthy to highlight that digitalizing the Nigerian economy leads to increased capital demand both at the industrial and aggregate economy levels. The use of this increased capital entails increased demand for skilled labour relative to unskilled labour services. By implication, the Nigerian government and authorities should target increased skill acquisition and development programs to match the increased employment opportunities that digitalizing Nigeria offers. These programs ought to target mostly the use of high technologies and machines to match the digital demands of firms and businesses as a result of digitalizing Nigeria.

The adverse effects of digitalization are mostly surmountable and can be mitigated in other cases. There remains a role to be played by policymakers and well-crafted regulations to address challenges emanating from the proliferation of digitalization (Wen et al., 2022). The unemployment effect, particularly on unskilled labour, can be alleviated by stakeholders intervening to make the necessary investments to train the labour force for the skills required for the future of work. The government's investments in realizing adequate digitalization for the economy may result in adverse effects on its welfare initially but overall benefits in the long run. These investments can be directed towards ensuring that the proximity deficiency of rural households to digital technologies is limited over time. Also, investments can be directed towards providing reliable electricity supply at internationally regarded standards with most added generating capacity being clean and void of economic detriment. As such, policyholders and stakeholders alike can position the Nigerian economy to realize significant economic benefits from a well-implemented national digitalization plan.

There are some study limitations encountered during this study. One of these limitations is around the Social Accounting Matrix (SAM) of Nigeria and its background construction information. Without such details, it was not feasible to take the result analysis further to examine the transition mechanism of the disaggregated households into different categories in the face of increases in income due to digitalization. For instance, it would be interesting to examine the different numbers of households that transition to rich households from poor households both in the rural and urban areas due to their increased income given digitalization. Similarly, one could also examine how many households become educated or increase their education levels due to their increased income given digitalization. Similar other categorizations such as digitalization access, could also be employed for similar analysis. Secondly, modelling assumptions can also translate into limitations, for example, in the energy and environment block of the EEICGE model, a 10% carbon abatement or efficiency rate is assumed based on Nigeria's National Climate Change Policy (NCCP) plan and target even when the plan does not explicitly state a carbon abatement rate but itemized actionable steps towards abating significant greenhouse gas emissions in Nigeria.

CRediT authorship contribution statement

David Iheke Okorie: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Adeniran Adedeji:** Validation, Supervision, Resources, Project administration, Investigation, Conceptualization. **Chinedu Ifionu:** Writing – original draft, Resources, Project administration, Investigation, Conceptualization.

Appendix

Table A
Employment - Primary Factor Inputs

	"+" 5% points change			"-" 5% points change		
	Unskilled Labour	Skilled Labour	Capital	Unskilled Labour	Skilled Labour	Capital
2024	8.066	13.227		8.719	13.576	
2025	7.619	12.882	8.261	7.489	12.388	8.407
2026	5.367	10.666	12.255	5.422	10.315	12.544
2027	4.295	9.576	16.914	4.505	9.356	16.335
2028	4.379	9.600	18.183	4.722	9.500	18.723
2029	3.594	8.720	15.028	3.051	8.731	15.670
2030	2.797	7.655	12.433	2.472	7.035	12.161
2031	2.481	6.164	10.756	2.075	6.469	10.194
2032	2.152	6.651	8.932	2.827	6.045	8.204
2033	1.820	5.125	7.948	1.561	5.595	7.082

Table B
Interest Rate and Investment Prices

	"+" 5% points change		"-" 5% points change	
	Interest Rate	Investment Prices	Interest Rate	Investment Prices
2024	−0.147	0.027	−0.151	0.028
2025	−0.233	0.037	−0.240	0.039
2026	−0.315	0.043	−0.325	0.045
2027	−0.375	0.041	−0.387	0.043
2028	−0.399	0.031	−0.413	0.033
2029	−0.290	−0.007	−0.300	−0.007
2030	−0.208	−0.031	−0.216	−0.031
2031	−0.150	−0.043	−0.157	−0.044
2032	−0.112	−0.049	−0.118	−0.050
2033	−0.088	−0.051	−0.093	−0.052

Table C
Aggregate Price Indexes

	"+" 5% points change		"-" 5% points change	
	CPI	Deflator	CPI	Deflator
2024	−0.147	0.027	−0.151	0.028
2025	−0.233	0.037	−0.240	0.039
2026	−0.315	0.043	−0.325	0.045
2027	−0.375	0.041	−0.387	0.043
2028	−0.399	0.031	−0.413	0.033
2029	−0.290	−0.007	−0.300	−0.007
2030	−0.208	−0.031	−0.216	−0.031
2031	−0.150	−0.043	−0.157	−0.044
2032	−0.112	−0.049	−0.118	−0.050
2033	−0.088	−0.051	−0.093	−0.052

Table D
Real Domestic Output

	"+" 5% points change		"-" 5% points change	
	Real GDP @ Basic Price	Real GDP @ Market Price	Real GDP @ Basic Price	Real GDP @ Market Price
2024	0.033	0.069	0.032	0.069
2025	0.063	0.121	0.061	0.121
2026	0.100	0.178	0.098	0.179
2027	0.138	0.231	0.136	0.232

(*continued on next page*)

Table D (*continued*)

	"+" 5% points change		"-" 5% points change	
	Real GDP @ Basic Price	Real GDP @ Market Price	Real GDP @ Basic Price	Real GDP @ Market Price
2028	0.171	0.269	0.169	0.271
2029	0.173	0.237	0.172	0.238
2030	0.170	0.211	0.170	0.212
2031	0.165	0.190	0.165	0.190
2032	0.158	0.173	0.159	0.173
2033	0.150	0.159	0.151	0.159

Table E
Sectorial Growth of Digitalization

	"+" 5% points change												
	FBT	TAF	OTHI	ELE	OTU	TRD	TRAN	FIS	REPA	EDU	HLT	OSER	TELC
2025	0.021	0.011	0.024	0.021	0.058	0.015	0.023	0.013	0.043	0.034	0.018	0.034	8.275
2026	0.056	0.029	0.062	0.057	0.141	0.042	0.061	0.036	0.108	0.086	0.047	0.087	11.551
2027	0.106	0.055	0.113	0.107	0.243	0.082	0.110	0.070	0.191	0.154	0.089	0.154	14.057
2028	0.166	0.087	0.171	0.170	0.352	0.134	0.167	0.114	0.281	0.230	0.140	0.225	14.984
2029	0.229	0.123	0.231	0.237	0.450	0.191	0.223	0.163	0.364	0.301	0.195	0.290	10.024
2030	0.269	0.150	0.267	0.287	0.476	0.237	0.250	0.203	0.392	0.331	0.236	0.307	6.583
2031	0.291	0.168	0.285	0.320	0.460	0.268	0.258	0.230	0.387	0.333	0.264	0.299	4.284
2032	0.301	0.180	0.290	0.339	0.425	0.286	0.254	0.246	0.364	0.317	0.280	0.279	2.788
2033	0.304	0.186	0.287	0.348	0.382	0.292	0.242	0.252	0.333	0.293	0.287	0.255	1.830
	"-" 5% points change												
	FBT	TAF	OTHI	ELE	OTU	TRD	TRAN	FIS	REPA	EDU	HLT	OSER	TELC
2025	0.022	0.011	0.024	0.023	0.059	0.015	0.023	0.013	0.044	0.036	0.019	0.034	8.300
2026	0.059	0.030	0.063	0.061	0.143	0.044	0.061	0.036	0.111	0.091	0.051	0.089	11.586
2027	0.112	0.057	0.114	0.114	0.248	0.086	0.111	0.071	0.196	0.162	0.095	0.157	14.093
2028	0.175	0.090	0.174	0.180	0.359	0.139	0.168	0.116	0.289	0.240	0.149	0.230	15.018
2029	0.240	0.127	0.235	0.252	0.459	0.199	0.224	0.167	0.374	0.313	0.207	0.296	9.955
2030	0.279	0.155	0.271	0.304	0.484	0.247	0.252	0.208	0.401	0.342	0.250	0.312	6.471
2031	0.300	0.173	0.290	0.339	0.468	0.279	0.259	0.236	0.393	0.340	0.277	0.303	4.167
2032	0.308	0.185	0.295	0.358	0.431	0.297	0.254	0.251	0.368	0.321	0.292	0.282	2.685
2033	0.308	0.190	0.292	0.367	0.387	0.303	0.242	0.256	0.336	0.295	0.298	0.257	1.749

Table F
Output and International Trade

	"+" 5% points change			"-" 5% points change		
	Domestic Output	Import	Export	Domestic Output	Import	Export
2024	1.102	1.450	0.715	1.082	1.486	0.699
2025	2.173	2.027	1.602	2.153	2.086	1.587
2026	3.418	2.504	2.662	3.399	2.580	2.652
2027	4.655	2.726	3.748	4.641	2.812	3.745
2028	5.650	2.568	4.658	5.646	2.655	4.666
2029	5.425	1.005	4.671	5.428	1.033	4.687
2030	5.017	0.266	4.350	5.019	0.275	4.361
2031	4.557	−0.018	3.912	4.555	−0.010	3.913
2032	4.110	−0.074	3.467	4.104	−0.060	3.461
2033	3.705	−0.031	3.065	3.697	−0.012	3.054

Table G
International Trade Revenue & Price

	"+" 5% points change			"-" 5% points change		
	Export Prices	Import Duties Revenue	Export Taxes Revenue	Export Prices	Import Duties Revenue	Export Taxes Revenue
2024	−0.347	0.099	0.051	−0.339	0.100	0.053
2025	−0.775	0.157	0.071	−0.766	0.160	0.073
2026	−1.283	0.213	0.088	−1.276	0.217	0.090
2027	−1.806	0.253	0.097	−1.802	0.257	0.099
2028	−2.253	0.266	0.094	−2.253	0.270	0.097
2029	−2.297	0.174	0.046	−2.303	0.175	0.047
2030	−2.154	0.113	0.027	−2.159	0.112	0.027
2031	−1.944	0.074	0.023	−1.944	0.073	0.024
2032	−1.726	0.050	0.028	−1.723	0.048	0.029
2033	−1.528	0.035	0.035	−1.522	0.034	0.037

Table H
Consumption (in units)

	"+" 5% points change					"-" 5% points change				
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Govt	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Govt
2024	1.487	1.290	−0.111	0.011	−0.399	1.590	1.373	−0.164	−0.040	−0.421
2025	2.584	2.395	0.163	0.434	−0.518	2.788	2.568	0.077	0.356	−0.554
2026	3.842	3.669	0.611	1.044	−0.566	4.160	3.944	0.498	0.943	−0.611
2027	5.076	4.921	1.221	1.798	−0.504	5.509	5.301	1.088	1.682	−0.554
2028	6.073	5.924	1.943	2.606	−0.309	6.608	6.397	1.804	2.488	−0.358
2029	5.771	5.643	2.769	3.313	0.280	6.295	6.110	2.680	3.241	0.259
2030	5.394	5.207	3.131	3.529	0.610	5.889	5.644	3.069	3.479	0.604
2031	5.016	4.739	3.217	3.473	0.768	5.478	5.141	3.168	3.430	0.766
2032	4.670	4.301	3.150	3.283	0.818	5.101	4.669	3.108	3.242	0.817
2033	4.362	3.912	3.009	3.041	0.808	4.765	4.250	2.971	3.000	0.806

Table I
Consumption Budget/Expenditure

	"+" 5% points change				"-" 5% points change			
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	PHH Rural	PHH Urban	RHH Rural	RHH Urban
2024	0.003	0.006	−0.051	−0.050	0.005	0.009	−0.053	−0.053
2025	0.012	0.018	−0.075	−0.075	0.018	0.024	−0.080	−0.079
2026	0.026	0.034	−0.095	−0.094	0.035	0.045	−0.102	−0.101
2027	0.044	0.054	−0.104	−0.103	0.057	0.069	−0.112	−0.111
2028	0.064	0.075	−0.096	−0.095	0.081	0.093	−0.105	−0.104
2029	0.083	0.091	−0.034	−0.033	0.101	0.110	−0.039	−0.038
2030	0.092	0.097	0.007	0.007	0.109	0.117	0.004	0.004
2031	0.094	0.098	0.032	0.033	0.111	0.116	0.030	0.031
2032	0.092	0.095	0.046	0.047	0.108	0.112	0.045	0.045
2033	0.088	0.090	0.054	0.054	0.103	0.106	0.052	0.052

Table J
Real Consumption Budget/Expenditure

	"+" 5% points change				"-" 5% points change			
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	PHH Rural	PHH Urban	RHH Rural	RHH Urban
2024	0.130	0.134	0.077	0.077	0.135	0.139	0.076	0.077
2025	0.221	0.227	0.134	0.134	0.231	0.237	0.133	0.133
2026	0.317	0.325	0.196	0.197	0.332	0.341	0.195	0.196
2027	0.401	0.411	0.253	0.253	0.421	0.432	0.251	0.252
2028	0.454	0.464	0.293	0.294	0.477	0.490	0.291	0.292
2029	0.373	0.380	0.255	0.256	0.394	0.403	0.253	0.254
2030	0.309	0.315	0.224	0.225	0.327	0.335	0.222	0.222
2031	0.261	0.265	0.199	0.200	0.277	0.283	0.197	0.197
2032	0.225	0.228	0.180	0.180	0.240	0.244	0.177	0.178
2033	0.198	0.201	0.164	0.164	0.212	0.215	0.162	0.162

Table K
Economic Agents' Savings

"+" 5% points change						
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm	Govt
2025	0.003	0.006	−0.051	−0.050	−0.053	−0.123
2026	0.012	0.018	−0.075	−0.075	−0.079	−0.172
2027	0.026	0.034	−0.095	−0.094	−0.101	−0.204
2028	0.044	0.054	−0.104	−0.103	−0.111	−0.202
2029	0.064	0.075	−0.096	−0.095	−0.104	−0.152
2030	0.083	0.091	−0.034	−0.033	−0.040	0.040
2031	0.092	0.097	0.007	0.007	0.003	0.165
2032	0.094	0.098	0.032	0.033	0.029	0.240
2033	0.092	0.095	0.046	0.047	0.044	0.281
	"-" 5% points change					
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm	Govt
2025	0.005	0.009	−0.053	−0.053	−0.056	−0.130
2026	0.018	0.024	−0.080	−0.079	−0.085	−0.184
2027	0.035	0.045	−0.102	−0.101	−0.108	−0.220

(continued on next page)

Table K (*continued*)

"+" 5% points change						
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm	Govt
2028	0.057	0.069	−0.112	−0.111	−0.120	−0.220
2029	0.081	0.093	−0.105	−0.104	−0.114	−0.171
2030	0.101	0.110	−0.039	−0.038	−0.046	0.032
2031	0.109	0.117	0.004	0.004	0.001	0.163
2032	0.111	0.116	0.030	0.031	0.026	0.241
2033	0.108	0.112	0.045	0.045	0.042	0.283

Table L
Economic Agents' Income

"+" 5% points change							
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm	Govt	ROW
2025	0.003	0.006	−0.051	−0.050	−0.053	−0.027	0.023
2026	0.012	0.018	−0.075	−0.075	−0.079	−0.037	0.039
2027	0.026	0.034	−0.095	−0.094	−0.101	−0.043	0.056
2028	0.044	0.054	−0.104	−0.103	−0.111	−0.042	0.071
2029	0.064	0.075	−0.096	−0.095	−0.104	−0.031	0.081
2030	0.083	0.091	−0.034	−0.033	−0.040	0.008	0.067
2031	0.092	0.097	0.007	0.007	0.001	0.033	0.057
2032	0.094	0.098	0.032	0.033	0.029	0.048	0.050
2033	0.092	0.095	0.046	0.047	0.044	0.056	0.046
"-" 5% points change							
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm	Govt	ROW
2025	0.005	0.009	−0.053	−0.053	−0.056	−0.028	0.022
2026	0.018	0.024	−0.080	−0.079	−0.085	−0.039	0.038
2027	0.035	0.045	−0.102	−0.101	−0.108	−0.046	0.054
2028	0.057	0.069	−0.112	−0.111	−0.120	−0.046	0.069
2029	0.081	0.093	−0.105	−0.104	−0.114	−0.035	0.078
2030	0.101	0.110	−0.039	−0.038	−0.046	0.006	0.064
2031	0.109	0.117	0.004	0.004	0.001	0.033	0.055
2032	0.111	0.116	0.030	0.031	0.026	0.048	0.048
2033	0.108	0.112	0.045	0.045	0.042	0.056	0.044

Table M
Primary Input Prices

	"+" 5% points change			"-" 5% points change		
	Unskilled Labour	Skilled Labour	Rental Rate of Capital	Unskilled Labour	Skilled Labour	Rental Rate of Capital
2024	0.035	0.001	−6.801	0.038	0.004	−6.943
2025	0.065	0.007	−11.122	0.070	0.015	−11.381
2026	0.099	0.019	−15.343	0.108	0.033	−15.700
2027	0.132	0.036	−18.699	0.145	0.055	−19.134
2028	0.159	0.056	−20.437	0.175	0.079	−20.924
2029	0.150	0.078	−15.918	0.167	0.102	−16.238
2030	0.139	0.089	−12.206	0.156	0.112	−12.404
2031	0.127	0.092	−9.376	0.144	0.113	−9.500
2032	0.117	0.091	−7.311	0.133	0.110	−7.397
2033	0.107	0.087	−5.837	0.122	0.105	−5.908

Table N
Economic Agents' Capital Income

	"+" 5% points change					"-" 5% points change				
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Firm
2024	−0.053	−0.053	−0.053	−0.053	−0.053	−0.056	−0.056	−0.056	−0.056	−0.056
2025	−0.079	−0.079	−0.079	−0.079	−0.079	−0.085	−0.085	−0.085	−0.085	−0.085
2026	−0.101	−0.101	−0.101	−0.101	−0.101	−0.108	−0.108	−0.108	−0.108	−0.108
2027	−0.111	−0.111	−0.111	−0.111	−0.111	−0.120	−0.120	−0.120	−0.120	−0.120
2028	−0.104	−0.104	−0.104	−0.104	−0.104	−0.114	−0.114	−0.114	−0.114	−0.114
2029	−0.040	−0.040	−0.040	−0.040	−0.040	−0.046	−0.046	−0.046	−0.046	−0.046
2030	0.003	0.003	0.003	0.003	0.003	0.001	0.001	0.001	0.001	0.001
2031	0.029	0.029	0.029	0.029	0.029	0.026	0.026	0.026	0.026	0.026
2032	0.044	0.044	0.044	0.044	0.044	0.042	0.042	0.042	0.042	0.042
2033	0.052	0.052	0.052	0.052	0.052	0.050	0.050	0.050	0.050	0.050

Table O
Economic Agents' Labour Income

	"+" 5% points change				"-" 5% points change			
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	PHH Rural	PHH Urban	RHH Rural	RHH Urban
2024	0.011	0.011	0.011	0.011	0.014	0.014	0.014	0.014
2025	0.025	0.025	0.025	0.025	0.033	0.033	0.033	0.033
2026	0.045	0.045	0.045	0.045	0.057	0.057	0.057	0.057
2027	0.067	0.067	0.067	0.067	0.083	0.083	0.083	0.083
2028	0.089	0.089	0.089	0.089	0.110	0.110	0.110	0.110
2029	0.101	0.101	0.101	0.101	0.123	0.123	0.123	0.123
2030	0.105	0.105	0.105	0.105	0.126	0.126	0.126	0.126
2031	0.103	0.103	0.103	0.103	0.123	0.123	0.123	0.123
2032	0.099	0.099	0.099	0.099	0.117	0.117	0.117	0.117
2033	0.094	0.094	0.094	0.094	0.110	0.110	0.110	0.110

Table P
Equivalent Variation (EV) Welfare Measure

	"+" 5% points change					"-" 5% points change				
	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Govt	PHH Rural	PHH Urban	RHH Rural	RHH Urban	Govt
2024	3.657	4.611	3.146	7.991	−1.283	3.828	4.793	3.115	7.927	−1.347
2025	5.893	7.859	5.549	14.683	−1.662	6.214	8.216	5.509	14.636	−1.758
2026	8.248	11.392	8.257	22.287	−1.822	8.725	11.936	8.202	22.252	−1.937
2027	10.258	14.572	10.833	29.584	−1.630	10.884	15.298	10.764	29.565	−1.749
2028	11.468	16.681	12.773	35.061	−1.005	12.221	17.562	12.696	35.066	−1.110
2029	8.883	13.709	11.298	31.234	0.979	9.542	14.494	11.180	31.144	0.977
2030	7.327	11.498	10.172	27.607	2.074	7.929	12.203	10.041	27.442	2.115
2031	6.476	9.914	9.334	24.435	2.574	7.048	10.562	9.209	24.222	2.622
2032	6.063	8.798	8.710	21.773	2.710	6.623	9.407	8.600	21.535	2.748
2033	5.895	8.008	8.230	19.578	2.646	6.447	8.588	8.137	19.332	2.668

Table Q
Composite Intermediate Energy Demand

	"+" 5% points change		"-" 5% points change	
	Composite Electricity	Composite Fossil Fuel	Composite Electricity	Composite Fossil Fuel
2024	1.059	−11.753	1.034	−12.218
2025	1.502	−18.631	1.437	−19.416
2026	1.814	−25.033	1.692	−26.088
2027	1.881	−29.732	1.691	−30.992
2028	1.621	−31.596	1.363	−32.974
2029	0.294	−23.045	−0.025	−24.015
2030	−0.474	−16.136	−0.806	−16.790
2031	−0.862	−10.997	−1.180	−11.451
2032	−1.014	−7.380	−1.306	−7.727
2033	−1.032	−4.926	−1.295	−5.224

Table R
Carbon Emissions and Intensities

	"+" 5% points change		"-" 5% points change	
	Carbon Emission	Carbon Emission Intensity	Carbon Emission	Carbon Emission Intensity
2024	1.104	7.399	1.085	7.466
2025	2.178	13.410	2.158	13.588
2026	3.426	20.113	3.409	20.406
2027	4.667	26.137	4.654	26.530
2028	5.665	29.734	5.663	30.175
2029	5.441	23.441	5.447	23.593
2030	5.033	18.811	5.037	18.818
2031	4.572	15.369	4.572	15.307
2032	4.124	12.790	4.120	12.700
2033	3.719	10.843	3.711	10.746

Data availability

Data will be made available on request.

References

Abendin, S., Pingfang, D., & Nkukpornu, E. (2022). Bilateral trade in West Africa: Does digitalization matter? *International Trade Journal, 36*(6), 477–501.
Adera, E. O., Waema, T. M., & May, J. D. (Eds.). (2014). *ICT pathways to poverty reduction: Empirical evidence from East and Southern Africa*. IDRC.
Anyim, W. O. (2021). Twitter ban in Nigeria: Implications on economy, freedom of Speech and information sharing. *Library Philosophy and Practice, 0*, 1–13.
Ayakwah, A., Damoah, I. S., & Osabutey, E. L. C. (2021). Digitalization in Africa: The case of public programs in Ghana. In J. B. Abugre, L. C, E. P. Osabutey, & S. Sigué (Eds.), *Business in Africa in the era of digital technology. Advances in theory and practice of emerging markets*. Cham: Springer. https://doi.org/10.1007/978-3-030-70538-1_2.
Babatunde, O. A. (2013). Impact of economic reform on the Nigerian telecommunications Sector. *Advances in Management and Applied Economics, 3*(3), 141.
Balogun, A. L., Marks, D., Sharma, R., Shekhar, H., Balmes, C., Maheng, D., et al. (2020). Assessing the potentials of digitalization as a tool for climate change adaptation and sustainable development in urban centres. *Sustainable Cities and Society, 53*, Article 101888.
Balsmeier, B., & Woerter, M. (2019). Is this time different? How digitalization influences job creation and destruction. *Research Policy, 48*(8), Article 103765.
Barefoot, K., Curtis, D., Jolliff, W., Nicholson, J. R., & Omohundro, R. (2018). *Defining and measuring the digital economy* (Vol. 15). Washington, DC: US Department of Commerce Bureau of Economic Analysis.
Baumüller, H., & Addom, B. K. (2020). The enabling environments for the digitalization of African agriculture. *2020 annual trends and outlook report: Sustaining Africa's agrifood system transformation: The role of public policies* (pp. 159–173).
Burfisher, M. (2017). *Introduction to computable general equilibrium models* (2nd ed.). Cambridge University Press.
Burniaux, J.-M., & Truong, T. P. (2022). *GTAP-E: An energy-environment version of the GTAP model*. West Lafayette, Indiana, USA: Center for Global Trade Analysis, Purdue University.
Charbonneau, K. B., Evans, A., Sarker, S., & Suchanek, L. (2017). *Digitalization and inflation: A review of the literature*.
Chen, P. (2022). Is the digital economy driving clean energy development?-New evidence from 276 cities in China. *Journal of Cleaner Production, 372*, Article 133783.
Csonto, B., Huang, Y., & Tovar, C. (2019). *Is digitalization driving domestic inflation? Washington D.C*. United States of America: International Monetary Fund (IMF) Working Paper. WP/19/271.
Czernich, N., Falck, O., Kretschmer, T., & Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal, 121*(552), 505–532.
Da Piedade, C. (2022). *Digital connectedness and exports upgrading: Is sub-Saharan Africa catching up?*. No. hal-03819047).
Edward, J., & Malecki, B. M. (2007). The digital economy. *Business Organization Production Processes and Regional Developments*.
Fujimori, S., Hasegawa, T., & Masui, T. (2017). AIM/CGE V2.0: Basic feature of the model. In S. Fujimori, M. Kainuma, & T. Masui (Eds.), *Post-2020 climate action* (pp. 305–328). Singapore: Springer.
Gartner. (2017). *The gartner 2018 CIO Agenda industry insights l gartner*. Inc.
Gillett, S. E., Lehr, W. H., Osorio, C. A., & Sirbu, M. A. (2006). *Measuring the impact of broadband deployment*. Washington, DC: Prepared for the US Department of Commerce, Economic Development Administration.
Giuliani, D., & Ajadi, S. (2019). 618 active tech hubs: The backbone of Africa's tech ecosystem. *Ecosystem Accelerator*.
Gomez-Plana, A., & Latorre, M. C. (2015). *The impact of foreign multinationals in ICT sectors: A CGE evaluation*.
Habibi, F., & Zabardast, M. A. (2020). Digitalization, education and economic growth: A comparative analysis of Middle East and OECD countries. *Technology in Society, 63*, Article 101370.
Hernandez, K., Faith, B., Prieto Martín, P., & Ramalingam, B. (2016). The impact of digital technology on economic growth and productivity, and its implications for employment and equality: An evidence review. *IDS evidence report 207*. Brighton: IDS.
Hilty, L., & Bieser, J. (2017). *Opportunities and risks of digitalization for climate protection in Switzerland*.
Iddrisu, A. G., & Chen, B. (2022). Economic growth through digitalization in Africa: Does financial sector development play a mediating role? *International Journal of Emerging Markets*. https://doi.org/10.1108/IJOEM-02-2022-0278
Iraoya, A., Onyekwena, C., Okorie, D., & Adeniran, A. (2024). Evaluation of the effects of African continental free trade area (AfCFTA) on Africa's biodiversity. *The Global Development Network Working Paper Series No.: 92*.
Iyatse, G., & Adepetun, A. (2021). $12b e-commerce suffers as Twitter ban costs N7.5 billion in three days. *The Guardian, 37*(15, 502), 1–2.
Jaiyeola, T. (2024). *Telcos bet big on Nigeria with N732bn investment in 2023*. Nigeria: Business Day. https://businessday.ng/technology/article/telcos-bet-big-on-nigeria-with-n732bn-investment/.
Karonnon, P., & Rajeev, M. (2023). *The role of telecommunication service sector in Indian economy - an analysis of the output and employment linkages*. Karnataka, India: Institute for Social and Economic Change (ISEC).
Kohnert, D. (2021). *The impact of digitalization on poverty alleviation in Africa*. https://doi.org/10.2139/ssrn.3944941. October 20.
Lee, M.-C., & Su, L.-E. (2014). Social accounting Matrix balanced based on Mathematical optimization method and general Algebraic modeling <CITEREF RID="vrpa-25-04-18-Hall1">ystem. *British Journal of Economics, Management & Trade, 4*(8), 1174–1190.
Lemelin, A., & Decaluwe, B. (2007). Issues in recursive dynamic CGE modeling: Investment by destination, savings, and public debt. A survey. *Poverty and Economic Policy Network, Universite Laval, Quebec*.
Li, Y., Yang, X., Ran, Q., Wu, H., Irfan, M., & Ahmad, M. (2021). Energy structure, digital economy, and carbon emissions: Evidence from China. *Environmental Science and Pollution Research, 28*, 64606–64629.
Lim, J., Toh, M., & Xie, T. (2021). Impact of digital economy agreements on ASEAN development: Estimates from a CGE model. *Presented during the 25th annual conference on global economic analysis (virtual conference)). Purdue university*. West Lafayette: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6617.
Loo, B. P., & Ngan, Y. L. (2012). Developing mobile telecommunications to narrow digital divide in developing countries? Some lessons from China. *Telecommunications Policy, 36*(10–11), 888–900.
Lubin, D. A., & Esty, D. C. (2014). *Bridging the sustainability gap*. MIT Sloan Management Review. June 2014[.
Matthess, M., & Kunkel, S. (2020). Structural change and digitalization in developing countries: Conceptually linking the two transformations. *Technology in Society, 63*, Article 101428.
Meijers, H. (2012). Does the internet generate economic growth, international trade, or both?. *United nations university working paper series 2012(050)*. Maastricht, The Netherlands: United Nations University.
Mentsiev, A. U., Engel, M. V., Tsamaev, M. V., Abubakarov, M. V., & Yushaeva, R. S.-E. (2020). The concept of digitalization and its impact on the modern economy. *Advances in Economics, Business and Management Research, volume 128 International Scientific Conference "Far East Con*.
Myovella, G., Karacuka, M., & Haucap, J. (2020). Digitalization and economic growth: A comparative analysis of <CITEREF RID="vrpa-25-04-18-Hall1">ub-Saharan Africa and OECD economies. *Telecommunications Policy, 44*(2), Article 101856. March 2020.
Nagle, F. (2018). The digital commons: Tragedy or opportunity? A reflection on the 50th anniversary of Hardin's tragedy of the commons. *A reflection on the 50th anniversary of Hardin's tragedy of the commons (December 13, 2018)*. Harvard Business School Strategy Unit Working Paper.
Ndou, V. (2004). E-government for developing countries: Opportunities and challenges. *The Electronic Journal on Information Systems in Developing Countries, 18*(1), 1–24.
Ndukwe, E. (2011). *The telecommunication revolution in Nigeria*. Okada: Convocation Lecture delivered at Igbinedion University.
Ndung'u, N., & Signé, L. (2020). The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse. *Foresight Africa Report, 5*(1), 1–177.

Njangang, H., Beleck, A., Tadadjeu, S., & Kamguia, B. (2022). Do ICTs drive wealth inequality? Evidence from a dynamic panel analysis. *Telecommunications Policy, 46*(2), Article 102246.

Okamgba, J. (2024a). *Telcos, subscribers reject 5% excise duty, Punch News, Nigeria*. https://punchng.com/telcos-subscribers-reject-5-excise-duty/.

Okamgba, J. (2024b). *FG plans reform as telecoms sector attracts $191m FDI*. Nigeria: Punch News. https://punchng.com/fg-plans-reforms-as-telecoms-sector-attracts-191m-fdi/.

Okorie, D. I. (2017). Testing the existence of Cobb-Douglas and CES production functions in Nigeria. *International Journal of Academic Research in Business and Social Sciences, 7*(3), 270–297.

Okorie, D. I. (2021). The energy use of capital inputs: Towards cleaner production in Nigeria. *Environmental Challenges, 4*, Article 100104.

Okorie, D. I. (2025). Making hay while the sun shines: Energy security pathway for Africa. *Energy Policy, 198*, Article 114512.

Okorie, D. I., & Lin, B. (2024). Global <CITEREF RID="vrpa-25-04-18-Hall1">hocks and fiscal <CITEREF RID="vrpa-25-04-18-Hall1">timulus: A tale of an oil-dependent-exporting country. *Financial Innovations, 10*(26).

Okorie, D. I., & Wesseh, P. K. (2023). Climate agreements and carbon intensity: Towards increased production efficiency and technical progress. *Structural Change and Economic Dynamics, 66*, 300–313.

Okorie, D. I., & Wesseh, P. K. (2024). Fossil fuel subsidy removal, economic welfare, and environmental quality under alternative policy schemes. *Journal of Cleaner Production, 450*.

Ologunde, A. O., Owoyomi, A. E., Elumilade, D. O., & Makinde, J. T. (2006). The effects of privatisation and deregulation policies on Nigerian telecommunication industry. *The Nigerian Academic Forum, 10*(1), 134–142.

Qiang, C., Rossotto, C., & Kimura, K. (2009). Economic impacts of broadband. In *Information and communications for development 2009: Ex-tending reach and increasing impact*. Washington DC: World Bank.

Qureshi, Z. (2022). Combating inequality and building inclusive prosperity in the digital era. AN INCLUSIVE FUTURE? *TECHNOLOGY, NEW DYNAMICS, AND POLICY CHALLENGES, 1*.

Rohman, I., & Bohlin, E. (2010). On the ICT economy in the European countries: Investigating the contribution of the ICT sector using the input-output model. *21st European regional Conference of the international telecommunication society (ITS)*. Denmark: Copenhagen.

Scott, C. (2012). *Does broadband Internet access actually spur economic growth? Paper*. December, 7.

Seele, P., & Lock, I. (2017). The game-changing potential of digitalization for sustainability: Possibilities, perils, and pathways. *Sustainability Science, 12*, 183–185. https://doi.org/10.1007/s11625-017-0426-4

Terraincore. (2024). *Telecoms investment in Nigeria: Why invest in Nigeria's booming telecom sector*. https://terraincore.com/telecoms-investment-in-nigeria/.

Wandaogo, A. A. (2022). Does digitalization improve government effectiveness? Evidence from developing and developed countries. *Applied Economics, 54*(33), 3840–3860.

Wang, J., & Xu, Y. (2023). Digitalization, income inequality, and public health: Evidence from developing countries. *Technology in Society, 73*, Article 102210.

Wen, H., Wen, C., & Lee, C. C. (2022). Impact of digitalization and environmental regulation on total factor productivity. *Information Economics and Policy, 61*, Article 101007.

Xing, W., Ye, X., & Kui, L. (2011). Measuring convergence of China's ICT industry: An input-output analysis. *Telecommunications Policy, 35*(4), 301–313.

Yeo, Y., Hwang, W. S., & Lee, J. D. (2023). The shrinking middle: exploring the nexus between information and communication technology, growth, and inequality. *Technological and Economic Development of Economy, 29*(3), 874–901.

Yeo, Y., & Jung, S. (2024). Assessing the economy-wide impacts of digital transformation in the Korean economy: A social accounting matrix multiplier approach. *Telecommunications Policy, 48*(10), 102871.

Yin, Z. H., & Choi, C. H. (2023). Does digitalization contribute to lesser income inequality? Evidence from G20 countries. *Information Technology for Development, 29*(1), 61–82.

Yu-Kyoung, C. (2012). Analysing relationships between transportation and communication industries based on input-output table. *Journal of Korean Society of Transportation, 30*(4), 33–42.

Zhang, S., Ma, X., & Cui, Q. (2021). Assessing the impact of the digital economy on green total factor energy efficiency in the post-COVID-19 era. *Frontiers in Energy Research, 9*, Article 798922.

Zhang, X., Shinozuka, M., Tanaka, Y., Kanamori, Y., & Masui, T. (2021). How ICT can contribute to realize a sustainable society in the future: A CGE approach. *Environment, Development and Sustainability*, 1–27.

Zhou, J. (2013). Digitalization and intelligentization of manufacturing industry. *Advanced Manufacturing, 1*, 1–7. https://doi.org/10.1007/s40436-013-0006-5

Zumofen, R., Kakpovi, B. G., & Mabillard, V. (2022). *Outcomes of government digitization and effects on accountability in Benin*. Transforming Government: People, Process and Policy (ahead-of-print).

Zvereva, A. A. (2019). Impact of the economy digitalization on welfare in the developed and developing countries/A. *A. Zvereva, Zh. S. Belyaeva, K. Sohag* (Vol. 4,(Iss. 15), 1050–1062. https://doi.org/10.17059/2019-4-7. Economy of Region.