Chapter

Modelling Digital Economy Implications on Long-Run Economic Development

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Abstract

This chapter develops frameworks and models to examine digital transformation into digital economies via digital technologies' applications at both the macro and micro levels via both positive and negative externalities generated by digital technologies and pollutant emissions. A productivity mixed method approach has been developed based on the chapter modified frameworks and models to be employed at both the macro and micro levels to utilise the digital technology applications that will help in transforming digital economies to sustain their economic development. The study provided digital economy frameworks and policies to help in implementing digital transformation and to develop and use the new technologies needed for sustainable economic growth through technological progress, human capital skills development and environmental protection via green productivity technological progress. The study contributes to the knowledge body via proposed productivity mixed method frameworks and models that examine digitisation processes. The aggregate economies, industries, companies and other businesses will be provided with frameworks and guidelines to implement digital technologies' applications that will help them to be transformed into digital sustainable economies. The most significant contribution of this study is treating digital technology cybersecurity negative externalities spill over effects similar to their negative externalities of pollutants' emissions counterparts, besides developing capital productivity framework and model that were ignored in most of the studies.

Keywords: digital economies, externalities, digital transformation, cybersecurity, green productivity, COVID-19 implications

1. Introduction

Economics like other social sciences has no one standard definition of the digital economy due to the subjective nature of the social sciences as has been mentioned by [1]. Conversely, a satisfactory definition must place importance on the generation and exploitation of digital knowledge over digital technology applications to create new value in the economy. Undeniably, knowledge is information that is put to productive work through digital technology applications. Knowledge includes information in any form, know-how and know-why among others. The digital economy is not confined to information and communication technology (ICT) digital applications. Before the evolution of the digital technologies, it was the knowledge that remained embodied in human beings' 'human capital' and technology that was embodied in the capital investment undertaken by the Asian economies that brought about the so-called Asian miracle [2].

In this respect, cybersecurity economics is the economics that discourses the concerns of protection of digital technology applications that premeditated to enable the economic activities that are ordinariness face cybercrimes that cost the individuals, companies and the countries enormous amount of money and interrupt the economic and financial activities around the world as it has been indicated in ICT-based sustainable development as reported in [ICT & Sustainable Development Goals (SDGs) report, 2015]. ICT-based sustainable development reports the ICT role in attaining SDGs that is presented by the United Nations (UN) for its members to achieve SDGs that are planned to be implemented comprehensively within 2030. Besides, the report points apprehension of the potential shortcomings of ICT-based sustainable development, these trace on at least six broad areas such as the online world will literally reshape brain development, possibly leading to a loss of human skills. Moreover, the virtual or online communities will somehow crow out, meaning that real human communities heading to a decline in human interactions, trust and sociality; this is will lead to what so-called 'bowling alone' phenomenon as assumed by sociologist Robert Putnam. Further, the robots are estimated to relocate human work to the point of initiating bulk unemployment and economic pessimism. This point faced the argument that there might be the sheen of truth in such arguments, but the central circumstance is that with suitable public policies, technological advances develop well-being as this is measured to be the positive externalities of digital technology that formed the digital economy around the world. Nevertheless, the negative externalities allied through the advance of this technology are the cybersecurity negative externalities and the disparity of the human skills to optimise the digital dividends created in terms of a long-run sustainable economic growth involvement via the digital technology contributions to produce economic well-being [2].

Meanwhile, the fourth concern, the digital economy is subject to network failures than a production-based economy that is overtaken by a knowledge-based economy due to ICT revaluation and currently by a digital economy via the emergent digital technologies such as giant performance catastrophes due to the Internet or power network could bring the economy to irresistible incursion. Additionally, the next concern is that the interruption of the networked economy will become deliberate turns of cyber-warfare or what so-called cybercrimes [1]. The last concern is of excessive nervousness as that the digital-technology-based economy is a surveillance economy, with worldwide snooping and detriment of privacy. The infiltration might be by government giant digital technologies organisations or a smart partnership of the two or a grouping both everywhere [2]. These depictions of cybersecurity externalities' uncertainties were offered disgraceful validation by Edward Snowden, as not of the least of which was the ambiguous and trickeries of endorsed institutions concerning their surveillance policies [2].

The abovementioned fears will be used in this study to corroborate the cybersecurity negative externalities' concerns associated with digital-technologies-based economic activities corresponding with their environmental externalities' complements that both created as unwanted output alongside the chief product that negatively impacted the economies worldwide and made vast economic mortalities and even formed uncertainty on the democracy and election results as the alleged Russian interruption in US Presidential election and the Chinese Giant mobile company products of Huawei that is prohibited from using the Google system for its 5G products concerning spying activities among others. The innovation made by the digital revolution led by digital-technologies-based accompanying by obstacles deliberated above that should be overwhelmed particularly the cybersecurity negative externalities correlated to security concerns that cost the economies and endangered them to innovate. Contradictory, the humankind's know-how with technology dating back to the commencement of the industrial revolution that disregards the unintended shortcomings of technology to unlimited peril, the digital revolution should offer responsible resolutions to overcome the cybersecurity negative externalities of these obstacles to progress in accomplishing the SDGs as planned to be flourished by 2030 [2].

Regarding the negative externalities associated with environmental damages, Ahmed [3] presents that the concept of Green Productivity (GP) is drawn from the incorporation of two central progressive strategies, namely productivity enhancement and environmental safeguard. Productivity offers the framework for boundless progress, whereas environmental precaution delivers the underpinning for long-run economic growth and sustainable development [3].

Consequently, GP is an approach for enhancing productivity and environmental performance for inclusive socio-economic development. GP is an influential strategy that can complement economic growth and environmental protection for long-run economic growth and sustainable development. It presents small and medium businesses with a methodology to attain a competitive advantage by existence of improved business models. It is consequently an accurate approach to upsurge productivity and safeguard the environment simultaneously [3].

Furthermore, the United Nations (UN) Sustainable Development Summit held in New York in September 2015 approved the goal of the sustainable development agenda by 2030 [4]. The UN summit proposed a new indicator framework, accompanying with global and collective indicators, for international partnership and cooperation to accomplish sustainable development for the period of 2015 and 2030, including 17 new Sustainable Development Goals (SDGs). In fact, every country should arrange these 17 SDGs based on its country need and development stages not only as arranged by UN. For example, some countries need to implement goal 16 (peace, justice and strong insinuations), other goals took place as the institutional failure, bad leadership and governance among others.

It should be recalled that before implementing the 17 SDGs, this study proposes that these 17 SDGs should be revised as some of them outdated due to the digital economy issues brought by industrial revaluation 4.0 digital technologies and new businesses models associated with COIVD-19 implications.

Meanwhile, changes in productivity considered are key concerns in any economy due to the connection between productivity and living standards [2–6]. The definitive aims of productivity improvement are countless competitiveness, greater profitability, upper living standards and well economic and social fortune. In this regard, Total Factor Productivity (TFP), labelled as the combined contribution of the factors of production qualities, is an indicator of the technological progress that displays the spillover effects that must transfer the technology to the hosting economy and upgrade the skills of its human capital, which is what is named productivity-driven. TFP can explain the growth in a digital economy since it captures endogenous technical change and other features of the digital economy, including diffusion of digital knowledge, organisation, restructuring, networking and new business models that would contribute to market efficiency and productivity [2, 3, 5].

According to [7], digital technology in the form of the Internet, mobile phones and all the other digital tools used to collect, store, analyse and share information digitally consumes and has grown swiftly everywhere in the world. It has been projected that 70% of the households have mobile phones than have access to electricity and clean water in developing countries. Moreover, Internet users' number has more than tripled in a decade appraised to be in the range of 1 billion in 2005, 3.2 billons by the end of 2015. This means businesses, people and governments are more connected than before the digital revolution. The digital divide displays the gap in access to ICT applications within nation or between nations. In this respect, digital dividends (the income generated via using digital technology applications) are the broader development that benefits from using digital technologies. In several occurrences, digital technologies enhanced growth, expanded opportunities and better-quality service delivery. The digital dividends aggregate effect has dropped little and is unequally disseminated. For the digital technologies to benefit everybody everywhere in the world, it would be needed to close the residual digital divide, particularly in Internet access as it has been shown during COVID-19, many countries and business are not able to run online during movement control orders. Though, countless digital adoption will not be enough if it has not created value-added digital dividends from the economic activities.

2. Digital economy flagships and pillars

Digital economy flagships and pillars should be established as the groundwork for the digital economy institutions and facilities needed for its activities. With respect to digital economy flagships and pillars, certain countries are in an advanced stage in establishing digital economy flagships and pillars, some are in the starting stage and some have not thought about it. For instance, Malaysia developed their knowledge economy master plan in 1996 and embedded the digital economy flagships in stages that should be completed in 2020. Some other countries are ongoing in developing the digital economy foundation, and some are in the initial stages of digital economy flagships and pillars progress. Reviewing the countries' experiences that scheduled and established their economies into digital economies, such as countries in America, Europe and Southeast Asia, this study found that Malaysia's experience is a upright sample to monitor as the country prearranged comprehensively for the digital economy foundations. Multimedia Super Corridor (MSC) was developed for knowledge economy flagships and pillars, among economic corridors in several Malaysian states that are upgraded to digital economy flagships and pillars with a revised digital economy master plan [6].

To acquire significant advantage from the digital technologies, countries also need to work on the analog matches; such as strengthening regulations that guarantee competition between businesses, by adapting workers' digital skills to the demands of the digital economy and by guaranteeing that institutions are accountable. It should be noted that increasing human capital (skilled workers) particularly digital skills is a perquisite of progressing and realising digital technologies' applications in economic sectors and companies. With the accurate digital human skills, digital technologies will enable economic activities, due to the fact that technology in general and digital technologies' applications in particular are architects that need the right human skills to function [6].

To develop a competitive edge in a digital economy would need a highly skilled digital human capital besides other skilled workers. Highly skilled and talented human capital is likewise energy to grow the digital economy. The 'know-how' that goes into the production of innovative products to enable companies, businesses, organisations and countries to be competitive in the global market habitation will be provided by their exceptional skills. Besides, out-migration drains the limited talent pool: several professionals and technical personnel and students overseas have migrated to the countries that provided chances to progress; achieve their mental satisfaction to contribute and to enjoy their achievements senses among other benefits missed in their home countries. Another chance is to bring in the indispensable skilled human from overseas to the home countries which is liberalising recruitment with chances and benefits equal to what have enjoyed overseas to progress in their home countries. The education institutions should play a significant role as the foundation of the human capital development that is considered to be one of the important pillars to develop a digital economy [8].

Additional significant challenge that will be faced in the determination to transfer to a digital economy would be the capability to construct an innovative capacity in the country; hence, innovative goods and services could be developed for the digital economy [8]. With amplified liberalisation of economies and the elimination of tariff barriers via trade agreements and economic unions, goods and services produced by companies and countries will have to compete with corporations and national companies in general and specifically Small and Medium Enterprises (SMEs).

Research and Development (R&D) present amount of financial and other resources allocated in most of the countries as a percentage of GDP is minor compared with other countries that developed their economies into digital economies. The governments must foster an environment where creative and innovative thinking are fulfilled. Encouragements should be prearranged to persons and companies who originated cutting-edge concepts, innovative technologies and products in recognition to such inventions, innovations and outstanding discoveries. These prizes and credit should be firmly for the contribution of an innovative products and processes that would enrich innovative capacity and competitive standing in the universal marketplace [7].

Particular countries are highly qualified to be education centres that attract students around the globe, with the existing condition, higher institutions graduates and technicians are the most important sources of Gulf countries' human capital. If the education institutions established well, graduates could compete around the globe through developing economies into digital economies with the right foundations to facilitate the economic activities and businesses. The current business model practiced should be refined to encounter digital economy foundations' requirements. The current business model's improvement to meet the COVID-19 implications most likely will contribute and complement economic value added to the economic progress and accomplish the anticipated digital economy if deliberate it well in a short period of time as the latter countries will catch up very fast to achieve their economic growth. SMEs are the backbone of the economies everywhere in the world; 90–99% of the companies in in most of the countries are SMEs that were not well classified define and are not existed in some countries. Further, SMEs are considered as the digital economy corner stone in transferring the technology and upgrading the local human capital skills through Foreign Direct Investment (FDI) spill over effects brought by the multinational companies to the host countries [1].

Furthermore, cyber laws should be familiarised to overwhelm the cyber complications allied with digital economy activities. Cyber-crimes may take place overseas, and in this respect, there is an urgent need for collaboration around the world to overcome cyber-crimes through smart partnerships. It should note that the conclusive currency of a digital economy is intellectual property rights (IPRs) implementation via the rule of law based on the World Trade Origination (WTO) agreements. IPRs includes copyrights, patents, trademarks, service marks and goods of geographical indication. It should be noted that IPRs are legal monopolies awarded to original owners of copyrights and patents to enable them to benefit from their discoveries and ensure the sustainable inventions and innovations [2].

Emergent digital economy master plan to address the policies and developing digital economy institutions to move to a digital economy is considered to be the first step. This study will be useful for digital technologies policy formulation as an underpinning of the digital economy development. In this background, an appraisal of the digital technologies and productivity growth contributions in each of advanced countries in general and in the East Asian countries specifically will afford guidelines for the policy-makers to articulate applicable national and international digital technologies policies. This study findings based on the study frameworks and models developed are expected to help formulating policies to stimulate digital technologies investment to clue in enlightening human capital and infrastructure needed to support active digital technologies usage. It is likely that it can capitalise the interaction within the countries and between other countries and make full use of the competitive advantages in of all countries to impressed its deficiencies. The countries will be capable of fast-tracking the association towards technology-savvy nations that has been attained by Japan, South Korea and China, among others [6].

According to United Nations (UN) [4], there is a need to discourse security concerns connected with digital technology applications, hence to warrant the accomplishment of the implementation of the digital technology applications. More precisely, the concerns that should to be addressed are to guarantee security and privacy of existing e-channels, such as automated teller machine (ATM) and electronic point of sale (EPOS) among others, and to resolve all network problems. Building individuals' and societies' consciousness and counselling the communities about the reimbursements and use of new digital technologies and digital services are required. Here should be rigorous promotions to teach the public, particularly directing the urban and rural populations; consequently, they are conscious of the digital economy concepts and scopes to build the knowledge of digital socialites that is vital on which a digital economy would be based. Moreover, Ahmed [2] presents an appropriate regulatory setting, concerning user guidelines, trusts, rights and protections, right integration and a smart partnership between telecommunications network operators and the economy sectors, suitable staff training and presenting client literateness for appropriate use, evolving reliable and drivable digital technology's structure and rigorous digital products and service design are crucial to implement digital economy applications. Besides, collaborations, cooperation and smart partnerships between private and public sectors within countries and between countries to construct digital economies are instantly required particularly the smart partnership within a country and between the countries as the digital economy is a universal phenomenon that connected the world economy.

Lastly, as [2, 3] show, the sustainability of higher economic growth will remain to be productivity-driven not input-driven as experienced by most of the countries. The input-driven caused the collapse of the Soviet Union in 1990s as a result of combining many countries and used their resources without technological progress to sustain the economic development and long-run economic growth. The productivity-driven that should sustain higher and long-run economic growth will be achieved through the enhancement of TFP as a technological progress that combined the three dimensions of sustainable development (economic development, environmental protection and social sustainable development via human capital development and digital technologies). Such amplification needs to strain the human capital quality, demand intensity, economic restructuring, capital structure, technical progress and environmental standards. In this respect, the green productivity through green TFP creates the sustainable development concept of progressing technologically, socially and environmentally that will relieve to realise the sustainable development dimensions required for long-run economic growth and to guarantee its sustainability. That is, it will maintain the privileges of the upcoming, as well as existing, generations for them to gain a better life span.

3. Literature review

Feyen et al. [9] address the important cybercrimes prevention via data protection and interoperability as addressed by [10]. The study suggested that cybercrimes become more important via cross-border spill overs of antitrust and data-governing ace decisions, as well as the potential to improve fintech, and the digital transformation of financial service will be through harmonisation of standards in areas of cybercrimes prevention, data protection and interoperability, among others. In this respect, collaboration and smart partnerships can help via regulatory consistency and peer learning within the countries and between the countries that will achieve the higher well-being of the entire population and around the globe.

Furthermore, [11] mentioned that the financial ecosystem digitisation will be centre to economic growth in overall and an enhancement in several economic activities with a certain effect on customer experiences. The study addresses the need of cybersecurity and cyber management resolutions accomplished of rapidly recognising threat circumstances, counting cyber-attacks on digitised services and products and counsel the users on the possible forthcoming threat.

Meanwhile, Sabău et al. [12] identifies the importance of corporate governance to increase the digitalisation process among companies. In this respect, corporate governance and social responsibility are required elements to develop digital economy and to achieve digital inclusion. The study findings can be used to improve the public governance, investors, companies, governments to highpoint good corporate governance role for increasing the overall well-being of the society within the digital economy. As well as to preserve transparency enlarged, in a digital ecosphere appears comparable an easy thing to do.

Smart partnerships are very important within and between the nations in this regard [13] appraise the convergence across the European Union (EU) 28 members in the digital economy arena grounded on the Digital Economy and Society Index (DESI) and its dimensions via the log t club convergence method. The study empirical finding found that during the study period (2015–2020), there was no inclusive convergence across EU 28 members in the digitalisation context.

Accordingly, [3, 14] explain that the methods used to measure productivity growth mostly ignore the pollutants that are produced by the production process as undesirable products and unpriced output. For instance, pollutant emissions produced as undesirable output in addition to the main output of production are omitted from the productivity accounting framework and other approach that estimated productivity growth. This chapter tries to incorporate green productivity methods by taking into account pollutant emissions into production functions as un-priced inputs. The pollutant emissions under consideration include carbon dioxide (CO_2) emissions (that measures air pollution), Biochemical Oxygen Demand (BOD) emissions (that measures organic water pollution) and their mixture in the formula of total pollutant emissions, that is, combined air and water pollutions' emissions. Though, other pollutants' emissions should be measured, such as noise pollution and all other types of pollutants' emissions. It should be mentioned that, in 2018, the Nobel Prize for Economic Sciences was awarded to William D. Nordhaus and Paul M. Romer for research undertaken in the 1970s. William D. Nordhaus was awarded the prize for his research that addressed negative externalities, such as pollutant emissions, whereas Paul M. Romer was awarded the prize for his research concerning the new factors of production inclusion in the production function such as digital technology in the form of ICT and human capital to achieving long-term economic growth through technical progress and green development that sustain long-run economic growth via what recently called digital economy. Moreover, Romer [15–19] emphasised how the economy can expand the boundaries, and thus the possibilities, of its future activities. In his focus on the fundamental challenges of climate change, Nordhaus [20–29] stressed the importance of the negative side, and thus the restrictions, of the endeavours in bringing about future prosperity.

Moreover, Ahmed's [14, 30, 31] studies indicated that the greatest apparent absence in the growth accounting models undertaken by preceding studies was found to be the exclusion of externalities, such as the pollutant emissions, which were generated by the manufacturing and other economic sectors. The mentioned studies intended to add to the accessible literature on the growth accounting and econometric approaches, in that these studies combined together both methods to calculate the total factor productivity (TFP) and TFP per unit of labour growth as residuals. This residual identified by Solow [32, 33] via internalising the pollutant emissions with the traditional factors of productions employed in conventional production functions. Accordingly, green TFP and green TFP per unit of labour growth became indicators of green productivity. That is taking into account economic development and environmental protection benefiting from the studies undertaking by [34–40]. Finally, [6] recalled that: 'It has been documented in the Solow [32, 33] empirical work on economic growth that after accounting for physical and human capital accumulation, something else accounts for the bulk of output growth in most countries. Together, physical and human capital accumulations are definitely critical for economic growth. The development becomes more complex with the role of knowledge in the economic growth procedure'.

As has been mentioned earlier, in many instances, digital technologies boosted growth, expanded opportunities and improved service delivery. Their aggregate impact has fallen short and is unevenly distributed. For digital technologies to benefit everyone everywhere requires closing the remaining digital divide, especially in Internet access. To develop a competitive edge in a digital economy would need a highly skilled labour force. Greatly skilled human capitals are the fuel to the digital economy engine of growth. Highly skilled workforces will offer the 'know-how' gained via learning by doing those energies into the production of innovative products that empower companies, businesses and countries to be competitive worldwide.

Thanks to COVID-19-positive economic impact that forced people to work from home to sustain economic activities that was not acceptable around the globe due to technophobia in the heart and minds of the decisions makers and governments' officials to accept online comprehensive activates. High involvement on online activities is allowed via the digital technologies' applications to run daily activities via digital governance. This study developed frameworks and models to be employed and empirically examined the impact of COVID-19 and the digital technology's role in sustaining the economic growth. Besides, the study offers recommendations and policy implications to transfer the economies into digital economies that would sustain economic development under any undesirable conditions, such as COVID-19 that triggered massive economic losses. In this respect, digital economic development is expected to diminish the economic fatalities related with forthcoming global pandemics.

The main objective of this research is to model and examine the digital economy's positive and negative externalities spill over effects on the sustainable economic growth through employing a mixed method approach, consisting of quantitative and qualitative analysis at macro and micro levels.

The study recommended foundations to transform public and private sectors into a digital economy to achieve the Sustainable Development Goals (SDGs) agenda and to overwhelm the COVID-19 and upcoming pandemics' negative externalities. It will likewise be used to moderate the COVID-19 and forthcoming pandemics' negative impact through enabling economic activities under disinclinations via using the proposed frameworks and models that modified productivity approaches to accommodate digital technologies' applications.

The study fills the gaps in growth theories through developing three different frameworks and econometric models, and internalising pollutants' emissions as private and unpriced inputs in the three models. Further, the green capital productivity model is the exclusive contributing model developed in this research; it has not been assumed and empirically examined in previous studies, with the exception of the studies undertaken by [2, 3, 5, 41].

The significant contribution of this study has modified the fundamental findings of Nobel Prize Laureates' research findings [29] to integrate innovation and climate change in the form of green productivity as well as existing studies in developing frameworks and models to measure digital economy indicators such as digital technology positive externalities and negative externalities such as cybersecurity shortcomings and negative externalities generated by pollutants' emissions. The role of these externalities on long-term sustainable economic growth has been ignored by several past studies undertaken in these areas. These three modified frameworks and models in a significant method articulate the technological progress issues and sustainable economic growth as one of the most important sustainable developments and long-run economic growth dimensions.

4. Methodology development process

This study employed digital economy's positive and negative externalities in unindustrialised study frameworks and models in this chapter. At both the macro and micro economic levels, this chapter anticipates to use a mixed approach of quantitative and qualitative analysis. In this subdivision, a parametric analysis based on a combined method of parametric analysis is developed. The method combines both growth accounting that is non-parametric approach and econometric that is parametric approach. This method was developed to be applied in two steps: the first step is an econometric approach to estimate the study parameters (explanatory variables coefficients), whereas the second step plugs these parameters into the models to calculate the productivity indicators. Three frameworks and models have been developed based on [1–4, 6, 30, 31, 42] modified extensive growth theory and intensive growth theory (labour productivity and capital productivity). The aforementioned mentioned studies modified and combined the production function and Solow's residual [32, 33] and refined by [43] to fill the gaps in both approaches that cast doubts on the results generated by both. The framework (**Figure 1**) is an extensive growth theory presentation of Model 1 that consists of the output (Gross Domestic Product [GDP]) as a function of capital, labour, digital technology and pollutant emissions for pollution are the explanatory variables based on their quantity. In addition, the framework presents TFP that combined the inputs quality contribution (explanatory variables) that indicated that technological progress to be transformed into sustainable digital economies.

This chapter suggests a digital productivity framework, a digital labour productivity framework and digital capital productivity framework (**Figures 1–3**) to be used at the country level. The frameworks will measure the' digital economy productivity implications via the collection of a primary data survey and the analysis of qualitative focus groups interviews with concerned experts. The qualitative approach will capture

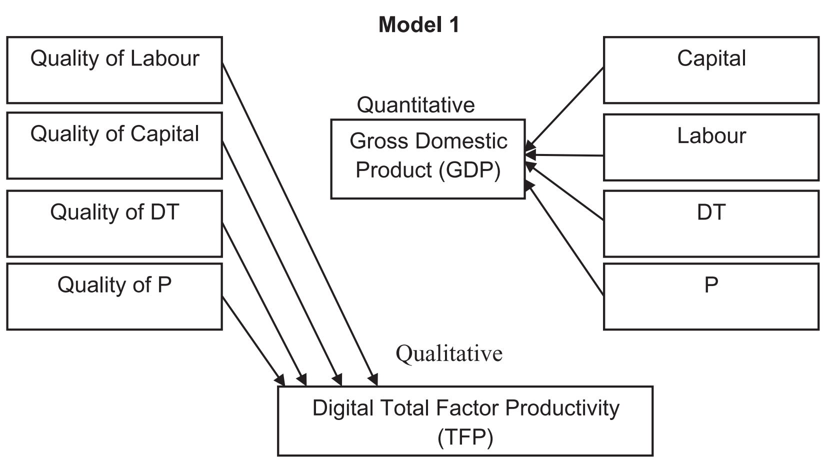

Figure 1.
Productivity framework, extensive growth theory. Source: Modified from [2].

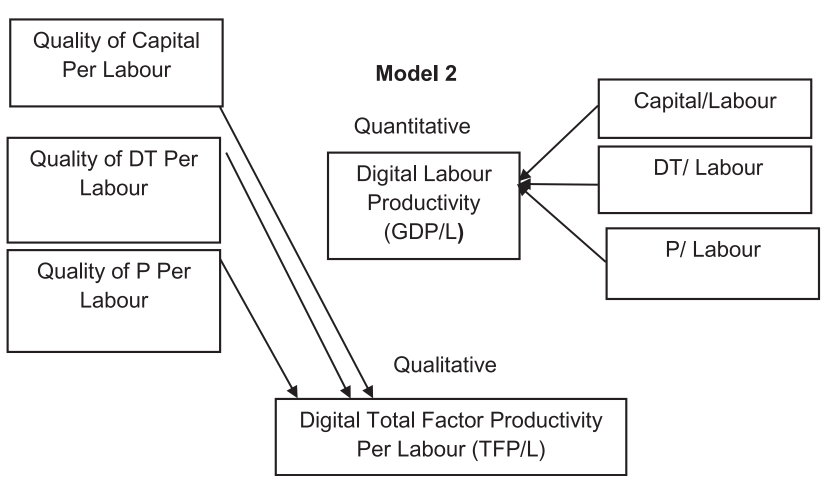

Figure 2.
Total factor productivity per worker framework, intensive growth theory. Source: Modified based on [2].

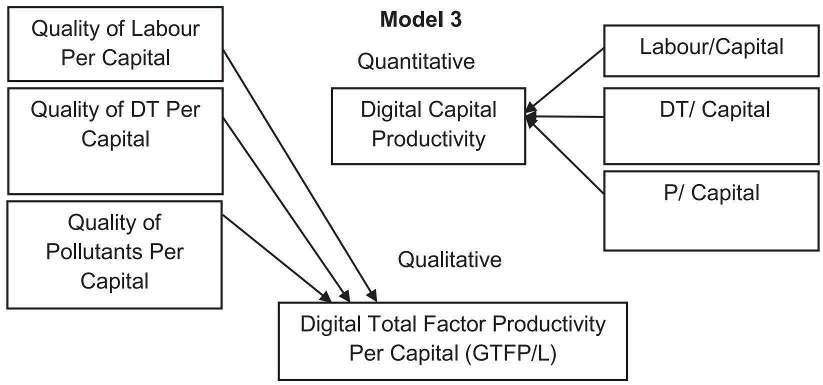

Figure 3.
Digital capital productivity framework, intensive growth theory. Source: Modified based on [2].

information and data that have not been published in the form of secondary data and information.

The production function for an economy can be categorised as follows:

$$\text{GDPt, i} = \text{F (Kt, i, Lt, i, DTt, i, Pt, i, Tt, i)} \quad (1)$$

where country i = 1, 2, … in Years t, output real GDP is a function of real fixed physical capital input K, labour input L, DT for digital technology that includes digital technologies' variables including cybersecurity variables, while P represents the pollutant emissions, and time T proxies for TFP as a technological progress of the digital economies and sustainable development indicator.

4.1 Extensive growth theory

This subsection offers the extensive growth theory based on GDP that is decomposed into physical capital, employment, digital technology (DT) and pollutants' emissions (P). The chapter tries to fill the gap found in [30] research via modifying this model into a parametric model and providing statistical analysis for it in the first step, as follows:

$$\Delta \text{lnGDPt, i} = a + \alpha.\Delta\text{lnKt, i} + \beta.\Delta\text{lnLt, i} + \lambda.\Delta\text{lnDTt, i} + \theta.\Delta\text{lnPt, i} + \varepsilon t, i \quad (2)$$

t = Number of years and i is number of countries.
where.
α is the output elasticity with respect to capital
β is the output elasticity with respect to labour
λ **is** the output elasticity with respect to digital technology
θ is the output elasticity with respect to pollutants' emissions
a is the intercept or constant of the model[1]
ε is the residual term[2]
ln is the logarithm to transform the variables

[1] The intercept term, as usual, gives the mean or average effect on dependent variables of all the variables excluded from the model.
[2] The residual term proxies for the total factor productivity growth that accounts for the technological progress of the economy through the quality of input terms.

Δ is the difference operator denoting proportionate change rate.

The intercept (a) in Eq. (2) has no place in the calculation of the productivity growth indicators based on the estimated results of Eq. (2) by succeeding a second step. The second step computes the progression rates of productivity indicators, transforming Eq. (2) as an extension of the basic growth accounting framework. The production function is indicated in the parametric form of the above equation as follows:

$$\Delta \text{lnTFPit} = \Delta \text{lnGDPit} - [\alpha.\Delta \text{lnKit} + \beta.\Delta \text{lnLit} + \lambda.\Delta \text{lnDTit} + \theta.\Delta \text{lnPt, i}] \quad (3)$$

Where the masses are assumed by the average value shares as follows:

$\Delta \text{lnGDPit}$ is the growth rate of output

$\alpha.\Delta \text{lnKit}$ is the contribution of the aggregate physicall capital

$\beta.\Delta \text{lnLit}$ is the contribution of the aggregate labour

$\lambda.\Delta \text{lnDTit}$ is the contribution of the digital technology

$\theta.\Delta \text{lnPit, i}$ is the contribution of the pollutants$'$emissions

$\Delta \text{lnTFPit}$ is the total factor productivity growth

The model decomposes the growth rate of GDP into the contributions of the rates of growth of the aggregate physical capital, labour, digital technology and pollutants' emissions, plus a residual term, typically referred to as the growth rate of TFP.

4.2 Intensive growth theory (labour productivity)

This subsection establishes an intensive growth theory framework (**Figure 2**) for Model 2, the labour productivity or output per labour (GDP)/labour as a function of capital per labour, digital technology per labour and pollutants' emissions per labour are the explanatory variables based on their quantity. Furthermore, the framework offers the total TFP per labour (TFP/L) that is expressed as the combined contribution of the quality of the explanatory variables.

This subsection demonstrates the decomposition of labour productivity into capital deepening, increased usage of digital technology per unit of labour and pollutants' emissions per unit of labour. Likewise, following [30, 31, 44–46], when constant returns $\beta = (1\text{-}\alpha\text{-} \ \lambda)$to scale is imposed, Eq. (2) becomes:

$$\ln GDPt,\ i = \text{a} + \alpha.\ln \text{Kt, i} + \lambda.\ln DTt, i + \theta.\ln Pt, i + (1 - \alpha - \lambda - \theta).\ln \text{Lt, i} + \varepsilon\text{t}, i$$
$$\text{t} = \text{Number of years} \quad (4)$$

However, there are two options for dividing the variables by L:

1. Dividing the variables (data) by L before the analysis, in which the equation is given as: $\ln(\text{GDP/L})_\text{T} = \text{a} + \alpha \ln(\text{K/L})_\text{T} + \lambda \ln(\text{DT/L})_\text{T} + \theta.\ln(\text{P/L})_\text{T}$

   This will not be used in this study.

2. Dividing the variables by L during the analysis through programming the variables that will be used in this study, as follows

$$\ln(\text{GDP/L})_\text{T} = \text{a} + \alpha 1 \ln(\text{K/L})_\text{T} + \alpha 2\left[\ln\ (\text{K/L})_\text{T}\right]^2 + \lambda 1 \ln(\text{DT/L})_\text{T}$$
$$+ \lambda 2\left[\ln\ (\text{DT/L})_\text{T}\right]^2 + \theta 1 \ln(\text{P/L})_\text{T} + \theta 2\left[\ln\ (\text{P/L})_\text{T}\right]^2$$

The output elasticity is calculated with respect to capital per labour, digital technology per labour and pollutants' emissions per labour, i.e.$\alpha = \alpha 1 + \alpha 2$, $\lambda = \lambda 1 + \lambda 2$ and $\theta = \theta 1 + \theta 2$, respectively. Following [44, 30], the production function can be in the form:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/L})\mathrm{t,i} = \mathrm{a} + \alpha 1.\Delta \ln\ (\mathrm{K/L})\mathrm{t,i} + \alpha 2[\Delta \ln\ (\mathrm{K/L})\mathrm{t,i}]^2 + \lambda 1.\Delta \ln\ (\mathrm{DT/L})\mathrm{t,i} \\ &+\lambda 2[\Delta \ln\ (\mathrm{DT/L})\mathrm{t,i}]^2 + \theta 1.\Delta \ln\ (\mathrm{P/L})\mathrm{t,i} + \theta 2[\Delta \ln\ (\mathrm{P/L})\mathrm{t,i}]^2 + \varepsilon \mathrm{t}, i \\ &\mathrm{t} = \textit{Number of years} \end{aligned} \tag{5}$$

It then, follows that:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/L})\mathrm{t,i} \text{ is the digital labour productivity contribution} \\ &\overline{\alpha}.\Delta \ln \overline{(\mathrm{K/L})} = \alpha 1.\Delta \ln (\mathrm{K/L})\mathrm{t,i} + \alpha 2[\Delta \ln\ (\mathrm{K/L})\mathrm{t,i}]^2 \\ &\text{is the contribution of the capital deepening} \\ &\overline{\lambda}..\Delta \ln \overline{(\mathrm{DT/L})} = \lambda 1.\Delta \ln (\mathrm{DT/L})\mathrm{t,i} + \lambda 2[\Delta \ln\ (\mathrm{DT/L})\mathrm{t,i}]^2 \\ &\text{is the contribution of the digital technology per labour} \\ &\overline{\theta}..\Delta \ln \overline{(\mathrm{P/L})} = \theta 1.\Delta \ln (\mathrm{P/L})\mathrm{t,i} + \theta 2[\Delta \ln\ (\mathrm{P/L})\mathrm{t,i}]^2 \\ &\text{is the contribution of the pollutants}' \text{ emissions per labour} \\ &\varepsilon \mathrm{t,i} \text{ is the residual term that proxies for TFP per labour growth } (\Delta \ln (\mathrm{TFP/L})\mathrm{t,i}) \\ &\Delta \text{ is the difference operator denoting proportionate change rate} \end{aligned}$$

As mentioned in extensive growth theory, the intercept (a) has no position in the calculation of the productivity growth rate indicators. Consequently, it develops:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/L})\mathrm{t,i} = \overline{\alpha}.\Delta \ln\ \overline{(\mathrm{K/L})}\mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/L})}\mathrm{t,i} + \overline{\theta}.\Delta \ln\ \overline{(\mathrm{P/L})}\mathrm{t}, \\ &\mathrm{i} + \Delta \ln (\mathrm{TFP/L})\mathrm{t,i} \end{aligned} \tag{6}$$

Where $\overline{\alpha}$, $\overline{\lambda}$ and $\overline{\theta}$ indicate the dividends of capital per labour, digital technology per labour, the pollutants' emissions per labour. Total factor productivity per labour [(TFP/L) is the TFP per labour] contribution as an indicator of digital productivity and sustainable long-run economic growth spill over effect.

Besides, to calculate the TFP per worker, and other productivity indicators contributions, Eq. (6) transforms:

$$\begin{aligned} &\Delta \ln (\mathrm{TFP/L})\mathrm{t,i} = \Delta \ln (\mathrm{GDP/L})\mathrm{t}, \\ &\mathrm{i} - \left[\overline{\alpha}.\Delta \ln\ \overline{(\mathrm{K/L})}\ \mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/L})}\ \mathrm{t,i} + \overline{\theta}.\Delta \ln\ \overline{(\mathrm{P/L})}\ \mathrm{ti}\right] \end{aligned} \tag{7}$$

Subsequently, Eq. (7) guides the decomposition of digital labour productivity growth into the contributions of capital per labour, increasing the production rate of digital technology per labour and the pollutants' emissions per worker production as a by-product or unpriced products besides the main products, alongside the combined contribution of the stated inputs qualities. This is articulated as digital TFP per labour contribution that is indicated as the digital technology spill over effect.

4.3 Intensive growth theory (capital productivity)

The digital capital productivity framework for Model 3 (**Figure 3**) is a demonstration of the digital capital productivity or output per capital (GDP/capital) as a function of labour per capital, digital technology per capital and the pollutants' emissions per capital, considered to be the explanatory variables based on their quantities. Furthermore, the framework presents the digital TFP per capital (TFP/K) as the combined contribution of the qualities of the inputs demonstrated above in the capital productivity function.

Henceforth, the digital capital productivity decomposes into labour per capital, digital technology per capital and the pollutants' emissions per capital, as presented in [1–6]. When constant returns to scale $[\alpha(1\text{-}\beta\text{-}\lambda - \eta)]$, has been imposed, Eq. (2) becomes:

$$\ln GDPt,\ i = \mathrm{a} + (1-\beta-\lambda-\delta).\ln \mathrm{Kt,i} + \beta\ \ln \mathrm{Lt,i} + \lambda.\ln DTt, i + \delta.\ln Pt,\\ i + \varepsilon\mathrm{t}, i\mathrm{t} = \mathrm{N}umber\ of\ years \tag{8}$$

Accordingly, Eq. (8) has been transformed by dividing each term by K (capital input). The output elasticity was formerly calculated with respect to labour per capital, digital technology per capital and the pollutants' emissions per capital, i.e. $\beta = \beta 1 + \beta 2$, $\lambda = \lambda 1 + \lambda 2$, $\delta = \ \delta 1 + \delta 2$, correspondingly. Convening to [1, 2, 5, 6], the capital productivity production function can stand in the following formula:

$$\begin{aligned}&\Delta \ln (\mathrm{GDP/K})\mathrm{t,i} = \mathrm{a} + \beta 1 \Delta \ln\ (\mathrm{L/K})\mathrm{t,i} + \beta 2[\Delta \ln\ (\mathrm{L/K})\mathrm{t,i}]^2 + \lambda 1 \Delta \ln\ (\mathrm{DT/K})\mathrm{t,i}\\ &+\lambda 2[\Delta \ln\ (\mathrm{DT/K})\mathrm{t,i}]^2 + \delta\Delta \ln\ (\mathrm{P/K})\mathrm{t,i} + \delta\Delta \ln[\Delta \ln\ (\mathrm{P/K})\mathrm{t,i}]^2 \varepsilon\mathrm{t}, i\\ &\mathrm{t} = Number\ of\ years\end{aligned} \tag{9}$$

It couriers in the following terms:

$\Delta \ln (\mathrm{GDP/K})\mathrm{t,i}$ is the digital capital productivity contribution capital productivty
$\overline{\beta}\Delta \ln \overline{(\mathrm{L/K})} = \beta 1 \Delta \ln (\mathrm{L/K})\mathrm{t,i} + \beta 2[\Delta \ln (\mathrm{L/K})\mathrm{ti}]^2$
is the contribution of the labour per capital
$\overline{\lambda}\Delta \ln \overline{(\mathrm{DT/K})} = \lambda 1 \Delta \ln (\mathrm{DT/K})\mathrm{t,i} + \lambda 2[\Delta \ln (\mathrm{DT/K})\mathrm{ti}]^2$
is the contribution of the digital technology per capital
$\overline{\delta}\Delta \ln \overline{(\mathrm{P/K})} = \delta 1 \Delta \ln (\mathrm{P/K})\mathrm{t,i} + \delta 2[\Delta \ln (\mathrm{P/K})\mathrm{ti}]^2$
is the contribution of the pollutant emisssions per capital
$\varepsilon\mathrm{t,i}$ is the residual term that proxies for digital TFP per capital growth($\Delta \ln (\mathrm{TFP/K})\mathrm{t,i}$)
Δ is the difference operator denoting proportionate change rate.

It Following the output and labour productivity models' procedures, the intercept (a) has no value in the calculation of the productivity growth indicators as measuring other variables that are not considered in the models, subsequently it drives as follows:

$$\Delta \ln (\mathrm{GDP/K})\mathrm{t,i} = \overline{\beta}.\Delta \ln\ \overline{(\mathrm{L/K})}\mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/K})}\mathrm{t,i} + \overline{\delta}.\Delta \ln\ \overline{(\mathrm{P/K})}\mathrm{t},\\ \mathrm{i} + \Delta \ln (\mathrm{TFP/K})\mathrm{t,i} \tag{10}$$

Where $\overline{\beta}$, $\overline{\lambda}$ and $\overline{\delta}$ indicate the portions of labour per capital, the digital technology per capital, the pollutants' emissions capital and (TFP/K), is the digital TFP per capital contribution as a digital technology spill over effect indicator to transform the countries, sectors firms understudy into sustainable digital economies.

Finally, to compute the average annual growth rate contribution of the TFP per capital, alongside other productivity indicators' contributions in the model, Eq. (10) converts into the followings:

$$\begin{aligned} &\Delta \ln (\mathrm{TFP/K})\mathrm{t}, \mathrm{i} = \Delta \ln (\mathrm{GDP/K})\mathrm{t}, \\ &\mathrm{i} - \left[\overline{\beta}.\Delta \ln \ \overline{(\mathrm{L/K})}\ \mathrm{t}, \mathrm{i} + \overline{\lambda}.\Delta \ln \ \overline{(\mathrm{DT/K})}\ \mathrm{t}, \mathrm{i} + \overline{\delta}.\Delta \ln \ \overline{(\mathrm{P/K})}\ \mathrm{ti}\right] \end{aligned} \tag{11}$$

The digital capital productivity growth decompresses into the labour per capital contribution, increasing production of the digital technology per capital and the pollutants' emissions per capital as a desirable output in the form of unpriced products. Besides, the digital TFP per capital contribution as combined input qualities as reaffirmed in Eq. (11).

5. Discussion

It has been stated by World Bank [10] that beyond pandemic periods, the statistical capacity to yield and commendably employ fundamental economic and social data is inadequate. Numerous lower economic states are incapable to precisely track public finances, report on external debt or screening their development goals. Without such data, the capability to grasp regimes accountable and track progress shortcomings, as well as data governance preparations to enable countless data use while protecting against misappropriation stays in their beginning. It should be recalled that the legal and regulatory frameworks for data are inadequate in lower-income countries, which all too frequently have gaps in critical safeguards as well as shortages of data-sharing measures. There, the data systems and infrastructure that enable interoperability and allow data to flow to more users are incomplete. In this respect, less than 20% of low- and middle-income countries have modern data infrastructure such as colocation data centres and direct access to cloud computing facilities in same countries calls Department of Statistics that collected data via annual survey among others. Even where promising data systems and governance frameworks exist, a lack of institutions with the requisite administrative capacity, decision-making autonomy and financial resources holds back their effective implementation and enforcement. To discourse these worries, the World Development Report 2021 requests for a new social contract for data to permit the usage and recycle of data to generate economic and social worth, encourages unbiased chances to benefit from data and raises inhabitants' confidence that they will not be abused by misappropriation data provided. Nevertheless, in looking for such a social contract, lower-income countries are otherwise frequently deprived since they lack the infrastructure and skills to capture data and turn them into value. It should be noted that the scales and organisations to contribute rightfully in universal data marketplaces and their governance and the institutional and regulatory frameworks to build trust in data organisations.

Thanks to the World Development Indicators (WDI) of the World Bank and International Monetary Fund (IMF) financial database system for providing free access to their databases that assisted many researchers, scholars to conduct research around the globe. Thanks to other organisations such as International Telecommunications Union (ITU) of the UN, among others, if they provide free access to their databases to help those who are in need to this data and are not able purchase it due to financial constraints to conduct research worldwide.

The proposed quantitative data for this research ranging from GDP, gross physical capital, human capital proxies, air, water and other pollutants' emissions proxies, human capital index, human development, CO_2 emissions, the level of well-being, etc. which do not include only material/economic aspects will be obtained from the World Development Indicators (WDIs) of the World Bank, financial data system of International Monetary Fund (IMF) and other data sources including individual countries and institutions.

While digital technology proxies will be obtained from International Telecommunications Union and other sources provided this data include cybersecurity data.

The fundamental element is that with appropriate public policies, technological progresses foster the well-being that is deliberated positive externalities of digital technologies that have designed the digital economy everywhere in the world. Nonetheless, there are negative externalities accompanying with this technology progress in the form of undesirable output alongside the desirable output. These negative externalities associated with digital technology progress comprising cybersecurity and the mismatch of human skills in augmenting the digital dividends created by the new factors of production significant contribution to the long-run sustainable economic growth. Besides its counterparts' negative externalities generated as undesirable output by pollutants' emissions that this study based the digital technologies negative externalities assumption on it.

This chapter develops the innovation and climate change integration with economic growth. The Sustainable Development Goals (SDGs) agenda to achieve sustainability issues will be empirically examined via this chapter models and frameworks to realise the long-term economic growth based on a digital economy transformation that will allow to technologically progress and environmentally and socially sustainable. This advancement is essential to sustain long-term economic growth, protect the environment and sustain social evolution through innovation and the spill over effects carried about by the implementation of the SDGs agenda.

It should be noted that the supreme momentous impact in terms of the methodology is that three positive and negative externalities productivity frameworks were established and exhibited how to measure the apprehension variables through primary data (questionnaire) and qualitative analysis (interview and case studies). Furthermore, for the studies that will employ secondary data, this chapter closed the gaps of existing productivity models through three modified models to estimate and calculate digital technologies positive and negative externalities alongside traditional productivity indicators' contributions to industries, firms, sectors and the economies in a combined econometric and the traditional growth accounting methods to estimate explanatory variables' coefficients that is disregarded by growth accounting studies. Whereas in a second step, productivity indicators are proposed to be calculated through plugging of the estimated explanatory variables' coefficients into the models to calculate the productivity indicators that were ignored in the econometric method. In doing so, the study contributes significantly via filling extensive growth theory (output) and intensive growth (labour productivity) gaps. Furthermore, the most significant contribution of this study is treating the digital technologies cybersecurity negative externalities spill over effects equivalent to the negative externalities generated by pollutants' emissions and developing capital productivity framework and model that were ignored in most of the studies with the exception of [1–4, 41] studies.

Moreover, these frameworks and models can be applied at the microeconomic level for sectors, companies and other business based on the available data. Besides, the proposed qualitative method to capture the information and data that cannot be captured via quantitative method, this they will be in form of interviews with the experts and case studies among other qualitative methods such as focus groups among others. The proposed three frameworks and models can be employed to analyse secondary data through econometric estimation and the calculation of productivity indicators for the secondary data at the Macro and micro levels. A questionnaire survey to collect the primary data can be designed and distributed based on this chapter proposed frameworks. Likewise, a qualitative approach can be conducted via interviews with experts to capture the data and information that could not be captured via a quantitative approach.

6. Conclusions and policy implications

The research ideas and output are expected to contribute to and fill the knowledge gaps in the form of modified models and frameworks that examine the digital economy and digital inclusion at the macro and micro levels; these aim to achieve digital transformation. The empirical findings will be generated via employing this chapter proposed models and frameworks can help to develop recommendations based on the empirical findings will be generated and policy implications that will be generated based on the most expected significant empirical findings to be used by policymakers, industry and academics. It could also be used by international organisations and other concerned institutions around the world as a podium to implement the SDGs to sustainable digital economies and businesses around the globe.

To ensure enhanced coherence, it needs to utilise these study frameworks and models to empirically examine the SDGs sustainability issues in general and digital technologies in particular. In doing so, they could achieve long-term economic growth based on a digital economy transformation that will allow them to be transformed into the digital technological base required to sustain long-term economic growth. They would also protect the environment through the innovation and spillier effect brought by the implementation of the SDGs agenda related to the digital inclusion in general and financial inclusion in particular. This study's outcomes will provide a digital economy framework and policy implications and recommendations to enhance cooperation, collaboration and smart partnership between and within the countries in the fields of knowledge transfer, technological progress, digital assets and the development of intellectual property. Adopting the suggested frameworks could help sustain long-term economic growth to overcome the impact of COVID-19 and possible future pandemics. Digital technology applications can facilitate the economic activities needed to fight hunger and achieve food security, provide good health and well-being, quality education, clean water and sanitation, affordable and clean energy, industry, innovation and infrastructure.

It will provide recommendations, policy implications and solutions to the problems facing in implementing the digital technology applications to transform their economies into digital economies and to implement the new technologies in the future to achieve the SDGs.

The aggregate economy, economic sectors, industries and companies will be provided with solutions and guidelines to implement digital technology applications to transform into digital economies. The proposed frameworks and models will be empirically examined in the economies, sectors and companies to provide practical solutions to sustain the economic development via the digital solutions needed to overcome the problems and lessons learned in the post-COVID-19 era and to develop policies to be implemented by public and private sectors to achieve sustainable development.

This study proposed ideas based on frameworks and models that will be useful for digital technology policy construction as a foundation for the establishment and growth of a digital economy based on digital economy level. In this setting, a contrast of digital technology's contributions to productivity growth would provide guidelines for policy-makers to frame suitable national digital transformation policies in line with the digital transformation programme. The findings from this study will likewise support the construction of a digital technology investment policy and help the development of the human capital and infrastructure needed to support the effective use of the digital technology, this should be supported by good governance, implementation of corporate social responsibility.

It should be noted that the countries can capitalise on their synergy within and between the countries to fully practice the competitive advantages to overhaul their digital assets' deficiencies. In that circumstance, the countries will be able to accelerate the movement towards a digital technology-savvy nation that is accomplished by the members of the Organisation for Economic Cooperation and Development (OECD), such as Europe, USA, Canada, Australia, Japan and South Korea and non-OECD countries such as China.

This study proposed that a digital transformation programme should be taken by countries to narrow the digital divide and dividends brought by digital technologies and to improve digital technology dividends. This would contribute to the transformation of digital economies and make a difference for the nations to enjoy high living standards and well-being, like their OECD counterparts. In addition, classifying the lagging concerning the adoption of digital technology and human capital development delivers a standard to improve cooperation and a smart partnership within and between countries. In this respect, the first phase to relocation to digital economies is an emerging digital economy master plan to identify the policies and strategies to develop digital economy flagships and pillars to improve the existing digital economy flagships and pillars for the countries such as Malaysia, among others, including refining and developing digital economy institutions that needed to facilitate knowledge economy activities and governed them. In this respect, the guidelines are provided for developing a digital economy blueprint and policy implications for digitising the whole economies in general and Small and Medium Enterprises (SMEs) and Micro level in particular. A framework for a digital transformation and developing digital economies should be produced to serve as a guideline for digital economy implementation.

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