



Green Technological Progress Implications on Long-Run Sustainable Economic Growth

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Abstract

The main objective of this study is to model and examine the green technological progress's positive and negative externalities spillover effects on the sustainable economic growth of 15 economies from Asia, the Pacific, and Latin America. The study calculated labour and capital contributions to green total factor productivity growth via the inclusion of CO₂ emissions as undesirable output or private unpriced input and energy consumption that proxies for unmeasured pollutant emissions. The results, in most cases, confirm that a high level of air pollutant emissions generated by these countries' economic development affected the growth rates of TFP growth as an indicator of green technological progress. The significant contribution of this study is to integrate innovation and climate change in the form of green productivity (green technological progress). The role of these externalities on long-term sustainable economic growth has been ignored by several past studies undertaken in these areas.

Keywords Economic growth · Green technological progress · CO₂ emissions · Energy consumption · Asia · The Pacific · Latin America

Introduction

The concept of green productivity (GP) is drawn from the integration of two important developmental strategies, viz. productivity improvement and environmental protection. Productivity offers the context for constant enhancement, whereas environmental fortification delivers the underpinning for sustainable development. Consequently, it is a GP approach for productivity augmentation and environmental

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presentation for inclusive socio-economic development (). Moreover, the Asian Productivity Organization (APO, 2002) showed that the GP programme acts as a disaster inhibition instrument in Asia, whereas its concentration is on productivity enhancement and environmental safety. In the concluding investigation, the GP programme circulates disaster deterrence over comprehensive environmentally approachable production procedures. As demonstrated in the two cases (productivity enhancement and environmental shield), the GP programme really improves productivity by taking an active attitude in averting catastrophes to the environment and to the organisations themselves and society at large as well. Through nearly 50 GP connected schemes in 1998, the GP concept has remained entrenched in the 18-member country productivity movements of the Asian Productivity Organization. Tied with further environmentally wide-ranging practices, like green accounting and green purchasing, the GP programme is brilliant for organisations and governments to adapt more responsible and accountable in following sustainable development (Asian Productivity Organisation, 2002).

Moreover, Romer's (1986, 1987a, 1987b, 1990, 1993) fundamental endogeneity of technological change focus highlighted how the economy can inflate the limitations, and consequently the potentials, of its forthcoming happenings that are so-called positive externalities. Besides, Nordhaus (1974, 1975, 1977, 1994, 2013, 2014, 2017, 2018) fundamental challenges of climate change focus stressed the negative side of economic activates or the so-called negative externalities. Both Romer and Nordhaus accentuate that the market economy, whereas a commanding engine of human development, has vital inadequacies; their contributions have thus distended understandings of how government policy could possibly augment the long-run well-being. It should be noted that the current study joins Romer and Nordhaus's fundamental research findings in developing a framework and model to measure the green technological progress that is employed in long-term sustainable economic growth measurement in its twofold extents (sustainable technological progress and environmental sustainability).

Furthermore, as indicated in the United Nations Environment Program (UNEP) report, sustainable development (SD) is similarly often precise as the development that expands healthcare, education, and social well-being. Such human development is now documented as serious to economic development. Approximately, the authors have extended the sustainable development definition supplementary to comprise a fast revolution of the technological base of industrial civilisation. They argue that new technology that is a detergent (green technology), more resourceful, and thrifter of natural resources is desired to diminish pollution, support steady the climate, and accommodate growth in populations and economic activity. Sustainable development is a progression necessitating parallel worldwide evolution in a disparity of proportions (economic, human, environmental, and technological progress).

Concerning the negative externalities connected with environmental reimbursements, Ahmed (2018) indicates that the green productivity notion is careworn from the integration of two chief progressive approaches, namely, productivity augmentation and environmental precaution. Productivity offers the framework for ceaseless progress, whereas environmental precaution delivers the underpinning for long-run economic growth and sustainable development.

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 through the existence of improved business models. It is consequently an accurate approach to upsurge productivity and safeguards the environment simultaneously Ahmed (2018). Additionally, the United Nations (UN) Sustainable Development Summit held in New York in September 2015 approved the goal of the sustainable development agenda by 2030 (UN (2015)). The UN summit proposed a new indicator framework, accompanied by global and collective indicators, for international partnership and cooperation to accomplish sustainable development for 2015 and 2030, including 17 new Sustainable Development Goals (SDGs). Every country should arrange these 17 SDGs based on its country's needs and development phases not distinct as agreed by the UN. For instance, for some countries' prerequisites to implementing goal 16 (peace, justice, and strong insinuations), before other goals are acquired, these countries experience institutional failure, depraved leadership, and lack of governance and economic planning beside as shortcomings that should be fixed via implementing goal 16.

It should be noted that Bill Gates (The Telegraph, 2022) warns that the world will miss nearly all UN development goals by 2030 without radical inventions. "In a report published on Tuesday 13 September 2022, the Bill and Melinda Gates Foundation said that all the 17 development goals set by world leaders in 2015 would be missed unless cutting-edge solutions emerged. It said that without new innovation, some goals, such as gender equality, would not be hit until 2108 – three generations later than expected". There is a need to link the SDGs to the digital technological issues brought by the digital revolution before implementing the 17 SDGs. This study recommends these 17 SDGs should be revised as some of them are obsolete due to the digital economy issues brought by fourth industrial revaluation (Industry 4.0) digital technologies and new business models associated with COIVD-19 implications. The revision of the 17 SDGs should be taken and link to the digital technology brought by digital revolution and issues brought by COIVD-19 implications; otherwise, the SDGs' goals will not be achieved by 2030.

In this respected, Ahmed (2022a, 2022b) reviews the new issues that should be considered to review the SDGs as indicated in the Digital Economy Report 2021 that takes a profound joint into the development and policy implications of cross-border flows of digital big digital data as principal to all fast-evolving digital technologies. These comprise digital data analytics, artificial intelligence (AI), blockchain, the Internet of Things (IoT), cloud computing, and other Internet-based services. The topic is appropriate, as the enlargement of big digital data flows elements for the accomplishment of virtually all the SDGs. Countries around the world are struggling to oversee how to contract with them from a policy outlook. The definitive method selected at national and international levels will affect not only trade, innovation, and economic progress but also an array of issues interrelated to the advantages delivery from digitalisation in the form of digital dividends.

Literature Review

It should be noted that Ahmed (2012a, 2012b) studied an empirical model to examine factors determining the green total factor productivity (GTFP) and TFP growth. Besides, several studies followed Ahmed (2012a, 2012b) such as the study undertaken by Ahmed, (2020; unlike Ahmed (2012a, 2012b) study that is used both econometrics and growth accounting approaches, Zhu et al. (2018) analyse the GTFP in China mining and quarrying industry via employing data envelopment analysis (DEA) approach during 1991–2014. It should be recalled that Zhu et al.'s (2018) results indicate that the GTFP showed a positive contribution as a result of technological advancement used by the Chinese mining and quarrying industry. Moreover, Rusiawan et al. (2015) found a TFP negative average growth by internalising CO₂ emissions in Indonesia during the period 1976–2010. Maciel and Freitas (2019) “in an exploratory and bibliographical research propose a model for the measurement of the level of Organizational Green Productivity through the environmental problems generated by productive activities and the concern of organisations to align their productivity to environmental protection. The study measures GP at levels (high, medium, low), as well as the situation of the company before such levels (optimum, good, regular, bad and awful)”.

Further, using the translog model, Misra (2019) computed the TFP in India in periods 2001–2008 and 2009–2015 and found that the TFP growth decreased in the second period, which indicated the post-international financial crisis period. Further, Shen et al. (2020) utilised the stochastic frontier analysis method to calculate sustainable total factor productivity growth in 30 China provinces in the period 2006–2016 by incorporating human development index and ecological footprint index in translog in the production function. The result reveals that the overall sustainable TFP growth was slow in Chin.

Meanwhile, Ahmed (2012a, 2012b) found that the growth rates of TFP decreased when CO₂ emissions internalised in the model in Malaysia, Indonesia, the Philippines, Singapore, Thailand, China, Japan, and South Korea, where the impact of CO₂ emissions on productivity growth attributed to the low contribution of GTFP growth.

Finally, Astorga et al. (2011) studied productivity growth in Latin American countries, particularly Argentina, Brazil, Chile, Mexico, Colombia, and Venezuela. The result reveals that the growth of TFP was low during the century and negative in the third sub-period. They also mentioned that fixed capital accumulation and skilled labour were considered major productivity growth sources throughout the twentieth century in Latin America. Goel and Ram (1994) examine research and development (R&D) as an important factor that determined the sources of economic growth in less developed countries (LDCs). Jones (1995) argues that the scale effect prediction of many R&D-based growth models is inconsistent with the industrialised countries' time series evidence.

Meanwhile, changes in productivity are a vital apprehension in any economy due to the linking between productivity and living standards (Ahmed (2020, 2018, 2017 and 2012a, b)). The ultimate goals of productivity enhancement are uncountable competitiveness, larger profitability, higher living standards, and well economic

and social prosperity. In this regard, total factor productivity (TFP) is categorised as the collective contribution of the factors of production qualities and an indicator of the technological progress (green technological progress) that shows the spillover effects that should transfer the technology to the hosting economy and upgrade the skills of its human capital, which is called productivity driven. TFP can describe the balanced growth that captured both positive and negative externalities spillover effects (green technical progress) in an 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.

Nevertheless, the approaches used to measure productivity growth commonly overlooked the pollutants emissions that produced as undesirable output beside the main products. For instance, pollutant emissions produced as undesirable output in addition to the production core output were omitted in the studies employed the productivity accounting framework. This study tries to encompass productivity measures by taking into account pollutant emissions into production functions as unpriced inputs and proxies other pollutants emissions that priced such as energy consumption that captured unmeasured pollutants emissions. The pollutant emissions under consideration include carbon dioxide (CO₂) (which measures air pollution) and energy consumption. This followed Solow (1956, 1957) by internalising the pollutant emissions composed with the inputs used in conventional production functions. Accordingly, TFP growth converted green productivity (green technological progress). This takes into account economic development and environmental protection followed Pittman (1983), Gollop and Roberts (1983), Baumol and Oates (1988), Chaston et al. (1997), Gollop and Swinand (1998), Gollop and Swinand (2001), and Harchaoui et al. (2002) studies.

This study combined the integration and environmental protection in the form green technological progress that is addressed in the ultimate discoveries of Nordhaus and Romer's (2018) research results that granted the Nobel Prize in economics 2018. Their findings presented introduced frameworks and models to measure long-term sustainable economic growth through developing framework and model to measure green technological progress. The green technological progress notion is strained from the integration of innovation and environmental protection based on two vital progressive strategies, namely, productivity improvement and environmental protection. Productivity offers the context for continuous enhancement, while environmental shield delivers the sustainable development underpinning.

Hence, green technological progress is an approach for enhancing productivity and environmental presentation for inclusive socio-economic development. It is a dynamic approach that can balance economic growth and environmental safety for sustainable development. It tenders small and medium enterprises with a method to accomplish a competitive advantage by existence better but using less. It is thus an accurate plan to upsurge productivity and guard the environment simultaneously.

This study fills the gaps in growth theories by developing a framework and an econometric model and internalising the pollutants' emissions as private and unpriced inputs of carbon dioxide (CO₂) and energy consumption that proxies for the pollutants emissions that are not captured by CO₂. Accompanying, the green

technological progress model is this study significant contribution. Furthermore, this study closed the gap in the growth accounting theory model by providing statistical analysis in a parametric form that removed the doubt in the results generated.

Methodology and Estimation Process

Determining the inputs and outputs qualities are essential to measuring green TFP. Therefore, capital, labour, and energy consumption are considered standard inputs, while Gross Domestic Product per Capita and CO₂ emission are considered desirable and undesirable outputs, respectively (see Shao et al., 2016; Li & Lin, 2016; Zhu et al., 2018). Therefore, this study follows the existing literature trend and used capital, labour, and energy consumption as inputs. The output gross and CO₂ emission are chosen as desirable and undesirable outputs, respectively. Data and research focus are more important for variables selection (Feng et al., 2017; Rusiawan et al., 2015).

This study modified and empirically examined the model proposed by Ahmed (2020) and filled its gap via including the GDP per capita and energy consumption that were ignored by Ahmed's study to calculate green total factor productivity (GTFP) per capita using the growth accounting method via internalising CO₂ emission and energy consumption with capital and labour as the main factors in the period 1990–2018 the empirical data from 15 selected countries of Asia, Pacific, and Latin America.¹ To fill the gap in the growth accounting approach and measuring the GTFP per capita, this study proposes using parametric analysis based on a combined method of parametric analysis and Divisia index approach developed by Jorgenson et al. (1987). This technique considered filling the gaps in both econometric estimation and growth accounting into two steps to calculate GTFP per capita. First, the econometric model has been estimated, and then the estimated coefficients have been plugged into the growth accounting model to calculate the GTFP per capita indicators. This study applied an extensive growth model to estimate the inputs' coefficients and calculate the GTFP per capita and other productivity indicators following Ahmed's (2006, 2007, 2010, 2012a, 2012b 2018, 2020) studies. For this purpose, this study used the Cobb–Douglas production function and Solow's residual model as a modified model to fill the gaps mentioned. Thus, the production function expressed in the following equation:

$$GGDP_{i,t} = f(K_{i,t}, L_{i,t}, CO_{2i,t}, EC_{i,t}, T_{i,t}) \quad (1)$$

where $GGDP$, K , L , CO_2 , EC , and T proxied for GTFP are green real per capita gross domestic product, physical capital, labour, carbon dioxide emissions, energy consumption, and green total factor productivity, respectively; i represents country (1, 2, 3...0.15); and t represents years (1990–2018). Green real per capita gross domestic product is used to measure green outputs (green economic growth); gross fixed

¹ China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, Korea, Thailand, Australia, New Zealand, Argentina, Brazil, Chile, and Colombia.

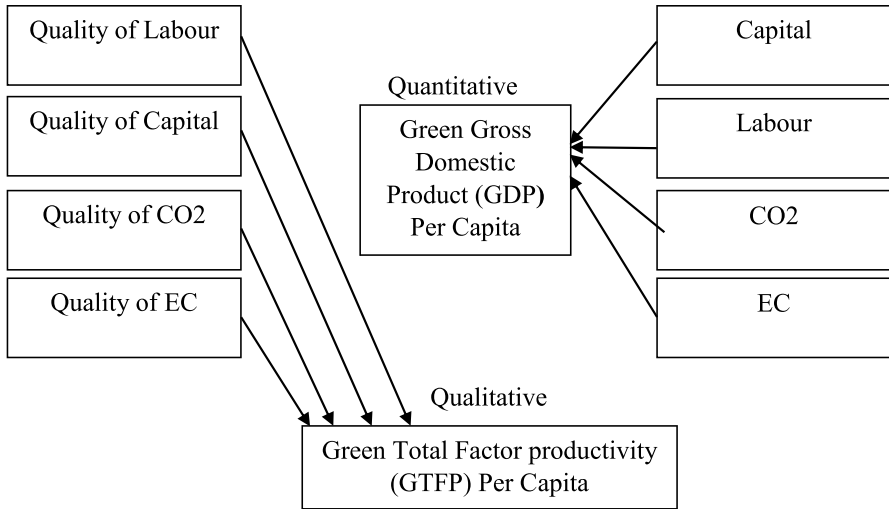


Fig. 1 Green productivity per capita framework and extensive growth theory (source: Ahmed (2020))

capital formation (% of GDP) is used as a proxy for physical capital; labour is captured by labour force; carbon dioxide emission CO₂ and energy consumption are for measuring air pollution and water pollution; energy consumption is used instead of biochemical oxygen demand (BOD) in Ahmed’s (2020) framework; GTFP proxy for technological advancement and sustainable development are indicators of the economies (Ahmed, 2020). Accordingly, Ahmed (2020) framework’s which described the combination of green gross domestic product (green economic growth) and green total factor productivity is presented in Fig. 1.

The extensive growth theory that expresses the relationship between physical capital, labour force, carbon dioxide emissions CO₂, energy consumption, and green real gross domestic product per capita can be presented in the following parametric model:

$$\Delta \ln GGDP_{i,t} = \alpha + \beta \cdot \Delta \ln K_{i,t} + \gamma \cdot \Delta \ln L_{i,t} + \delta \cdot \Delta \ln CO_{2i,t} + \varphi \cdot \Delta \ln EC_{i,t} + \mu_{i,t} \quad (2)$$

where α represents the intercept or constant of the model; β is the elasticity of output concerning capital; γ represents the elasticity of output for labour; δ is the elasticity of output with respect to carbon dioxide emissions; φ is the elasticity of output with respect to energy consumption; μ is the residual term²; \ln is the logarithm to transform the variables; and Δ represents the difference operator indicating proportionate change rate.

² The residual term used as a proxy for the growth of total factor productivity, which is considered as an economy technological progress through input quality terms.

In the computation of productivity growth indicators, the intercept has no longer been used (Ahmed, 2020); therefore, the next step is to calculate the growth rates of productivity indicators by converting Eq. 2 into the basic growth accounting extended framework as follows:

$$\Delta \ln GTFP_{i,t} = \Delta \ln GGDP_{i,t} - [\beta \cdot \Delta \ln K_{i,t} + \gamma \cdot \Delta \ln L_{i,t} + \delta \cdot \Delta \ln CO_{2i,t} + \varphi \cdot \Delta \ln EC_{i,t}] \quad (3)$$

where the shares of the average value gave the weights as $\Delta \ln GTFP_{i,t}$ is the growth rate of green total factor productivity; $\Delta \ln GGDP_{i,t}$ represents the output per capita growth rate; $\beta \cdot \Delta \ln K$ is the aggregate physical capital contribution; $\gamma \cdot \Delta \ln L_{i,t}$ is the aggregate labour contribution; $\delta \cdot \Delta \ln CO_{2i,t}$ is the contribution of aggregate carbon dioxide emissions CO_2 ; and $\varphi \cdot \Delta \ln EC_{i,t}$ is the contribution of aggregate energy consumption.

Data Sources

The data used in this study covered the period of 1990–2018 that was collected from different sources. Carbon dioxide emissions and energy consumption are obtained from the Statistical Review of the World Energy published by BP (2020), while gross domestic product per capita, gross fixed capital formation, and labour force are extracted from World Development Indicators database published by the World Bank (2020).

Econometric Analysis

This study goes through two steps to measure green total factor productivity (TFP). The first step is to estimate the econometric model of extensive growth theory for all individual countries presented in Eq. 2. The second step is to calculate productivity indicators for all individual countries. The model used in this study was specified in the first differences, and the calculated growth rates were used in the discussion of the results and findings of the study. Before estimating the model, the data stationarity was tested using Phillips–Perron (PP) and augmented Dickey–Fuller (ADF) unit root tests. GDP is the dependent variable, the independent variables are K which is the physical capital and L which is the number of labour force, CO_2 proxies for air pollutant emissions, and EC is the energy consumption, the results are presented in Tables 1 and 2, respectively.

The unit root test results in Table 1 revealed that gross domestic product per capita, carbon dioxide emission, and energy consumption are stationary for all the countries except China. In contrast, the gross fixed capital formation was found to be stationary for all the countries. However, the labour force was found to be stationary for all countries except India, Japan, and Singapore. The result in Table 2 supports the result in Table 1 and shows the gross fixed capital formation and labour force are stationary for China as well.

Table 1 Phillips–Perron (PP) unit root test at first difference

Country	Deterministic	GDP	<i>K</i>	<i>L</i>	CO ₂	EC
China	Constant	-1.9754	-3.2469**	-0.1412	-2.003	-1.8953
	Constant & trend	-2.6169	-3.26*	-4.4658***	-2.0549	-1.8855
India	Constant	-5.0972 ***	-5.9744***	-1.1487	-5.2057***	-4.7139***
	Constant & trend	-9.9418***	-6.1508***	-2.0623	-5.155***	-5.024***
Indonesia	Constant	-3.8133***	-3.1036**	-3.2772**	-4.6361***	-4.1414***
	Constant & trend	-3.7806**	-3.1885	-3.2452*	-4.8507***	-4.2951**
Japan	Constant	-6.0632***	-2.9878**	-2.3891	-6.2936***	-6.1279***
	Constant & trend	-5.9243***	-3.5357*	-1.688	-7.2026***	-7.4401***
Malaysia	Constant	-4.8577***	-4.2457***	-2.7659*	-6.3813***	-6.3867***
	Constant & trend	-4.7994***	-4.2002**	-2.8475	-12.8008***	-17.178***
Philippine	Constant	-3.2109**	-4.8767***	-4.277***	-4.5646***	-4.3333***
	Constant & trend	-4.9076***	-5.0071 ***	-5.2032***	-4.4707***	-4.2163**
Singapore	Constant	-6.3432***	-2.9846**	-1.8254	-3.4427**	-6.6207***
	Constant & trend	-6.775***	-2.9527	-1.9956	-3.4343*	-6.9272***
Korea	Constant	-5.2037***	-4.6692***	-5.0074***	-4.6288***	-4.2524***
	Constant & trend	-13.8287***	-6.4466***	-5.1549***	-5.2944***	-5.4933***
Thailand	Constant	-3.5927**	-3.3768**	-3.4868**	-3.2859**	-3.4397**
	Constant & trend	-3.5084*	-3.3618*	-4.798***	-3.6577**	-3.9556**
Australia	Constant	-3.8235***	-5.5563***	-3.8362***	-4.2664***	-5.1204***
	Constant & trend	-6.4648***	-6.475***	-3.9224**	-5.4831***	-6.8109***
New Zealand	Constant	-5.2913***	-4.8198***	-4.7503***	-7.2447***	-6.1531***
	Constant & trend	-5.6063***	-4.7691***	-4.7357***	-8.0004***	-6.2199***
Argentina	Constant	-3.9288***	-4.29***	-4.4215***	-4.623***	-4.9673***
	Constant & trend	-3.995**	-4.3353**	-4.5004***	-4.5506***	-5.1587***
Brazil	Constant	-3.7361***	-4.7377***	-3.613**	-4.2328***	-3.8275***
	Constant & trend	-3.7523**	-4.7984***	-5.397***	-4.5924***	-4.0517**
Chile	Constant	-3.4377**	-6.0764***	-3.2287**	-3.7035***	-4.3379***
	Constant & trend	-4.1641**	-5.9877***	-3.1792	-3.8402**	-5.0373***
Colombia	Constant	-3.0613**	-4.185***	-3.3125**	-5.6886***	-4.7986***
	Constant & trend	-2.9775	-4.1063**	-3.3248*	-5.586***	-4.7261***

***, **, and * denote significant at 0.01, 0.05, and 0.10 levels, respectively

Table 2 Augmented Dickey–Fuller (ADF) unit root test at first difference

Country	Deterministic	GDP	K	L	CO ₂	EC
China	Constant	-1.8163	-3.4948**	-2.1024	-1.8117	-2.2375
	Constant & trend	-2.4709	-3.5494*	-3.8492**	-1.8694	-2.2107
India	Constant	-4.9572***	-6.0468***	-1.1487	-2.3826	-2.3882
	Constant & trend	-4.3104**	-6.2149***	-2.0623	-2.1565	-2.9946
Indonesia	Constant	-3.8386***	-3.0803**	-3.3866**	-4.6361***	-4.1414***
	Constant & trend	-3.8166**	-3.1474	-3.3663*	-4.2527**	-3.9875**
Japan	Constant	-5.6289***	-3.0682**	-2.3624	-6.2936***	-6.2225***
	Constant & trend	-5.5206***	-3.7121**	-1.688	-4.4416***	-7.4401***
Malaysia	Constant	-5.8322***	-4.3079***	-4.7722***	-6.3813***	-2.4171
	Constant & trend	-3.9544**	-3.7906**	-4.7745***	-6.2793***	-7.0009***
Philippine	Constant	-3.2765**	-4.8813***	-0.6851	-4.4918***	-4.2115***
	Constant & trend	-3.9914**	-5.0071***	-1.465	-4.3852***	-4.0655**
Singapore	Constant	-4.8945***	-3.5781**	-1.8254	-4.1689***	-5.261***
	Constant & trend	-4.9928***	-3.0805	-1.9956	-4.1348**	-5.2***
Korea	Constant	-5.2016***	-4.9073***	-5.0074***	-2.6174	-3.3716**
	Constant & trend	-4.4893***	-3.3458*	-5.1549***	-4.1863**	-4.302**
Thailand	Constant	-3.5904**	-3.7698***	-3.5135**	-4.4226***	-4.2075***
	Constant & trend	-4.3575**	-3.7582**	-4.8291***	-3.5627*	-5.1275***
Australia	Constant	-3.8235***	-5.1472***	-3.9***	-4.2124***	-1.8452
	Constant & trend	-4.4576***	-5.0995***	-3.9812**	-3.661**	-2.63
New Zealand	Constant	-5.4885***	-4.8744***	-3.4259**	-3.0683**	-2.6218
	Constant & trend	-5.652***	-4.8258***	-3.0747	-8.3663***	-2.7772
Argentina	Constant	-3.9683***	-4.3215***	-4.4355***	-4.621***	-4.9628***
	Constant & trend	-3.9949**	-4.36***	-4.5004***	-4.5471***	-5.1576***
Brazil	Constant	-3.7361***	-2.8746*	-3.6613**	-2.7491*	-3.8275***
	Constant & trend	-3.7523**	-4.799***	-5.3766***	-4.5936***	-4.0517**
Chile	Constant	-3.4782**	-5.4772***	-3.2404**	-3.7252***	-4.3379***
	Constant & trend	-4.1971**	-5.3638***	-3.188	-3.9258**	-5.0377***
Colombia	Constant	-3.0295**	-4.1646***	-3.2888**	-2.8916*	-2.2051
	Constant & trend	-2.9388	-4.0844**	-3.2963*	-5.605***	-2.1787

***, **, and * denote significant at 0.01, 0.05, and 0.10 levels, respectively

To estimate the econometric model of extensive growth theory for all individual countries presented in Eq. 2, the ordinary least squares (OLS) have been applied. The results are reported in Table 3. The estimated coefficients for all individual countries presented in Table 3 indicate that the majority of the variables are significant at 1%, 5%, and 10% level.

The values of *R*-squared indicate that 0.997%, 0.996%, 0.975%, 0.899%, 0.989%, 0.963%, 0.982%, 0.990%, 0.988%, 0.995%, 0.982%, 0.970%, 0.972%, 0.997%, and 0.981% of variation in real per capita gross domestic product explained by physical capital, labour, carbon dioxide emissions, and energy consumption in China, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, Korea, Thailand, Australia, New Zealand, Argentina, Brazil, Chile, and Colombia respectively.

Productivity Analysis

The analysis implemented in this study compares the productivity indicators between some Asian, pacific, and Latin American emerging economies for the period 1990–2018. This study aimed to study the effect of governments' policies on improving productivity growth. In economics, total factor productivity measures the total output ratio to the total input factors, usually as capital and labour. However, this study aimed to calculate green total factor productivity by including carbon dioxide emission and energy consumption as factors that have a side effect on the production sector and sustainable development. Therefore, the annual growth

Table 3 Green productivity estimated coefficients

Country	Constant	<i>K</i>	<i>L</i>	CO ₂	EC	<i>R</i> -squared
China	− 100.5***	0.187	6.192***	− 4.826***	5.743***	0.997
India	− 7.914*	− 0.126	0.749**	− 0.766	2.170**	0.996
Indonesia	− 13.84**	0.434***	1.065***	0.108	0.00869	0.975
Japan	− 22.88***	− 0.175***	1.810***	0.785***	− 0.798***	0.899
Malaysia	− 7.711***	0.201***	0.866***	− 0.265	0.722**	0.989
Philippine	− 10.36	0.643***	0.946	0.293	− 0.632	0.963
Singapore	0.427	− 0.230**	0.609***	0.143	0.203	0.982
Korea	− 26.42***	− 0.261	2.041***	0.349	0.0532	0.990
Thailand	16.87***	0.173***	− 0.643**	− 1.046***	1.939***	0.988
Australia	− 2.407	0.0489	0.577***	0.582*	0.0426	0.995
New Zealand	− 1.388	0.146*	0.726***	0.315***	− 0.0734	0.982
Argentina	3.632	0.299***	0.0145	0.434**	0.523	0.970
Brazil	− 0.106	0.233***	0.352***	− 0.249	0.937***	0.972
Chile	− 9.220***	0.112***	1.009***	− 0.0731	0.593***	0.997
Colombia	− 5.241***	0.179***	0.706***	0.0126	0.420*	0.981

*, ** and *** denote significant at 0.01, 0.05, and 0.10 levels, respectively

Table 4 Productivity indicators (in percentage)

Country	GDP	<i>K</i>	<i>L</i>	CO ₂	EC	TFP
China	3.622E-05	0.0032	0.0045	-0.0112	0.0293	0.3221
India	0.0003	0.3551	0.0010	0.0026	0.0008	-0.0158
Indonesia	-0.0049	0.0098	-0.0056	-0.0002	-0.0054	-0.0219
Japan	-0.0012	0.0081	0.0059	-0.0004	-0.0027	-1.5356
Malaysia	-0.0049	-0.0188	0.0001	0.0068	0.0090	-0.0100
Philippine	-0.0132	0.0064	-0.0012	-0.0185	-0.0053	0.0012
Singapore	-0.0044	-0.0170	0.0024	-0.0216	-0.0056	-0.0159
Korea	0.0053	-0.0283	0.1686	0.0009	0.0246	-0.0031
Thailand	0.0031	-0.0170	-0.0082	0.0083	0.0014	0.0178
Australia	-0.0016	-0.0122	0.0022	-0.0042	-0.0097	-0.0146
New Zealand	0.0185	0.0568	0.0024	-0.0159	1.94E	-0.0093
Argentina	-0.0107	-0.0024	-0.0131	-0.0081	-0.0200	-0.0034
Brazil	0.0329	-0.0077	5.1E	-0.0168	-0.0092	0.0537
Chile	-0.0087	0.0043	0.0009	0.0035	-0.0154	-0.012
Colombia	0.0984	-0.0004	-0.0088	-0.0121	-0.0095	-0.0155

of green total factor productivity and its indicators are calculated and presented in Table 4.

Table 4 shows that the annual average growth rate of TFP varied between negative and positive among the countries involved in the study. In contrast, China, the Philippines, Thailand, and Brazil have shown a positive annual average growth rate of TFP among the group. The 0.3221 annual average growth rate of TFP of China is the highest one among the countries. This might be attributed to a positive contribution of capital, labour, and energy consumption as annual average growth rate despite the negative contribution of carbon dioxide emission. Availability of labour and capital inflow enhanced rapid development and expanding industries in China which reflects on positive TFP growth during this period. On the other hand, India shows a negative annual average growth rate of green TFP despite the positive contribution annual average growth rate of capital, labour, carbon dioxide emission, and energy consumption. This might be resulting from high pollutant emissions produced from industry expansion and the Asian financial crisis. The average growth of green TFP in Indonesia was found to be -0.0219; in the study period, this result was supported by Rusiawan et al. (2015). The negative growth of GDP and negative contribution annual average growth rate of labour and energy consumption have a significant role in affecting the average growth of green TFP despite the negative contribution of carbon dioxide emission.

It is also observed that Japan, Malaysia, Singapore, Korea, and Australia have shown decreasing annual average growth rates of TFP. This is probably affected by the declining contribution of capital average growth rate and the negative growth of GDP despite increasing the contribution of the labour average growth rate, decreasing the contribution of CO₂ emission average growth

rate, and energy consumption in Japan and Singapore. New Zealand displayed a decreasing annual average growth rate of TFP due to the decreasing CO₂ emission average growth rate contribution. Argentina has a declining annual average growth rate of TFP. From Argentina, it appears that all productivity indicators have a declining annual average growth rate contribution. Colombia differs from Argentina by increasing the annual average growth rate of GDP. Finally, Chile found to have a declining annual average growth rate of TFP despite the positive contribution of capital, labour, and CO₂ emission annual average growth rate.

Conclusion and Policy Implication

This study aimed to calculate green total factor productivity using the growth accounting method and internalising CO₂ emission and energy consumption with capital and labour as the main factors in the period 1990–2018 in 15 selected countries from Asia, Pacific, and Latin America. The data were obtained from the Statistical Review of World Energy and World Development Indicators database published by World Bank.

This study applied an intensive growth model rather than an extensive growth model. This study aimed to analyse the contributions of labour and capital to green total factor productivity growth by inclusion CO₂ emissions and energy consumption as undesirable output or private input.

The results, in utmost cases, confirm that a high level of air pollutant emissions generated by these countries' economic development affected the growth rates of TFP growth as an indicator of green technological progress.

This study tried to contribute to the growth accounting theory model by providing statistical analysis in a parametric form that removed the doubt in the results generated. The results, in most cases, confirm that a high level of air pollutant emissions in these countries' economic development had affected the growth rates of TFP intensity. This impact is resulting from internalising the CO₂ emissions produced in these countries' economic growth and high energy used as private inputs.

The study establishes that economic activities are connected with the growth rate of CO₂ emissions generated by these economies. This seems in the form of unpriced public bad goods that slow down the productivity growth of these economies in general and the countries' TFP contributions growth in particular.

The inclusion of carbon emissions and energy in this study was found to be the fundamental causes of Asia, Pacific, and Latin America productivity growth diminishing. The main effect of CO₂ emissions on green TFP is observed in the values of the annual average growth rate of green TFP. Productivity is the main key factor of industrial development and economic development of all countries around the globe. Applying imperative control procedures and industrial-based efficient inputs to curb pollution is important because of environmental taxes, environmental regulations, and industries based on clean energy, which

will protect the nations from the negative consequences of CO₂ emissions. From the findings of this study, it is evident that China has high productivity annual growth; this might be due to technological progress (Zhu et al., 2018) and skilled labour availability, capital inflow enhanced rapid development, and expanding industries in China.

This study proposed the urgent need of SDGs' revision to consider the digital technology issues and the COVID-19 implications in order to achieve the SDGs by 2030; otherwise, it will not be achieved as warned by Bill Gates. To warrant improved consistency of SDGs, there is a prerequisite to utilise these study framework and model via considering the new digital factors as big digital data as core to all fast-evolving digital technologies. These include data analytics, artificial intelligence, blockchain, the Internet of Things, cloud computing, and other Internet-based services. To analytically examine the SDGs' sustainability issues in general and digital technologies in particular, these new digital variables as positive externalities beside the negative externalities either environmental or cybersecurity's factors should be included in revising the 17 SDGs. Consequently, revising the SDGs and the inclusion of the new factors brought by digital technologies and the COVID-19 implications might accomplish long-term economic growth based on the integration of innovation and climate change needed by digital economy transformation that will consent the countries under study to be transformed into the digital technological base vital to sustain long-term economic growth. In doing so, these countries and business around the globe will guard the environment through the innovation and spillover effect brought by the implementation of the revised SDGs' agenda associated to the digital inclusion and sustainable development issues. This study's outcomes will provide a framework and model to boost cooperation, collaboration, and smart partnership between and within the countries in the fields of knowledge transfer, green technological progress, digital assets, and the development of intellectual property. The framework and model implementation might support sustainable long-term economic growth to overwhelm the COVID-19 effect and conceivable forthcoming pandemics. Through integration of digital technology applications that consider the negative externalities, it will ease the desirable and undesirable economic activities to fight hunger and achieve food security and provide good health and well-being, quality education, clean water and sanitation, affordable and clean energy, industry, innovation, and infrastructure among other SDGs.

Appendix

This section explains the data sources and the grouping of the countries under study according to income as classified by the world bank into different income categories such as (lower-income economies, lower-middle-income economies, upper-middle-income economies, and high-income economies) as presented in Tables 5 and 6.

Table 5 Description of variables and sources of data

Index	Abbreviation	Units	Source
Real per capita gross domestic product (dependent variable)	GDP	(Constant 2010 US\$)	World Bank (2020)
Fixed capital formation (independent variable)	K	(% of GDP)	World Bank (2020)
Labour force (independent variable)	L	Labour force, total	World Bank (2020)
Carbon dioxide emissions (private variable)	CO ₂	Million tonnes of carbon dioxide	BP (2020)
Energy consumption (private variable)	EC	Primary energy consumption per capita	BP (2020)

BP British petroleum. *World Bank*: World Development Indicators database

For operational and analytical purposes, economies are divided among income groups according to 2020 gross national income (GNI) per capita, calculated using the World Bank Atlas method. The groups are low income, \$1035 or less; lower middle income, \$4046–12,535; and high income, \$12,535 or more

Table 6 Countries and groupings according to income group/geographical region

	High income	Upper middle income	Lower middle income
Asia–Pacific countries			
China	Australia	China	India
India	Japan	Malaysia	Philippines
Indonesia	New Zealand	Thailand	
Japan	Singapore	Indonesia	
Malaysia	South Korea		
Philippine			
Singapore			
Korea			
Thailand			
Australia			
New Zealand			
Latin America and Caribbean countries			
Argentina	Chile	Argentina	
Brazil		Brazil	
Chile		Colombia	
Colombia			

Source: World Bank list of economies (June 2020)

Low-income economies (\$1035 or less)

Lower-middle-income economies (\$1036 to \$4045)

Upper-middle-income economies (\$4046 to \$12,535)

High-income economies (\$12,536 or more)

Data Availability The data used in this research is available to be shared upon request that was collected from different sources.

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