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ICT and education as determinants of environmental quality: The role of financial development in selected Asian countries

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Abstract: Rising environmental concerns due to extensive energy consumption and carbon emission in the process of developing information communication and technology (ICT) cannot be overshadowed by its significant contribution in economic growth. This study is an attempt to explore long run influences of ICT and education on environmental quality. By incorporating the role of financial development, energy consumption and income into the function of carbon emissions, the results obtained by the continuously updated and fully modified (Cup-FM) test indicate that economic growth, education and energy consumption stimulates carbon emissions intensity in Asian countries (1990-2018). The second-generation unit root tests and Lagrange Multiplier (LM) bootstrap cointegration method investigate stationary properties and cointegration. Our findings suggest that investment in technology and financial markets require policymakers' attention as we have empirically established long-run inverse impacts of financial development and ICT on carbon emissions. Furthermore, the study suggests a focus on clean energy policy as the rising pollution levels due to fossil fuel hampers long-run productivity. This paper contributes to the existing literature by proposing that ICT-led economic policies may help solve environmental quality and economic growth issues.

Keywords: Environmental Quality; ICT; Education; Financial development; Economic growth

1. Introduction

The advent of information and communication technologies (ICT) has influenced the global economy through various channels. It has introduced user-friendly e-commerce networks, turned remote areas into new market places, removed entry barriers in the markets, eased social and economic transmission in the education, health and trade sectors and made the production processes more efficient. The gains from ICT suggest its potential role in determining and driving sustainable development and long-term economic prosperity. However, meeting the desired objective of sustainable development goals is subject to green ICT. It has been argued that green ICT can reduce the growth-environment tradeoff and economization of resources (Asongu et al., 2018). By definition, green ICT refers to minimum negative impacts of information technology on the environment and climate changes. The negative impacts of ICTs are related to their cost of energy consumption and carbon dioxide (CO_2) emissions. The empirical literature finds that ICT increases electricity consumption and has nearly a 3% share in greenhouse gas emissions such as CO_2 (Røpke and Christensen, 2012). Avoiding the negative impacts requires upscaling the existing ICT structure to provide a low carbon-emitting process for smart agricultural, financial and industrial setups.

Green-ICT has been considered as a potential solution to environmental issues. This is because green ICT reduces energy consumption and CO_2 emissions by transforming the physical resource involvement into information resources that can be equally efficient in productivity (Sadorsky, 2012; Salahuddin and Alam, 2015). Furthermore, green ICT reduces the transaction and travel costs of those corporations and households that use fossil fuels, which in turn cause CO_2 emissions (Asongu, 2018a). Besides, switching to green ICT systems in countries where the current levels of ICT penetration are low (and where reliance on fossil energy resources is higher) might reduce CO_2 emissions at a higher percentage than in economies that already have higher ICT penetration

(Asongu, 2018b). Moreover, yearly global CO_2 emission reductions of 20% can be achieved by 2030 by systematically planning investment in and expanding the ICT sector[1].

Empirical literature supports two contradictory views on the effect of ICT penetration on the environment. On the one hand, there is extensive literature on the positive effects of ICT penetration on the environment. This literature group emphasizes the *direct substitution effects* of ICT penetration, suggesting that ICT penetration replaces the electricity input-based machines with less energy-intensive hybrid machines (Cai et al., 2013). For instance, (Choi et al., 2010) used a logistic growth model for the Japanese economy and found that energy and electricity consumption declined in the manufacturing sector due to ICT penetration. ICT simultaneously caused an upsurge in electricity consumption and CO_2 emissions in five other sectors (like residential and industrial).

On the other hand, another strand of literature stresses the *direct but negative effects* of ICT on environmental pollution. According to this group of literature, a primary concern is related to the increase in energy and electricity consumption in improving the information technology system. These concerns cannot be overlooked, especially when there is an increase in the production of electricity-dependent commodities. The International Energy Agency (IEA) claims that products like air conditioners, automatic and hybrid machines were contributing 59% of all global CO_2 emissions (2009). The IEA came up with startling estimates regarding electronic products while evaluating the track of CO_2 emissions caused by increased electronic products. However, research-based innovations can play a significant role in increasing the positive spillovers of ICT penetration. For example, by introducing efficient transmission systems in the machine manufacturing sectors of Japan, Korea and China, the contribution to CO_2 emission has been reduced to 34%.

Considering the indirect but positive association of ICT penetration and carbon emissions, appealing work by (Cho et al., 2007) has highlighted the *compensation effects* that ICT diffusion exerts. For example, the South Korean economy has substituted labor with information technology

[1] United Nations Framework Convention on Climate Changes reported (2015)

to reduce production costs in the first stage. The country later experienced positive causality between electricity usage and CO_2 emissions. Similarly, financial development (FD), trade openness, and the *income effect* attract foreign investors to emerging economies, where initial industrialization provides a platform for low-cost startups. On the other hand, easy access to funds nourishes exportable production results in energy consumption and CO_2 emissions and exposes the economy to the *residual effect* (Birdsall and Wheeler, 1993; Frankel and Romer, 1999).

Furthermore, a low-interest rate regime helps those establishing new businesses in terms of profitability. Also, new production plants increase energy resource utilization. However, the absence of a proper waste management policy gives these enterprises leverage that allows them to save their profits, which should be put toward the cost of reducing their CO_2 emissions (Dogan and Turkekul, 2015).

According to Omri, Daly, Rault, & Chaibi (2015), FD encourages people to move to urban areas for better financial returns and opportunities. As such, this resource consumption increment comes at a cost mainly identified through three leading factors. First, FD fosters increased urban populations and an increased waste burden that intensifies environmental problems. Secondly, financial openness boosts employment creation, making luxury items (like private vehicles, air conditioners and other CO_2 emission-creating products) far more affordable. These products add to carbon emissions in the long run. Thirdly, FD attracts foreign investors looking for production facilities with the fewest managerial issues concerning waste management. These foreign firms have been known to pay bribes to obtain a location to dump their production waste without incremental tax increases. This results in the recipient countries experiencing more complicated CO_2 emissions problems (Kasman and Kasman, 2015). However, these dynamics have ignored the role of education, awareness and trade terms, which have been repeatedly mentioned as potential interventions at climate policy conferences (2011, 2015 and 2018).

A recent debate over the complex relationship between negative externality, economic growth and ICT systems has encouraged researchers to explore their theoretical relationship through education and awareness patterns empirically. Consider that ICT refers to a convergence of multiple wires and optics systems to a single and efficient track that can reduce technology expansion's economic and social cost. As such, updated technology through education can play a vital role in this process. Countries like Korea and Japan are investing and expanding their ICT sectors to accelerate economic growth with minimal environmental damage. Several Korean and Japanese companies are coupling ICT with investment in research and development that explores the modern techniques used to reduce carbon emissions. The expansion of the ICT sector and efficient resource mobilization policies can help raise productivity while reducing energy and electricity consumption with the advent of the *transitional effect.* This has been caused by updated education and research that will help control CO_2 emissions in the long run (Coroama et al., 2013; Shahiduzzaman and Alam, 2014; Zafar et al., 2021).

According to the World Bank (2019), growing industrialization in major Asian economies has exposed the world to its highest-ever levels of per capita carbon emissions. China and India have excelled in all economic sectors by increasing ICT penetration and high-tech industrialization, but they jointly contribute nearly 35% of the world's total CO_2 emissions. During the last two decades, Asian economies like India, China, Japan, Thailand and Malaysia have expanded industrial startups to enhance their economic growth. Moreover, FD and liberalization have made these countries more attractive to large manufacturing sector foreign investors. Asian countries like China, India, Singapore, Japan, Thailand and Taiwan have experienced the environmental cost of economic growth, which coincided with the advent of financial openness, trade expansion and foreign direct investment during the past three decades. However, these economies have heavily invested in ICT penetration, to have positive ICT externality for their emissions management streams in the long run. The yearly increments of energy demand (2.4%), natural gas consumption (5.3%) and other fossil fuel consumption (8.9%) of high-tech industrialized Asian economies show that they are moving towards experiencing a nearly 60% higher energy demand in 2030 (as compared to 2000), along with the highest-ever CO_2 emissions rate (International Energy Agency, IEA 2019).

As per the recent SDG progress report, the Asian economies are failing to control the climatic shift issues. Therefore, they are gradually drifting away from attaining SDG 13 (UNESCAP, 2021). This situation can be attributed to the continual usage of fossil fuel-based energy solutions, and this energy usage pattern is exerting a negative environmental externality for the Asian economies. Moreover, following the *Limits to Growth* discourse, this dependence on fossil fuel solutions creates a deterrence on achieving energy security in these nations (Meadows et al., 1972). The latest energy security assessment report by United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP, 2021) has also mentioned this issue as a deterrent in attaining SDG 7. To combat these issues, the policymakers need to build a resilient environmental awareness mechanism, for which a policy realignment might be necessary.

Furthermore, in the educational assessment report, the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2018) has mentioned that embedding ICT and education in the pro-ecological policy regime might help the Asian countries attain the *Agenda 2030*. However, this policy realignment calls for effective mobilization of SDG financing, and this issue was discussed in the 2019 Asia-Pacific Conference on Financing for Inclusive and Sustainable Development (IISD, 2020). Therefore, to ascertain sustainable development in the Asian economies, a realigned policy framework is necessary, and there lies the need for the present study.

The literature has limited evidence on proposing an SDG-oriented policy framework for the Asian countries, and in the wake of Industry 4.0, this policy framework might prove crucial. During the Industry 4.0 era, ICT might emerge as a major enabler for economic growth; therefore, it needs to be utilized as a policy instrument for achieving sustainable development. Understanding the growing challenges related to carbon emissions management, this article has attempted to assess the role of ICT and education in determining the quality of the environment in Asian economies. Based on the study outcomes, this study proposes a policy framework considering ICT and education as primary policy instruments for reducing carbon emissions and sustaining economic growth patterns. The rapid economic growth of Asian countries has exposed them to many environmental challenges that are effectively the offshoots of financial liberalization and educational investment in information management systems.

Moreover, considering the unconcluded FD-carbon emission relationship, this paper empirically explores this relationship for Asian economies by controlling the share of economic growth and energy consumption. This study recommends a realigned policy framework, which might help Asian countries achieve sustainable development. The novelty of this study lies in the generalizability of the policy framework, which can serve as a benchmark for the other emerging industrialized economies facing the issues of carbon emission-led climatic shift. By far, this ICT and education-oriented developmental policy realignment approach have not been considered in the literature, and there lies the policy-level contribution of this study.

The remaining sections are structured as follows: Section 2 presents the discussion on relevant literature. Section 3 elaborates on model development and data. Section 4 reports the study outcomes and a discussion of the results, and Section 5 concludes the study by discussing suitable policy designs.

2. Literature review

Researchers have been raising concerns regarding the impact of ICT penetration on environmental sustainability. This impact is made through the inefficient utilization of energy resources, which go on to cause carbon emissions. This article examines the effects of ICT, FD, and education on environmental quality by examining the trend of carbon emissions in selected Asian countries.

Literature states that inefficient and unsustainable energy resource consumption exposes the economy to uncertain external shocks (like oil price shocks or demand-supply discrepancy concerns) and negatively impacts trade and financial sector growth (Suzuki et al., 1995; Toffel and Horvath, 2004; Almulali and Sab, 2012). Moreover, inefficient energy consumption in the ICT setup process has a *direct life cycle effect* on environmental degradation, manifested as increased emissions in the form of solid and gas wastes during the production process. Later, ICT has an *indirect life cycle effect* caused by the utilization of manufactured electric machines that emit CO_2 (Suzuki and Oka, 1998). Furthermore, Saidi et al. (2015) and Tunali (2016) have maintained that developing economies have an inverted U-shape relationship between ICT expansion and CO_2 emissions. This implies that when an economy starts replacing its existing inefficient energy inputs with efficient technology systems, the economy will initially experience an increase in energy consumption and carbon emission; later on, the hybrid technology enhances the energy conservation process and reduces the level of CO_2 emissions. To understand the dynamics of these variables, we have classified the literature review into three categories: 1) ICT-Environmental Quality Nexus, 2) Education-Environmental Quality Nexus, and 3) FD-Environmental Quality Nexus.

2.1 ICT-Environmental Quality Nexus

It is difficult to ignore how science and technology have transformed people's financial and economic decisions. However, this transformation has also raised concerns related to environmental quality in regions of the world with extensive ICT penetration. In this pursuit, one strand of literature has investigated the relationship between ICT and environmental quality by using cross-sectional and time-series data. For instance, by using regional data for China, Zhang & Liu (2015) investigate the link between ICT and emissions using a STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model from 2000 to 2010. The dynamic panel method results show that ICT has helped reduce emissions in all regions of China. However, an inverted U-shaped relationship between carbon emission and ICT has been reported by Añón, Gholami, & Shirazi (2017). The study uses data from developing and developed countries to check the nonlinear relationship between ICT and emissions.

Tracing back the extensive investment in ICT, most countries started investing during the latter half of the 1990s. Using data from 2000 to 2012, Asongu et al. (2018) query the link between ICT and carbon emissions. The study finds an insignificant impact of mobile and Internet on emissions in the linear form, while in the nonlinear form, mobile and Internet reduce emissions. The results provide suggestions for 44 sub-Saharan Africa countries by employing the Generalized Method of Moment. Another study by Asongu (2018b), using the same length data set, observed the relationship between ICT and CO_2 emissions. The estimated results indicate that ICT reduces emissions when ICT interacts with trade and FD in the long run. Finally, Danish, Khan, Baloch, Saud, & Fatima (2018) assessed the link between ICT and emissions for N-11 countries from 1990 to 2015. This study used second-generation econometric methods to overcome the issue of heterogeneity in the panel data. The augmented mean group results propose that ICT reduces emissions by increasing income levels, while ICT increases emissions by increasing FD in the studied region. Ozcan & Apergis (2018) examined the impact of internet use on environmental quality for emerging countries. They reported that a negative relationship exists between internet use and pollution. The study arrived at these findings by using panel methodology for the period 1990 to 2015.

In a recent investigation of the Tunisian economy from 1975 to 2014, Amri, Zaied, & Lahouel (2019) employed the autoregressive distributed lag method. The study finds a statistically insignificant relationship between ICT and carbon emissions. Using panel data from Iran, Dehghan & Shahnazi (2019) examined the impact of ICT on carbon emissions for the agriculture, services, industry, and transportation sectors. Dynamic OLS (ordinary least squares) results suggest a negative link between ICT and emissions for the transport and services sector but a positive and significant link with the industry sector. Shobande (2021) found a positive link between ICT and emissions level in Africa using fixed-effect method. For developing countries, (Mathieu et al., 2021) used the PMG-ARDL method and reported an insignificant link between ICT and environment for relatively high income developing countries but significant and negative for low income developing countries. Finally, Anser et al. (2021) examined the impact of ICT on carbon emissions with panel quantile regression method and found positive link between both variables.

2.2 Financial Development- Environmental Quality Nexus

Some literature has found a dynamic relationship between FD and environment quality, but the empirical results obtained mixed results on the relationship between FD and CO_2 emissions. For example, Jalil & Feridun (2011) have examined the role of financial expansion in China, ultimately finding a declining trend in carbon emissions due to FD. Adding to previous literature, Shahbaz, Solarin, Mahmood, & Arouri (2013) assessed the linkages of FD and emissions in the Malaysian economy. The study reported a negative relationship between these two variables. Moreover, Shahbaz, Kumar, & Nasir (2013) arrived at similar results for the South African economy. Shahbaz, Hye, Tiwari, & Leitão (2013) maintained a negative relationship between financial openness and carbon emissions in Indonesia. Using a long-run cointegration econometric method, Boutabba (2014a) suggests that a positive link exists between FD and environmental quality in India. Contrary, Omri et al. (2015) have found an insignificant and weak association between financial liberalization and environmental quality in Middle-East-North-Africa (MENA) countries. Shahbaz, Jawad, Shahzad, Ahmad, & Alam (2016) have suggested an asymmetric impact of FD on emissions by using quartile data from Pakistan. The study's results show that environmental quality decreases in line with increases in FD in the long run. Katircioğlu & Taşpinar (2017) investigated the Turkish economy's long-run data with structural breaks. Th

e results indicate that FD plays an ineffective role in mitigating carbon emissions. Huang & Zhao (2018) used province-level data from China to check the link between FD and emissions. The results indicate that FD reduces CO_2 emissions significantly. The results of a study by Salahuddin, Alam, Ozturk, & Sohag (2018) claim that an insignificant relationship exists between FD and emissions in the long run in Kuwait. For central and eastern European countries, studies have assessed the causal relationship between FD and carbon emissions. Saud, Chen, Haseeb, Khan, & Imran (2019) empirically established that FD has negatively affected the environmental quality of European economies. They employed the dynamic seemingly unrelated regression method to estimate the long-run connection between variables. A recent study on the Russian economy conducted by Bass, Burakov, & Freidin (2019) suggests a positive link between financial openness and carbon emissions. Shen et al., (2021) also reported positive link between FD and emissions by using province level data of China. However, Zafar et al. (2021) found negative link between FD and carbon emissions for Asia-Pacific Economic Cooperation countries. The similar results reported by Khan and Ozturk (2021) for 88 developing countries by using panel methods.

2.3 Education- Environmental Quality Nexus

In the modern world, education plays an important role in increasing environmental quality by reducing carbon emissions. Without education, it would be almost impossible to achieve sustainable economic growth and a sustainable environment. Recently, researchers and econometricians have shifted their focus away from other factors and education to check the impact of education on carbon emissions. For example, literature has identified that education can be one of the important determinants of emissions. Gangadharan & Valenzuela (2001) estimated the empirical relationship between education and emissions for 51 countries. They used different proxies to measure environmental quality. The panel methodology results concluded that education has an insignificant relationship with most of the environmental proxies. Managi & Jena (2008) probed the validity of EKC for India by including an educational index as an independent variable. The reported results show a positive relationship between emissions and the educational index. For Latin American countries, Sapkota & Bastola (2017) examined how foreign direct investment (FDI) and increasing human capital affect environmental quality. The study uses panel methodology and separately estimated the impacts for developing and emerging economies. The results show that human capital increases environmental quality in emerging economies but reduces environmental quality in low-income countries.

Using a long run ARDL cointegration method, Balaguer & Cantavella (2018) investigated the Australian economy (1950-2014) to explore the linear and nonlinear impact of education on carbon emissions. The study found an inverted U-shaped relationship between the dynamics of education expansion and carbon emissions. Bano, Zhao, Ahmad, Wang, & Liu (2018) used a similar estimation method to assess the link between human capital and emissions in the Pakistan economy (1971-2014). The study used four different proxies to measure human capital. The results suggest that human capital reduces emissions from the environment in the long run. Similar findings have been reported by Zafar, et al. (2019) and Zafar et al. (2020), who assessed the USA and OECD economies and concluded that education reduces the ecological footprint. Another study conducted by Zafar et al. (2021) for Asia-Pacific Economic Cooperation countries and suggested that education helps to reduce emissions levels.

A broad overview of all the reviewed studies is summarized in Appendix 1. Based on the literature review, this study aims to contribute to existing literature by addressing the following gaps: Considering that financial development plays a vital role in ensuring investment flows to innovation and technology, this study has added financial development in ICT-growth nexus. Moreover, carbon emission and education are inversely correlating variables. Therefore, this study has employed education as an explanatory variable to establish the impact of ICT penetration on the existing carbon emission level that has not been widely debated in previous literature.

3. Model development and data

3.1. Model development

Since the 1960s, literature has engaged in an unsettling debate regarding the impact of ICT on economic growth. One theoretical link between ICT and economic growth states that data show how ICT accelerates economic growth by reducing financial costs. For example, improved and energy-efficient machines save energy resources, and improvements in transmission mechanism services help the economy utilize physical resources more efficiently. Ample literature has found a positive contribution of ICT in economic growth in developing countries (Engelbrecht and Xayavong, 2007). However, researchers have introduced the environmental effects of ICT into the ICT-growth nexus during the past two decades because rapid ICT development has changed both growth patterns and environmental regulations. Some studies reported the positive results (and others the negative effects) of ICT on environmental quality. Different researchers have used various indicators of ICT. For example, Schaefer, Weber, & Voss (2003) considered handsets (mobile phones) as an ICT indicator. The study emphasizes the positive effects of carbon emissions and energy demand when carrying headsets.

The dynamics between financial openness, development and carbon emissions are composite. They affect each other differently, through consumption and production patterns, in terms of both intensity and rigor. For instance, when FD refers to the ease of doing business, it affects investors' behavior and profitability. In response, investors can expand production by hiring labor and investing capital. Considering that investors create increased labor demand, the income made due to that labor will eventually be used to purchase consumer products included in the ICT setup. This will ultimately trigger emissions growth and energy demands. On the other hand, an increase in capital demand could potentially directly boost energy demand. In that case, carbon emissions could rise in line with capital formation.

Similarly, FD offers easy consumption options via low-interest-rate borrowing. Consumers can maximize their financial utility by leasing cars, homes and many other high-end products. The consumption of machinery (like cars, mobile phones, laptops, automotive and automatic products) has a positive relationship with energy demand and carbon emissions (Shahbaz et al., 2013).

Low-cost debt-raising opportunities help economies to grow out of stagnant productivity traps. However, higher production leads to additional energy demands and increased negative effects on the environmental quality of countries that have waste management and pollution issues (Dasgupta et al., 2002). In another link, literature reports that a low education rate can negatively affect openness and emissions due to a lack of awareness regarding the efficient utilization of machines and nonrenewable resources (Gangadharan and Valenzuela, 2001). Therefore, this study intends to reinvestigate the dynamic relationship between ICT, FD, education and carbon emissions so that the study can suggest policy recommendations accordingly.

This study has constructed the following models for the empirical estimation of the role of ICT, education, and FD in determining the long-term environmental quality in 16 Asian economies. However, carbon emissions are used as a proxy to represent environmental quality.

Model 1

$$\ln CO_{2i,t} = a_0 + b_1 \ln Y_{i,t} + b_2 \ln ENG_{i,t} + b_3 \ln EDU_{i,t} + b_4 \ln ICT_{i,t} + b_5 \ln FD_{i,t} + e_{i,t}$$

where CO_2 is the carbon emissions per capita, i represents the cross-sections (1….16), t is the time period (1990 to 2018), α_0 represents constant term of the model and ε is the error term of the model. The β_1, $\beta_2, \beta_3, \beta_4, \beta_5$ represent the coefficient of economic growth (Y), energy use (ENG), education (EDU), information and communication technology (ICT), and financial development (FD), respectively.

Model 2

$$\ln CO_{2,it} = a_0 + b_1 \ln Y_{i,t} + b_2 \ln ENG_{i,t} + b_3 \ln EDU_{i,t} + b_4 \ln ICT_{i,t} + b_5 \ln FD_{i,t} + b_6(\ln EDU_{i,t} * \ln ICT_{i,t}) + e_{i,t}$$

In the second model, we add the interaction term between education and ICT ($lnEDU_{i,t} * lnICT_{i,t}$). The β_6 represents the coefficient of the interaction term.

Model 3

$$\ln CO_{2i,t} = a_0 + b_1 \ln Y_{i,t} + b_2 \ln ENG_{i,t} + b_3 \ln EDU_{i,t} + b_4 \ln ICT_{i,t} + b_5 \ln FD_{i,t} + b_6(\ln \mathrm{FD}_{i,t} * \ln ICT_{i,t}) + e_{i,t}$$

In the third model, we add the interaction term between FD and ICT ($lnFD_{i,t} * lnICT_{i,t}$). The β_7 represents the coefficient of the interaction term.

Following the recent policy discourse on the growth-environment nexus (e.g., Shahbaz et al., 2020, Zhao et al., 2021), the present study has adopted the target and explanatory model parameters at level, not at growth. Moreover, the SDG 13 talks about the carbon emissions in its absolute form, and hence, considering the model parameters in growth form might not comply with the specifications provided by the United Nations. It might appear that the said specification might lead to estimation issues. In the beginning of Section 4, this issue has been addressed using the multicollinearity statistics.

3.2. Data collection

The list of Asian countries includes Bangladesh, Cambodia, China, India, Indonesia, Iran, Japan, South Korea, Malaysia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam. As of 2018, these countries account for nearly 52% of the total GDP and 72% of the total CO2 emissions in Asia (World Bank, 2021). Hence, results obtained from this sample can be representative of the Asian economies. This study excludes other Asian countries due to the unavailability of data. The empirical analysis includes carbon emissions (in metric tons), economic growth (constant 2010 US dollar) energy consumption (kg of kilo equivalent), education (secondary school enrollment), FD (domestic credit provided to the private sector (% of GDP)). As the current series of GDP is influenced by price inflation, we use the constant series (2010 US dollar) of GDP to measure the true growth of our data series, i.e., adjusting for the effects of price inflation.

Furthermore, we converted all the variables into a natural logarithmic form. Log-linear conversion of data produces more efficient and consistent results compared to simple-linear transformation. This also allows for interpreting results directly as elasticities.

The interpretations of estimated coefficients are explained through point elasticities. Studies have used different proxies to measure ICT penetration. For instance, mobile phones, internet banking, and e-commerce are a few variables. Due to differences in the proxies used, the results and recommendations vary. A majority of the proxies were used individually or in aggregate form, including mobile cellular subscriptions (per 100 people), fixed broadband subscriptions (per 100 people), and fixed telephone subscriptions (per 100 people). Unlike existing studies, this paper uses a weighted ICT index by using the above-mentioned three proxies to measure ICT indicators. The authors constructed this ICT index with the help of a principal component analysis (PCA) for selected Asian countries. The table 1 presents the results of PCA.

3.3. Econometric methods

To carry out the empirical exercise, the methodological schema must be elucidated, outlining the methods applied in the study. Given the increasing economic complexity in the global scenario, it can be concluded that the countries under consideration are aligned with each other within a geopolitically collaborative space. Therefore, we analyzed the cross-sectional dependence between the model parameters. This analysis indicates the applicability of unit root tests of the first or second generation. In this study, we applied the unit root tests of the second generation; the cross-sectional dependence test confirmed the results. The root unit tests give us the order of integration among the variables while

Table 1 Principal Components Analysis

Eigenvalues: (Sum = 3, Average = 1)					
Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	2.080862	1.42364	0.6936	2.080862	0.6936
2	0.657221	0.395304	0.2191	2.738083	0.9127
3	0.261917	---	0.0873	3	1
Eigenvectors (loadings):					
Variable	PC 1	PC 2	PC 3		
NFBS	0.63648	-0.05545	-0.7693		
NFTS	0.559453	-0.65341	0.509963		
NMCS	0.530947	0.754967	0.384864		
Ordinary correlations:					
	NFBS	NFTS	NMCS		
NFBS	1				
NFTS	0.662014	1			
NMCS	0.598141	0.345294	1		

also disclosing their stationary properties. When their integration properties are observed, the long-term coefficients of the variables are evaluated using cointegration. This can be achieved in two steps: First, establish the long-term association between variables in the presence of cross-sectional dependence. Second, assess the variables' long-term coefficients. Considering that we are interested in evaluating the correct policy measures to address the research issue, it is necessary to address the bi-directionality of the policy measures and use heterogeneous causality testing in this pursuit. That is the study's broad methodological schema. The specifics of the experiments are recorded in subsequent subsections.

3.3.1 Cross-sectional dependence test

Studies have suggested that the consistency and soundness of the empirical results derived from panel data rely on the test applications used to explore data properties. Therefore, it is important to assess the panel data for unit root properties and the state of dependence in cross-sectional sets of observations. To explore the reliable association between variables, a cross-sectional dependency test is important. This is because panel data exhibit a state of correlation, due to the impact of regional and international integration levels. Considering that results obtained in the presence of cross-sectional dependence would be biased and inconsistent for use in further policy formulations, this study has employed a cross sectional test proposed by Pesaran (Phillips and Sul, 2003). This is followed by a Lagrange multiplier (LM) test, which explores panel cointegration status. Breusch and Pagan (1980) proposed that the LM test has strong significance for panel estimation, as the test handles the resampling issues of parametric as well as non-parametric data sets. Theoretically, the Pesaran test intuitively overcomes the problem of panel data when the number of observations (*N*) and time series (*T*) share magnitudes of the same orders. However, we have estimated the following equation for the empirical estimation of the Pesaran test (CD):

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right)}$$

Here, the cross-sectional errors estimated from the correlation level of countries i and j are represented by ρ_{ij}. However, the following equation of the Lagrange multiplier test has been employed to assess the cross-sectional dependence regarding period t and dimensions i in the panel data:

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it}$$

This equation has been used to derive null and alternative hypotheses. A null hypothesis exhibits that data is independent of the existence of cross-sections. However, the alternative hypothesis exerts the existence of cross-section dependencies in the data.

3.3.2. Panel unit root test

This study preferred to apply second-generation unit root tests to explore the stationary properties of panel data. This is because second generation tests are unswerving when used to assess cross sectional dependence. Particularly, we have used cross-sectional augmented IPS (CIPS) and cross-sectional augmented ADF (CADF). This is because they are relatively reliable tests, compared to first-generation unit root tests results. This is because first-generation unit root tests tend to be ineffective when cross-sectional dependence exists (Dogan and Seker, 2016). The IPS cross-section augmented unit root test can be applied through the following equation:

$$\Delta x_{it} = \alpha_{it} + \beta_i x_{i,t-1} + \rho T \sum_{j=1}^{n} \theta_{ij} \Delta x_{i,t-j} + \varepsilon_{it}$$

The null hypothesis derived from this equation exerts that each used time series is non-stationary. This equation has been proposed by Pesaran (2007), who used Δ to estimate the equation by setting it as the difference operator. However, the series of analyzed variables (x_{it}) has been used both at difference, as well as at level. Moreover, the intercept term has been represented by α, and T represents the time trend in the data; ε_{it} denotes the error term. However, the Schwarz information criterion (SIC) method has been used to determine the lag length.

3.3.3. Lagrange Multiplier bootstrap cointegration test

This study has used the Lagrange Multiplier (LM) bootstrap cointegration method developed by Westerlund and Edgerton (2007) to assess cointegration among variables in the presence of heterogeneity cross-sectional dependence in the panel data. The LM bootstrap test has significance, as it estimates the long run cointegration among variables. A null hypothesis indicates the presence of cointegration among the variables. However, the alternative hypothesis explains that there is no cointegration among the variables.

3.3.4. Long-run estimation

Next, we investigate the long-run elasticities. Literature has reported various econometric techniques that can be used to find elasticities. However, considering their benefits, we preferred to apply the continuously updated and fully modified (CUP-FM) method and continuously updated and bias-corrected (CUP-BC) methods, as proposed by Bai et al. (2009). These methods are more effective in panel estimations, as they control the cross-sectional dependence and unobserved non-linearity. Further, to cater to serial correlation and endogeneity problems, this study organized the CUP-BC estimator. Similarly, the CUP-FM estimator keeps the model parameters intact by limiting their distribution. Furthermore, the model parameters are continuously updated (CUP) with the help of iterations as soon they reach the convergence point.

3.3.5. Exploration of causality direction

Researchers and practitioners consider that an effective policymaking process relies heavily on the relationship between variables. Relying on long-run estimations can provide information about the association among variables, but these do not give any insight into the directional relationship. Literature has employed the Dumitrescu and Hurlin (DH) causality test, introduced by Dumitrescu and Hurlin (2012), to explore the causality direction between variables. This study follows the same test for three potential reasons. First, the DH causality test is effective in cases of unobserved heterogeneity. Secondly, the test uses a vector autoregressive (VAR) structure on stationary data. Third, the DH causality test can effectively explore the causal relationship between cross-sectional variables' cross-sections by running separate regressions on all cross-sectional sets

4 Results

As the independent variables signify economic development, theoretically there is a possibility of association between them. This association might lead to the problem of the multicollinearity, which can consequentially lead to spurious results. Hence, before starting the empirical analysis, it is essential to check for the multicollinearity in the data. The variance inflation factor (VIF) test outcomes reported in Table 2 suggests that the data to be free from the possible multicollinearity issues. This warrants the concurrent presence of the independent variables in the empirical model. Based on the results of this preliminary diagnostic test, the empirical analysis can be started.

Table 2. Multicollinearity test results

Variables	VIF	√VIF	Tolerance	R^2
lnGDP	2.16	1.47	0.4630	0.5370
lnENG	2.31	1.52	0.4329	0.5671
lnEDU	1.88	1.37	0.5319	0.4681
lnICT	1.46	1.21	0.6849	0.3151
lnFD	1.49	1.22	0.6711	0.3289

This study starts the empirical analysis by examining the Cross-sectional dependence in the data. The estimated results by CD tests are presented in Table 3. The significance level of all study variables implies that cross-sectional dependence exists among the variables.

Table 3. Cross-sectional Dependence tests result

Variables	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD
lnCO_2	2159.226***	131.6315***	34.46492***
ln*GDP*	3283.105***	204.1775***	57.28593***
ln*ENG*	1950.696***	118.1709***	32.65315***
ln*EDU*	2201.745***	134.3760***	44.89157***
ln*ICT*	3259.963***	202.6837***	57.06349***
ln*FD*	1440.787***	85.25645***	16.05407***

Note: $*** \, p < 0.01$; $** \, p < 0.05$; $* \, p < 0.1$.

Cross-sectional dependence enables us to choose such unit root tests, which also cater to cross-sectional dependence. Thus, we used CIPS and CADF tests to measure the stationary properties. The estimated results of the unit root test (see Table 4) show that all series of subject panel data sets are stationary at first difference and contain unit root at level.

Table 4. Second-generation Unit root tests result

	CIPS		CADF	
Variables	Level	First-Difference	Level	First-Difference
lnCO_2	-1.532	-4.518***	-1.601	-3.448***
ln*GDP*	-1.815	-3.941***	-1.861	-3.941***
ln*ENG*	-1.967	-4.651***	-1.848	-3.492***

lnEDU	-1.873	-3.644***	-2.110	-3.489***
lnICT	-2.076	-3.419***	-2.537	-3.787***
lnFD	-2.124	-4.630***	-2.313	-3.847***

Note: $*** p < 0.01$; $** p < 0.05$; $* p < 0.1$.

After knowing the study variables' unit root properties, the next step is to find cointegration among the variables. This study used the LM bootstrap Cointegration test to accomplish this objective. The results presented in Table 5 reveal cointegration among education, carbon emissions, energy demand, ICT and FD in the presence of economic growth as a control variable. The results reject the null hypothesis, which states that there is no-long run cointegration. Insignificant statistics of the LM test indicate the presence of a long-run relationship between the cross-sectional variables.

Table 5. LM bootstrap Cointegration test results

	lm statistic	robust p-value
LM bootstrap test	19.138	0.910

After finding the cointegration among variables, the next step is to find long-run elasticity. This study used Cup-BC and Cup-FM to find the long-run elasticities. The results have been explained through three different models, as depicted in Table 6 and the model diagnostics are reported in Appendix 2. The results show that a one percent increase in economic growth fosters an extra 0.2776% of carbon emissions in the long run. During the previous twenty years, Asian economies have witnessed a drastic surge in economic activities. However, they have only been able to attain sustainable economic growth by rapidly expanding their fossil fuels consumption. The rise in the use of fossil fuels was evidenced by the rise in activities and economic growth of these Asian countries. However, at the same time, fossil fuels increased the level of pollution in these countries. As these economies are fossil fuel-based, the increase in pollution is also therefore obvious. Asian countries produce the largest proportion of environmental pollution in the world. Many authors have reported similar results (between these two variables) in different countries. For example, Zaidi et al. (2019) reported for OECD countries. Zafar et al. (2019) reported for G7 and N11 countries. However, Lee (2013) and Ahmed, Rehman, & Ozturk (2017) reported a negative relationship between economic growth and emissions for G20 and south-Asian countries.

Table 6. Panel long-run tests result

	Model-1		Model-2		Model-3	
	CUP-FM	CUP-BC	CUP-FM	CUP-BC	CUP-FM	CUP-BC
lnGDP	0.277^{***}	0.301^{***}	0.294^{***}	0.308^{***}	0.296^{***}	0.336^{***}
	(3.2002)	(3.5421)	(3.2448)	(3.3860)	(3.5091)	(4.1224)
lnENG	0.644^{***}	0.638^{***}	0.627^{***}	0.629^{***}	0.581^{***}	0.539^{***}
	(11.2379)	(11.009)	(10.8931)	(10.7976)	(9.8671)	(9.0212)
lnEDU	0.267^{***}	0.277^{***}	0.240^{***}	0.259^{***}	0.239^{***}	0.240^{***}
	(4.6826)	(4.9199)	(3.8849)	(4.3845)	(3.7598)	(3.7883)
lnICT	-0.026^{***}	-0.027^{***}	-0.023^{***}	-0.016^{***}	-0.011^{***}	-0.022^{***}
	(10.2225)	(10.0823)	(2.3455)	(2.5541)	(7.4359)	(8.0156)
lnFD	-0.039^{***}	-0.029^{***}	-0.042^{***}	-0.030^{***}	-0.022^{***}	-0.022^{***}
	(3.8404)	(4.4404)	(3.5931)	(4.2786)	(4.9836)	(4.4900)
lnEDU*lnICT			-0.005^{***}	-0.006^{***}		
			(5.2715)	(4.9266)		
lnFD*lnICT					0.029^{***}	0.039^{***}
					(7.7645)	(6.6204)

Note: $*** \; p < 0.01$; $** \; p < 0.05$; $* \; p < 0.1$. t-statistics are presented in the parenthesis.

The estimated results indicate that even a one percent incremental rise in energy consumption will foster nearly 0.6442% more carbon emissions. This result also supports earlier findings that Asian countries are the largest energy consumers and carbon emitters globally. The positive coefficient of energy consumption is significantly higher than other variables. This implies that energy consumption is the main reason for increasing emissions in the Asian region. As the major energy sources of Asian countries are fossil fuels, these nations by definition will consume conventional fuels to cater for their energy needs. Increases in oil, coal and gas consumption reflect the rising economic activities and economic growth of Asian countries. On the dark side, however, such consumption also increases the level of pollution in these countries. The primary reason for the increasing gas rate is the industrial utilization of oil, coal and gases. Asian countries also face the same economic challenges as those being faced by other developing countries. The biggest challenge is achieving economic growth with minimum damage to the environment. Rising emissions not only increase environmental pollution but also negatively affect human health. Rural people in Asian countries need to be educated about environmental degradation. They should be provided green loans for improving their energy demand green equipment requirements. Similarly, the role of urban populations is very important in transforming economies from using conventional energy sources to employing clean energy sources. Similar results are reported by Ali, Abdullah, & Azam (2017) for Malaysia, and Zaman & Moemen (2017) for countries with different income levels.

In line with existing literature, this study has found a significantly positive association between education and emissions. Estimated results verify environmental deterioration due to education. As the education level increases by one percent, the Asian region experiences a 0.2674% proliferation in carbon emissions. This result confirms that, when education improves, the level of economic activities also increases. With the increase in vocational opportunities, energy demands also increase. As the primary energy sources of Asian countries are nonrenewable fossil fuels, any increase in energy consumption negatively affects the environmental quality (Hill and Magnani, 2002).

Our findings imply that ICT decreases the carbon emissions in the Asian region, with the results confirming that a 1% increase in ICT rentals results in a -0.0268% decrease in carbon emissions. Though small (but significant) effects have been estimated for ICT in terms of the impact on environmental pollution, it has been found that Asian economies experience improved air quality due to increases in ICT penetration. However, different indicators of ICT have been considered as general ICT penetration effects. In this study, Internet has been used as a separate measure of ICT and found a significantly bad impact of Internet on environmental quality. During the previous two decades, ICT has changed the working of different sectors in Asia. For example, the online shopping trend has boomed, the use of smartphones has accelerated, and shoppers' traveling costs have lowered significantly. When most of the population buys via the Internet, they do not need to go to markets. Therefore, they can save the traveling costs and reduce the traffic on the roads. This reduction of vehicle traffic means a corresponding reduction in nonrenewable energy use in that country.

The modernization of the ICT sector is very helpful in developing energy-efficient products that curtail emission levels. ICT is not only helpful for the energy sector but also FD in the country. Although the ICT cost (e.g., electricity cost) can be considered an incremental burden on governments, its benefits are far greater than its cost. For example, rural populations can easily access finance without visiting banks or financial institutions. They can save ample time through online banking and shopping etc. and thus, pressure of urbanization can also be avoided. ICT has brought about a revolution in the field of digital finance and e-commerce. Therefore, the role of ICT in environmental sustainability cannot be ignored. Amri et al. (2019) reported an insignificant relationship between ICT and emissions in Tunisia. A negative relationship between ICT and emissions in China was reported by Zhang & Liu (2015), Ozcan & Apergis (2018) for emerging countries, Sinha (2018) for India, and Chien et al. (2021) for BRICS countries.

A result worth noting is that Asian economies experienced a -0.0396% decline in emissions per one percent of FD. These Asian countries allocate sufficient funds to support the organizations that help achieve emissions reductions. Furthermore, these countries are willing to increase their investment in renewable energy sources that can reduce fossil fuels in Asian countries. As suggested by Tamazian et al. (2009), financial openness and liberalization may induce more foreign direct investment and R&D projects. FD is the largest contributor to green investment and environmental quality. Likewise, Blanford (2009) concluded that investment in R&D could improve energy-efficient technologies that can lower emissions. Negative results have been reported between FD and Omri et al. (2015) for MENA countries and Kuwait. However, a positive relationship is suggested by Boutabba (2014b) for India and by Shahzad, Kumar, Zakaria, & Hurr (2017) for Pakistan.

The interaction term between education and ICT has a negative relationship with carbon emissions. This relationship states that when education increases, the level of ICT also increases. Therefore, education provides leverage to the ICT sector in terms of controlling carbon emissions. Due to improvements in education and ICT sectors, more focus is being given to environmentally friendly technologies. More awareness programs are being arranged to improve environmental quality. Education, blended with ICT knowledge, increases the R&D level in a country, which can then be utilized to minimize carbon emissions. Asian countries possess a good percentage of education and ICT sectors that can be used as the backbone to the transformation of economies following sustainable development goals.

The interaction term between FD and ICT has a positive relationship with carbon emissions. This relationship states that when FD is increased through large-scale ICT equipment, the levels of energy consumption and carbon emissions also accelerate. Increasing investment in ICT infrastructure boosts the energy sector significantly but can also deteriorate the environment. From a policy perspective, investment should be kept high, but the proportion of nonrenewable energy used should be minimized. The availability of financial resources to ICT sectors will help control carbon emissions in Asian countries.

The next step is to find the panel causality to know the direction of long-run relationships. This study used Pairwise Dumitrescu and Hurlina, (2012) panel causality test to attain this objective. The test results are shown in Table 7.

Table 7. Pairwise Dumitrescu and Hurlin (2012) panel causality test results

	$\Delta lnCO_2$	ΔlnY	$\Delta lnENG$	$\Delta lnEDU$	$\Delta lnICT$	$\Delta lnInFD$
$\Delta lnCO_2$		4.7739^{***} (0.000)	3.1755^{***} (0.001)	3.0839^{***} (0.0020)	4.4701^{***} (0.000)	1.8158^{***} (0.0694)
ΔlnY	2.3075^{**} (0.0210)		7.8579^{***} (0.000)	3.9531^{***} (0.000)	6.4802^{***} (0.000)	2.9683^{***} (0.0030)
$\Delta lnENG$	4.5155^{***} (0.000)	0.5167 (0.6053)		3.1039^{***} (0.0019)	10.8872^{***} (0.000)	3.8861^{***} (0.000)
$\Delta lnEDU$	1.3266 (0.1846)	5.9941^{***} (0.000)	3.4425^{***} (0.0006)		10.9993^{***} (0.000)	2.8691^{***} (0.0041)
$\Delta lnICT$	6.4579^{***} (0.000)	4.7667^{***} (0.000)	8.6441^{***} (0.000)	10.5028^{***} (0.000)		7.3366^{***} (0.000)
$\Delta lnFD$	4.5161^{***} (0.000)	3.3212^{***} (0.0009)	2.1292^{**} (0.0332)	3.8787^{***} (0.000)	6.1406^{***} (0.000)	

Note: $*** \, p < 0.01$; $** \, p < 0.05$; $* \, p < 0.1$.

This study finds that carbon emissions and economic growth have a bidirectional association by applying the DH causality test. Moreover, a feedback link exerts a significant association (at a 1% significance level) between energy use and carbon emissions. Zafar et al. (2019b) found similar results for OECD countries. However, a Granger casual association exists between education levels and carbon emissions and these results are not consistent with Zafar et al. (2020). A study has found a bidirectional link between ICT and CO_2 emissions. Ulucak et al. (2020) reported a unidirectional relationship between ICT and CO_2 emissions for BRICS countries.

Similarly, bidirectional and significant links have been found between FD and emissions; FD affects emissions at 1%, and carbon emissions affect FD at a 10% significance level. Similar results stated by Zaidi et al. (2019) for Asia Pacific Economic Cooperation countries. However, the growth hypothesis stands firm for GDP and energy use for our panel data. Nevertheless, this study's results support the literature that states a bidirectional-positive association exists between education and economic growth. Zafar et al. (2021) also stated a bidirectional-positive relationship between both variables. This study finds that ICT and economic growth have positive Granger causality in Asian economies and our results are matched with Ozcan and Apergis (2018). Likewise, FD and economic growth have maintained a positive bidirectional relationship. Ozcan and Apergis (2018) stated similar results for emerging countries. This study adds to the existing literature by maintaining that economic growth increases when economies experience ICT expansion and access to financial resources. Considering that the cost of growth is reflected as an increase in input demand, so energy resource demand rises in line with increases in ICT expansion to attain economic growth. In summary, awareness and the experiential learning process accelerated by the education rate increment directly affect economic activities like FD and ICT penetration. In addition, residual effects occur in the form of emission increments.

Lastly, as the empirical model does not control for country- and time-fixed effects, the fixed effects regressions are carried out for Model 1, 2, and 3. This estimation exercise might act as a viable robustness check of the long run coefficient estimation. The test results reported in Table 8 demonstrates that the outcomes of the three empirical models using country- and time-fixed effects are robust, as the magnitudes and signs of the coefficients are not varying. Moreover, the F-statistics of the models denote the significance of the models.

Table 8. Robustness check results with country- and time-fixed effects

	Model-1		Model-2		Model-3	
lnGDP	0.253**	0.347*	0.249**	0.279***	0.267**	0.282*
	(6.32)	(4.03)	(3.22)	(5.11)	(-2.54)	(-2.11)
lnENG	0.793***	0.795***	0.795***	0.787***	0.744***	0.690***
	(11.39)	(11.60)	(11.29)	(11.30)	(9.48)	(8.71)
lnEDU	0.267*	0.286*	0.174**	0.157***	0.165**	0.134***
	(1.82)	(1.79)	(2.19)	(9.24)	(2.75)	(7.95)
lnICT	-0.152***	-0.146***	-0.193**	-0.119***	-0.159***	-0.101***
	(-8.24)	(-10.59)	(-2.16)	(-2.67)	(-2.79)	(-4.56)
lnFD	-0.167***	-0.131***	-0.166***	-0.133***	-0.173***	-0.138***
	(-8.05)	(-6.20)	(-7.78)	(-6.22)	(8.16)	(-6.50)
lnEDU*lnICT			-0.048*	-0.071***		
			(-2.19)	(5.32)		
lnFD*lnICT					0.021***	0.041***
					(8.34)	(2.57)
Constant	-2.096***	-2.214***	-2.115***	-2.168***	-1.907***	-1.903***
	(-12.14)	(-11.48)	(-10.47)	(-10.50)	(-8.57)	(-8.40)
Fixed effect	Country	Year	Country	Year	Country	Year
R-square	0.8796	0.8939	0.8803	0.8933	0.8700	0.8853
F-statistics	314.48***	61.91***	311.40***	60.01***	312.94***	61.10***

Note: $*** \, p < 0.01$; $** \, p < 0.05$; $* \, p < 0.1$. t-statistics are presented in the parenthesis.

5 Discussion of results

By far, the study outcomes are reported and individual components of the outcomes are analyzed. Now, to obtain a wholesome picture of the scenario, it is necessary to discuss all the segments of the study outcomes together. This study outcomes reveal the unsustainability of the countries' economic growth patterns while revealing the possible drivers of this ecologically unsustainable economic growth trajectory. The unsustainable economic growth pattern of these nations is exerting a negative environmental externality, and this externality is being caused by the major driver of this growth, i.e., energy consumption pattern. Given the fact that these countries are majorly dependent on the fossil fuel-based energy solutions, consumption of energy generated from these sources will eventually deteriorate the environmental quality by increasing the level of CO_2 emissions in the ambient atmosphere. This very energy consumption pattern also reveals that priority of the policymakers in these nations is to attain economic growth, even at the cost of environmental quality, and hence, this policy objective will be reflected in the other drivers of economic growth, as well. As the nations are treading along the rising economic growth trajectory, it can be assumed that the growth prospects of the nations might create job opportunities at various levels, and this job prospect will encourage the educational attainment. Now, this education is likely to be more growth-oriented compared to development-oriented, as the future labor force will be adding towards the economic growth of these nations. Driven by the myopic pro-growth policy agenda, the prospective labor force will be creating an unintentional tradeoff between growth and development, and their unintended and policy-probed lack of environmental awareness might add to the ambient air pollution problem. This argument is reflected by the study outcomes.

While saying this, it also needs remembering that the world has ushered in the era of fourth Industrial Revolution, and so as these countries. Therefore, the economic growth trajectory being attained by these nations will be more dependent on the technological innovations, which are dominated largely by the ICT solutions. As these solutions are more capital-intensive and less labor-intensive, hence these solutions will eb able to internalize the negative environmental externalities exerted by the economic growth trajectory itself. Moreover, usage of automation technologies has enabled these nations to achieve energy efficiency, which has reduced the consumption of fossil fuel-based energy solutions, and therefore, the consequential CO_2 emissions have been reduced. Now, in order to implement these solutions, proper channelization of funds is necessary, and the policymakers need to make use of the financial institutions and instruments for this purpose. The finances mobilized for catalyzing the research and development activities, as well as the renewable energy exploration projects, so that these nations can achieve the energy security, which is a predominant problem in these nations. Hence, the economic growth trajectory being projected by the financial development is also expected to internalize the negative environmental externalities exerted by the economic growth trajectory.

Saying this, it is also essential to mention that the financial development channels utilized in these nations are also aligned with the pro-growth policy agenda, and only driven by the global pressure of attaining the SDG objectives, the focus of financial mobilization is undergoing a transformation. Hence, majority of the financialization is still driven towards making the technological solutions more labor-intensive and less energy efficient. Moreover, the renewable energy generation in the Asian countries is still at a nascent stage, and the application of ICT is largely seen as a service enabler of manufacturing activities. Hence, the financial mobilization in presence of the ICT development can yet to have a positive impact on the environmental quality, whereas the financialization of renewable energy projects has already started. Therefore, the interaction between financial development and ICT development is exerting pressure on the environmental quality, and this is occurring majorly because of the existing financialization channels towards supporting the service-enabling role of ICT for the manufacturing services. At the same time, the rising environmental concern among the citizens is getting reflected in the newly formed ICT service providers, which are aimed at improving the energy efficiency of the existing production processes, and thereby, internalizing the negative environmental externalities. Owing to this reason, the interaction between educational attainment and ICT development exerts a positive environmental externality.

While saying this, it needs to be mentioned that the discussion of the results is based on the prevailing economic growth trajectory of the Asian countries, and hence, the factors leading to exertion of negative environmental externality in majorly considered in the empirical model. Alongside discussing the results, an extension of the model outcomes can be discussed in view of the policy instruments with the potential of internalizing negative environmental externalities. From a developmental perspective, consideration of the economic welfare could have provided additional insights for controlling the emissions level. In this regard, the Index of Sustainable Economic Welfare and Genuine Progress Indicator could have been the suitable policy instruments, which could have given a clear roadmap about internalizing the negative environmental externalities. Under the influence of these policy instruments, impacts of financial development and ICT on environmental degradation could have been more prominent, as these instruments can cover the broad aspects of sustainability, i.e., social, economic, and environmental aspects. However, in keeping with the scope of the environment-oriented research objective of the present study, these dimensions are kept outside the scope of the study. Saying this, given the multifaceted dimensions of these policy instruments, the tangential policy implications can be drawn based on the expected impact of these instruments.

6 Conclusions and policy implications

This study explores the dynamics of ICT penetration and education in Asian economies by considering economic growth as a control variable, in order to check the dynamics of ICT, education, FD, and emissions. Study outcomes indicate that energy demand and use rise in line with economic expansion. This study suggests that education leads to expansion of ICT innovation but in absence of green energy, ICT expansion is deteriorating environmental quality by increasing carbon emissions in Asia.

The empirical results exhibit the significant role of energy demand in the dramatic increase in carbon emissions. The rise of pollution levels due to the use of fossil fuels demands more attention from policymakers, who need to increase the proportion of clean energy. More financial resources are required; these funds can be used to invest in green infrastructure related to wind, solar, geothermal and bio sources of energy. More focus is required to be placed on modern and energy-efficient technology, which is the best solution to reducing the current proportion of nonrenewable energy being used. Asia has the largest potential in terms of advanced bio-energy sources, and Asian countries could have a clear competitive advantage by becoming the largest bio-fuel supplier and consumer. The economic growth of Asian countries largely depends on energy consumption. The growth pattern may be disturbed when appropriate actions are taken to control environmental pollution. However, there should be balanced control between growth rates and expansion in renewable infrastructure.

This study has suggested that ICT expansion through using green energy would contribute in carbon emissions reduction in Asian countries. These countries should focus more on ICT usage in all energy-intensive sectors. There should be more investment in ICT infrastructure, which in turn could be very helpful in achieving energy efficiency.

Industrial and transportation sectors particularly should use ICT to make the efficient use of energy. Moreover, while talking about the implementation of ICT-based solutions, the supply side aspect of ICT development needs to be discussed. Development and implementation of ICT-based solutions require energy consumption, and this cost of energy being the operational cost of ICT development, it needs to be borne by the end-users. Therefore, bringing energy efficiency in production processes and drifting towards capital-intensive solutions might reduce the burden of electricity cost on the end-users. Moreover, considering the decentralized electricity generation option might further reduce the cost of electricity by reducing the transmission losses, and at the same time, the overall environmental impact of the energy generation and distribution might be reduced. In this way, the ICT development process might complement the decentralized electricity generation systems for exerting additional positive environmental externality.

The findings reveal a positive relationship between education and carbon emissions. In the earlier stages of rising education, as economic activities increased, carbon emissions also increased. However, education always finds its best supporting role in the economy. Education prepares the individuals in the country who can develop innovative products that can control and reduce emissions. Similarly, education, with the blend of ICT, can bring about a technology revolution in a country. Asian countries have rising education rates and the fastest increasing ICT infrastructure in the world. These countries can effectively utilize their manpower to further boost growth rates and improve the environmental quality. Asian countries should increase awareness campaigns surrounding environmental sustainability. More R&D is desired and required, to limit the excessive use of energy and achieve the best utilization of available financial resources, because this study has found an adverse connection between FD and carbon emissions. This study's results support the Asian countries' policies regarding FD, since effective FD reduces the emissions in the environment. Policymakers in the Asian countries should develop policies that promote the FD program in this part of the world.

As this study focuses only on Asian economies, it is important to evaluate long run negative externalities of ICT expansion without opting green and renewable energy. However, this might be a good line of research for future because pro-carbon emission of ICT may affect the environmental quality and long run growth of neighboring countries as indicated by Balado-Naves et al. (2018).

Contribution of this study is in terms of proffering a policy framework, which can lead the Asian countries towards attaining the Agenda 2030. At the outset of the fourth Industrial Revolution, the ICT-led growth might help these countries in reducing the ambient air pollution and ensuring energy security. As internalizing the negative environmental externalities can have social implications, the recommended policy framework has the flexibility to incorporate the additional policy dimensions, e.g., Index of Sustainable Economic Welfare and Genuine Progress Indicator, and allowing this flexibility makes this policy framework a benchmark for the other emerging economies, which are also aiming at accomplishing the objectives of Agenda 2030 by bringing socio-ecological balance in their respective economic growth trajectories. Although non-consideration of these aspects might appear as a limitation of the present study, introducing the aspect of flexibility in the policy modeling makes this study a contribution in the literature by adding the policy dimension, which might cater to the other emerging economies.

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Appendix 1: Summary of reviewed literature

Author(s)	**Context**	**Variables**	**Method(s)**	**Results**
ICT-Environmental Quality Nexus				
Zhang and Liu (2015)	29 Chinese provinces (2000-2010)	CO_2 emissions, ICT output	• Driscoll-Kraay estimation • Feasible General Least Squares	• Eastern region: ICT negatively affects CO_2 • Central region: ICT negatively affects CO_2 • Western region: ICT positively affects CO_2 • All regions: ICT positively affects CO_2
Añón et al. (2017)	116 developing and 26 developed countries (1995-2010)	CO_2 emissions per capita, ICT Index (number of fixed telephone subscribers per 100 inhabitants, mobile cell phone subscribers per 100 inhabitants, PC owners per 100 inhabitants, percentage of individuals using internet and fixed-broadband subscribers per 100 inhabitants)	Driscoll-Kraay estimation	ICT-CO_2 association is inverted U-shaped
Asongu et al. (2018)	44 sub-Saharan African countries (2000-2012)	CO_2 emissions per capita, CO_2 from liquid fuel, Mobile phone subscriptions per 100 people, Internet penetration per 100 people	Two-step Generalized Method of Moments	Non-interactive regressions: ICT does not affect CO_2 emissions Interactive regressions: • ICT positively affects CO_2 emissions • Mobile phone penetration negatively affects CO_2 emissions from liquid fuel
Asongu (2018b)	44 sub-Saharan African countries (2000-2012)	CO_2 emissions per capita, Mobile phone subscriptions per 100 people, Internet penetration per 100 people	Two-step Generalized Method of Moments	ICT positively affects CO_2 emissions

Danish et al. (2018)	Next 11 countries (1990-2014)	CO_2 emissions per capita, Mobile phone subscriptions per 100 people, Internet penetration per 100 people	Mean Group estimators	ICT positively affects CO_2 emissions
Ozcan and Apergis (2018)	20 emerging economies (1990-2015)	CO_2 emissions per capita, Internet penetration per 100 people	Mean Group estimators	ICT negatively affects CO_2 emissions
Amri et al. (2019)	Tunisia (1975-2014)	CO_2 emissions per capita, Investments in ICT	Autoregressive-Distributed Lag	ICT has insignificant impact on CO_2 emissions
Dehghan and Shahnazi (2019)	Iran (2002-2013)	CO_2 emissions per capita, real ICT capital stock per capita	Dynamic Ordinary Least Squares	• Agriculture: ICT has insignificant impact on CO_2 emissions • Industry: ICT positively affects CO_2 • Transportation: ICT negatively affects CO_2 • Services: ICT negatively affects CO_2
Shobande (2021)	32 African countries (2000-2016)	CO2 emissions per capita, Internet penetration (per 100 people)	Fixed effect model, FGLS	• ICT positively affects CO_2 emissions
Anser et al. (2021)	26 European countries (2000-2017)	ICT goods exports (denoted by ICT) measured in % of exports good, carbon dioxide emission intensity (denoted by CO2) measured in kg/oil equivalent energy use.	Panel quantile regression	• ICT positively affects CO_2 emissions
Financial Development-Environmental Quality Nexus				
Jalil and Feridun (2011)	China (1953-2006)	CO_2 emissions per capita, ratio of liquid liabilities to GDP, ratio of the private sector loans to the nominal GDP	Autoregressive-Distributed Lag	Financial development negatively affects CO_2 emissions
Shahbaz et al. (2013a)	Indonesia (1975Q1-2011Q4)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	Autoregressive-Distributed Lag	Financial development negatively affects CO_2 emissions
Shahbaz et al. (2013b)	South Africa (1965-2008)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	Autoregressive-Distributed Lag	Financial development negatively affects CO_2 emissions
Shahbaz et al. (2013c)	Malaysia (1971-2011)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	Autoregressive-Distributed Lag	Financial development negatively affects CO_2 emissions

Boutabba (2014a)	India (1971-2008)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	Autoregressive-Distributed Lag	Financial development positively affects CO_2 emissions
Omri et al. (2015)	12 MENA countries (1990-2011)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	Generalized Method of Moments	Financial development negatively affects CO_2 emissions
Shahbaz et al. (2016)	Pakistan (1985Q1-2014Q4)	CO_2 emissions per capita, money and quasi-money, liquid liabilities as a share of GDP, domestic credit to the private sector as a percentage of GDP, stock market capitalization, stock market traded value, stock market turnover	Nonlinear Autoregressive-Distributed Lag	Financial development positively affects CO_2 emissions
Katircioğlu and Taşpinar (2017)	Turkey (1960-2010)	CO_2 emissions per capita, domestic credits by the banking sector as share of GDP, domestic credits to the private sector as share of GDP, broad money supply as share of GDP, ratio of commercial bank assets to central bank assets plus commercial bank assets, liquid liabilities as share of GDP	Dynamic Ordinary Least Squares	Financial development has mixed impacts on CO_2 emissions
Huang and Zhao (2018)	30 Chinese provinces (2000-2014)	CO_2 emissions per capita, non-state credit to nominal GDP	Input-Output analysis	Financial development has mixed impacts on CO_2 emissions
Salahuddin et al. (2018)	Kuwait (1980-2013)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	Autoregressive-Distributed Lag	Financial development has no significant impact on CO_2 emissions
Bass et al. (2019)	Russia (1990-2016)	CO_2 emissions per capita, share of loans provided to the energy sector	Autoregressive-Distributed Lag	Financial development positively affects CO_2 emissions
Saud et al. (2019)	18 Central and Eastern European countries (1980-2016)	CO_2 emissions per capita, financial development index	• Dynamic Seemingly Unrelated Regression • Fully Modified Ordinary Least Squares	Financial development positively affects CO_2 emissions

Shen et al. (2021)	30 provinces of China (1995-2017)	Carbon emissions (CO2) is estimated based on seven different fossil fuel burning such as natural gas, coke, coal, kerosene, fuel oil, diesel and gasoline and cement production, domestic credit provided to the private sector.	• Cross-sectionally augmented autoregressive distributed lags (CS-ARDL)	Financial development positively affects CO_2 emissions
Khan and Ozturk (2021)	88 developing countries (2000–2014)	CO_2 emissions per capita , (i) Financial system deposits to GDP; (ii) Domestic credit provided by financial sector (% of GDP); (iii) Domestic credit to private sector (% of GDP); (iv) Total Bank deposits to GDP (%); (v) Liquid liabilities (M3) as % of GDP	• System GMM method	Financial development negatively affects CO_2 emissions
Zafar et al. (2021)	APEC (1990-2018)	CO_2 emissions per capita, domestic credit to the private sector as share of GDP	• Panel quantile regression test	Financial development negatively affects CO_2 emissions
Education- Environmental Quality Nexus				
Gangadharan and Valenzuela (2001)	51 countries (1998)	CO_2 emissions, secondary school enrolment ratio	Cross-sectional Regression	Education positively affects CO_2 emissions
Managi and Jena (2008)	16 Indian states (1991-2003)	SO_2 emissions, NO_2 emissions, SPM emissions, persons who have passed at least matriculation	• Ordinary Least Square • Fixed Effect Regression • Dynamic Generalized Method of Moments	• Education negatively affects SO_2 emissions • Education positively affects NO_2 emissions • Education positively affects SPM emissions
Sapkota & Bastola (2017)	14 Latin American countries (1980-2010)	CO_2 emissions per capita, Average years of total schooling of age 15 +	• Fixed Effect Regression • Random Effect Regression	Education positively affects CO_2 emissions
Balaguer & Cantavella (2018)	Australia (1950-2014)	CO_2 emissions per capita, total number of students at graduate and postgraduate levels	Autoregressive-Distributed Lag	Education-CO_2 emissions association follows inverted U-shaped form
Bano et al. (2018)	Pakistan (1971-2014)	CO_2 emissions per capita, secondary school enrolment for general	Autoregressive-Distributed Lag	Education negatively affects CO_2 emissions

		education, secondary school enrolment for vocational education, human capital index based on average year of education and estimated outcomes		
Zafar et al. (2019)	United State of America (1970-2015)	Ecological footprint, human capital	Autoregressive-Distributed Lag	Education negatively affects ecological footprint
Zafar et al. (2020)	OECD (1990-2015)	CO_2 emissions per capita, secondary education enrolment gross as a proxy for education	Continuously updated fully modified (Cup-FM)" and "continuously updated bias corrected (Cup-BC)" estimation methods	Education negatively affects CO_2 emissions
Zafar et al. (2021)	APEC (1990-2018)	CO_2 emissions per capita, secondary education enrolment gross as a proxy for education	Panel quantile regression test	Education negatively affects CO_2 emissions

Appendix 2: Model diagnostics results

Diagnostic tests	Eq. (1)	Eq. (2)	Eq. (3)
Heteroskedasticity	0.24	0.68	0.59
(Breusch and Pagan, 1979)	(0.6244)	(0.4090)	(0.4441)
Normality	0.72	0.43	0.32
(Jarque and Bera, 1987)	(0.2553)	(0.2497)	(0.2643)
Serial Correlation	0.76	0.91	0.56
(Wooldridge, 2002)	(0.4680)	(0.9534)	(0.4951)
Omitted Variable Bias	1.23	1.66	1.15
(Ramsey, 1969)	(0.2986)	(0.1742)	(0.3302)
Endogeneity Bias	0.27	0.16	0.24
(Durbin, 1954; Wu, 1973; Hausman, 1978)	(0.9981)	(0.9867)	(0.9997)

p-values are within parentheses