



# Signifying the imperative nexus between climate change and information and communication technology development: a case from Pakistan

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## Abstract

The globe has faced technological affluence that enormously revolutionized the lives of humankind. Today, the manufacturing process of the energy sector, production sector, agriculture sector, and service sector is exclusively or partially based on ICT tools. The key intention of this investigation is to find out the impacts of the utilization of ICT on CO<sub>2</sub> emission. However, this investigation also evaluates the influence of investment in ICT and the trade of ICT tools on CO<sub>2</sub> emission. Further, the estimation examined the subsistence of environment Kuznets curve (EKC) theory, for the nation of Pakistan. The investigation employed an autoregressive distributed lag (ARDL) model and found that the utilization of ICT has a negative impact on CO<sub>2</sub> emission. Moreover, the long-run results revealed that the import of ICT equipment is more beneficial for the environment quality of Pakistan. However, ICT apparatus manufactured in Pakistan might produce electronic waste due to non-utilization of green technology. The study reported bidirectional causality between ICT and CO<sub>2</sub> emission. These results point towards that the emergence of ICT in industries and daily life possesses a significant and positive role in climate change in Pakistan. Also, this study corroborates the veracity of EKC in Pakistan.

**Keywords** CO<sub>2</sub> emission · ICT · Trade · FDI · EKC · Pakistan · ARDL · Granger causality

## Introduction

Global warming and environmental degradation have become a significant issue for emerging nations, and it has become an

essential part of recent domestic and international policy debates. The emergent environmental threat is a public concern and part of social, economic, and political preference (Ben Ayeche et al. 2016). The dangers of climate change and environmental deprivation have brought the consideration of researchers about the primary affiliation between environmental pollutants and several factors. Consequently, several studies have found it attractive to investigate the determinants of CO<sub>2</sub> emission and the glaring strength of the correlation between them. Energy consumption, trade openness, urbanization, financial development, income, foreign direct investment (FDI), economic growth, and information and communication technology (ICT) are found to be essential determinants of CO<sub>2</sub> emission (Sharma 2011; Tang and Tan 2015; Wang et al. 2018).

In the modern age of inventions and innovations, ICT has become an indispensable element of all kinds of industries. Today, the manufacturing process of the energy sector, production sector, agriculture sector, and service sector is entirely or partially based on ICT tools. The globe has faced technological affluence that enormously revolutionized the lives of humankind. Likewise, the global progress in ICT is exposed

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in Fig. 1, where an upward movement has exhibited in the utilization of ICT types of equipment through 2001–2019. Indeed, Asia is the crucial mainland of the world, although, in the emergence of ICT apparatus, numerous countries are still at the back of the developed nations, e.g., the USA, Europe, and Australia.

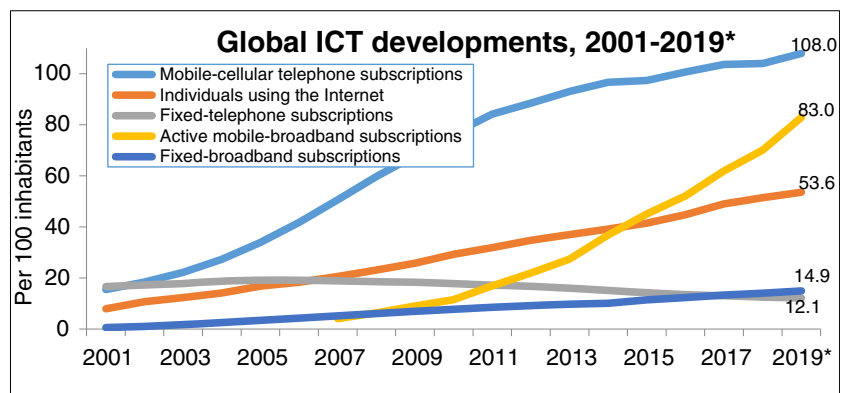
However, ICT is getting famous and acceptable in the general people of Pakistan (Imtiaz et al. 2015; GALLUP 2014). Currently, Pakistan has more than 152 million cellular subscribers and 60 million 3rd and 4th generation mobile internet subscribers. This number is expected to grow in the upcoming years due to the elimination of prices of data and smartphones (Khan 2019a). Furthermore, Pakistan generated 3.7% more mobile revenue in 2016 as compared with 2015, and its ratio of mobile revenue to total telecommunication revenue was also increased from 69 to 77% (ITU 2018). The government of Pakistan has also made efforts to provide easy access to ICT tools to the general public. In recent times, the government has provided the telecom services to un-served and under-served areas of Kharan, North Waziristan, Khuzdar, Chitral, Khyber Pakhtunkhwa, and Awaran. Moreover, 1037 km of optical fiber cable has been laid in twenty Tehsil Headquarters and the most important towns of Punjab and Baluchistan (Khan 2019a).

In May 2018, the government of Pakistan had introduced a new vision of ICT as “Digital Pakistan.” The principal aim of this vision is to provide the digital ecosystem with improved institutional framework and infrastructure; thus, digital services, applications, and other contents can be available hastily. It also intends to uplift the ICT ranking of Pakistan based on global indices and provides a benchmark for the infrastructure, socio-economic impact, skills readiness, affordability, and the business and innovation environment (Ministry of Information Technology 2018). Hence, ICT has become one of the significant strategic and rising industries of Pakistan. Conclusively, the growing trend of ICT in Pakistan, ICT-related policies, and vision of her government urged the author to analyze the environmental impacts of ICT in Pakistan.

Following the theory, ICT plays a vital role to heave the carbon dioxide emission (Houghton 2010). The increased utilization of ICT goods and economic growth has uplifted the demand for electricity in emerging nations. It can affect environmental quality by releasing a high amount of carbon emission (Danish et al. 2018a). However, various authors reported that ICT decreases the level of CO<sub>2</sub> emission by introducing smart electrical grids, digital transportation system, smart cities, efficient use of energy, and industrial process (Añón Higón et al. 2017; Danish et al. 2018b; Latif et al. 2017; Al-Mulali et al. 2015a, b). Latif et al. (2017) reported that investment in ICT could improve environmental quality. ICT industry helps to diminish the CO<sub>2</sub> emission, as consuming the internet diminishes the chances of air contamination and suggests investing in ICT to reduce air pollution (Wang et al. 2015). The various kinds of ICT apparatus, e.g., the internet, mobile phones, satellites, and computers, play an empirical role in dealing with the challenges related to environmental sustainability (Danish et al. 2018a). The on-hand study expounds on the significance of ICT for environmental quality in the context of Pakistan.

ICT has three kinds of impacts on the environment. ICT has a direct impact (i.e., ICT affect by electronic waste and use of energy); indirect impact (i.e., the effect of ICT instruments, like smart grids and intelligent transport system); and rebound impact, e.g., an effect supported by ICT due to its direct or indirect use (Houghton 2010). In the meantime, ICT development enhances international trade and flow, which facilitates the communication channels, and it may affect the environment quality (Ozcan 2018). In addition, ICT apparatus transferred from developed countries to emerging nations through FDI and trade may generate electronic waste, and it can harm the environment. However, communication among nations and knowledge shared through FDI bring awareness among people that can improve the excellence of the environment (Danish et al. 2018c). Since its independence, Pakistan has a great history of trade and investment relationship with the whole world, especially America and China. The United

**Fig. 1** Global ICT Development.  
\*Estimates. Source: ITU World Telecommunication/ICT Indicators database



Note: \*Estimates Source: ITU World Telecommunication/ICT Indicators database

States (US) not only is one of the leading sources of FDI but also has become the biggest exporting market in Pakistan. The US and Pakistan trade during 2018 was \$6.6 billion, a rise of 4% as compared with 2017. Moreover, US exports to Pakistan reached a record level of \$2.9 billion in 2018, while bilateral trade also has a significant rise in 2019 (US Department of State 2019).

Besides, the China-Pakistan Economic Corridor (CPEC) is the most significant foreign investment (FDI) of this decade with an agreement to invest \$64 billion in Pakistan (Kanwal et al. 2019; Shah 2015). The CPEC involves massive development projects such as infrastructure development, technology development, socio-economic development, industrial zones, and energy projects (Sial 2014; Rizvi 2019). As per policymakers, CPEC will enhance the international trade and FDI for Pakistan, as it connects Pakistan and China with Europe, Central Asia, and Africa (Ali 2015). Additionally, China has become the second biggest market for Pakistan; as bilateral trade between Pakistan and China is also escalating with the growth rate of 12.57%, governments of both states are eager to take this at the amount of \$20 billion in upcoming years (Irshad and Xin 2015). The prime minister of Pakistan and Chinese Premier Li Keqiang, during his visit to the second Belt and Road Forum (BRF), held in Beijing, signed the critical agreements related to technology advancement, socio-economic development, and 2nd phase of China-Pak Free Trade Agreement (The News I 2019).

Further, not only China but also other nations of the world are investing in Pakistan. The prince of Saudi Arabia visited Pakistan and agreed on the investment deal of \$20 billion (Bekhet et al. 2017). Moreover, Pakistan is going to enter one of the biggest commercial centers of the globe known as ASEAN economies, which has a trade level of \$2.6 trillion and an FDI level of \$136 billion. Pakistan and Malaysia signed the investment deals of \$800–\$900 million in the field of telecom, IT, agriculture, power generation, and textile industries (Khan 2019b). Hence, Pakistan fulfills its considerable portion of the needs of ICT through international trade and FDI. As well, Pakistan has bilateral free trade agreements with Afghanistan, Bahrain, Germany, France, Indonesia, Iran, Jordan, Mauritius, South Korea, Sri Lanka, Sweden, and Turkey (Ministry of Commerce 2012).

The increasing level of trade and investment in the ICT sector of Pakistan has grasped the attention of the author to inspect its environmental impacts. This examination imperatively contributes to the literature by analyzing the impacts of the utilization of ICT instruments on CO<sub>2</sub> emission in the context of Pakistan. This investigation illustrates how the emergence of ICT in the home sector, energy sector, food sector, service sector, and other manufacturing sectors can be propitious to eliminate the level of CO<sub>2</sub> emission in Pakistan. Moreover, this investigation evaluates the collisions of investment in ICT on CO<sub>2</sub> emission and identifies the

association between CO<sub>2</sub> emission and the trade of ICT tools in Pakistan. Besides, the study evaluates the linkage of FDI and trade openness with CO<sub>2</sub> emission. Also, the estimation reviewed the subsistence of environment Kuznets curve (EKC) theory, for the nation of Pakistan. The overall research questions of this study are as follows. First, does the use of ICT have a positive or negative correlation with CO<sub>2</sub> emission? Second, can the emergence of ICT in daily life and industrial sector help to improve the environment quality? Three, does the trade of ICT tools harm the environment quality? Fourth, does the manufacturing of ICT tools increase the CO<sub>2</sub> emission in Pakistan? Fifth, do the use of ICT, production, and trade of ICT instruments have a bidirectional contact with CO<sub>2</sub> emission? Sixth, do FDI and trade possess a destructive bonding with CO<sub>2</sub> emission? Seventh, does EKC theory exist in Pakistan? Finally, what implications can be derived from this analysis, especially to recognize the role of ICT in daily life? After answering these questions, we pursue to extend our knowledge about the use of ICT, the production of ICT tools, and the trade of ICT equipment in the context of Pakistan. Thus, policymakers, managers of environment control institutions, and the government of Pakistan can acquire assistance from the outcomes of this investigation to formulate novel strategies about the trade and investment levels in the ICT sector; so, the environment quality can be enhanced. As per the author's best information, this is the only examination, which scrutinizes the effect of ICT usage, trade of ICT tools, and foreign direct investment in the ICT sector on CO<sub>2</sub> emission in support of Pakistan.

In the beginning, the unit root of the variables has been scrutinized by using the three advanced methodologies, such as augmented Dickey-Fuller (ADF) test, Phillips-Perron (PP) test, and Kwiatkowski Phillips-Schmidt-Shin (KPSS) test. The examination showed varied outcomes, e.g., I(0) and I(1); thus, an extended version of autoregressive distributed lag (ARDL) bound testing method is utilized to evaluate the short-run and long-run elasticities. The remaining study is systematized as follows; Section 2 deals with the concise literature review, and Section 3 is designated for data and methodological path. Moreover, segment 4 defines the results and discussions, and Section 5 presents the conclusion of the investigation with policy implications. At last, References are placed in segment 6.

## Literature review

The liaison between ICT and CO<sub>2</sub> emission has become a burning issue of debate. For instance, Zhang and Liu (2015) extended the STIRPAT model to evaluate the influence of ICT industry on CO<sub>2</sub> emission, at the regional and national level of China. The study used secondary data from the period of 2000–2010 and found that the ICT industry significantly

helps to decrease the level of CO<sub>2</sub> emission at the national level. Moreover, the study found that a negative impact of the ICT industry on CO<sub>2</sub> emission is more significant in the innermost area of China instead of the eastern region. However, the western region showed insignificant results. The study also elaborated that more use of ICT without sustainable energy consumption adversely affects the environment quality. The examination made known that energy intensity has an impressive favorable influence on CO<sub>2</sub> emission. Moreover, urbanization has a remarkable and positive impact on CO<sub>2</sub> emission.

The study of Salahuddin and Alam (2015) argued that the use of the internet and economic growth are two primary sources of electricity consumption in Australia. Olló-López and Aramendía-Muneta (2012) stated that some kinds of ICT are helpful to decrease CO<sub>2</sub> emission. Lee and Brahmashree (2014) analyzed that ICT, GDP, and CO<sub>2</sub> emission have a positive relationship with each other. Also, Coroama et al. (2012) confirmed that ICT has a significant role in improving environmental quality, as it significantly decreases greenhouse gasses (GHGs). Ozcan and Apergis (2018) inspected the influence of internet usage on ecological quality for emerging nations and found that usage of the internet significantly reduced the level of CO<sub>2</sub> emission in twenty emerging nations. Conversely, the study reported that GDP, energy consumption, and trade significantly affect environmental quality, while there was a negative connection between financial development and CO<sub>2</sub> emission. Dogan et al. (2019) scrutinized the EKC hypothesis for Indonesia, Mexico, Turkey, and Nigeria by consuming the ecological footprints as a proxy variable for environmental degradation. The investigation found that exports have negative, but imports exhibited positive liaison with environmental degradation. The study concluded that exports, fossil fuel energy consumption, financial development, and urbanization are the very conventional sources of environmental degradation.

Additionally, Lu (2018) explored the effects of energy utilization, GDP, financial development, and ICT on CO<sub>2</sub> emission for twelve Asian nations. The examination found that ICT has a negative relationship with CO<sub>2</sub> emission, but financial development, energy consumption, and GDP significantly increased the level of CO<sub>2</sub> emanation. Añón Higón et al. (2017) examined the non-linear impacts of ICT by using secondary data of different developed and underdeveloped nations and found that ICT has an inverted U-shaped connection with CO<sub>2</sub> emission. Salahuddin et al. (2018) examined the impacts of energy consumption, GDP, and FDI on CO<sub>2</sub> emission in Kuwait, and concluded that these factors had long-term affiliation with each other. Danish et al. (2018) examined an association among GDP, trade, urbanization, and CO<sub>2</sub> emission by utilizing the ARDL model. The investigation stated that a decrease in per capita income caused an increase in CO<sub>2</sub> emission. The research also noted

that a large proportion of carbon dioxide production in the country is due to fossil fuel energy consumption, whereas trade has no significant influence on CO<sub>2</sub> emission, but urbanization significantly affects CO<sub>2</sub> emission. Ahmed et al. (2015) evaluated the hypothesis of EKC by using deforestation as the dependent variable. The GDP, trade openness, energy utilization, and population were used as independent factors. The study employed the ARDL model on annual data from 1980 to 2013 and found that GDP and energy consumption positively influenced the deforestation. However, trade openness has an insignificant and adverse effect on deforestation.

Dogan and Inglesi-Lotz (2020) evaluated the impact of the economic structure of European nations on environmental quality. The examination used the industrial share as a nomination factor of economic structure and found an insignificant EKC hypothesis for the European nation, but the U-shaped association was confirmed. However, the use of GDP growth confirmed the EKC hypothesis for European countries. Moreover, Dogan and Turkekul (2016) inspected the affiliation of CO<sub>2</sub> emission with GDP, the square of GDP, energy consumption, trade openness, financial development, and urbanization in the USA by employing the bound testing technique for cointegration. The assessment found that there was a bidirectional liaison between energy consumption and CO<sub>2</sub>, GDP and CO<sub>2</sub>, urbanization and CO<sub>2</sub>, trade openness and GDP, and urbanization and GDP. Further, the study could not find a significant EKC hypothesis for the USA. Blanco et al. (2013) analyzed the affiliation of FDI with CO<sub>2</sub> emission by using the data of eighteen states of Latin America. The study used the annual data from the period 1980 to 2007. The investigation applied the ARDL bound testing approach and discovered that FDI significantly affects the CO<sub>2</sub> emission and GDP. Moreover, the investigation stated that imperative causality flow was running from FDI to CO<sub>2</sub> emission, and recommends that investment in pollutant sectors should be strictly observed. Apergis and Payne (2009) used the data of 6 central states of America from the period of 1971–2004 to ascertain the association between energy usage, real output, and CO<sub>2</sub> emission. The study implied the panel error correction model and revealed that energy consumption has a direct and significant affiliation with CO<sub>2</sub> emission. Moreover, the quadratic relationship was noticed between real output and CO<sub>2</sub> emission. Ghosh (2010) implied the ARDL and Granger causality test to extract the relationship between GDP and CO<sub>2</sub> emission. The investigation utilized the data of the Indian economy from the period of 1971–2006 and discovered that there was no causality attachment between GDP and CO<sub>2</sub> emission for the long-term period. However, unidirectional short-run causality was significantly running from GDP to energy supply and energy supply to CO<sub>2</sub>



emission. Also, short-run bidirectional causality was reported between CO<sub>2</sub> emission and the economic growth of India.

Mahmood et al. (2019) analyzed the impact of biomass energy on CO<sub>2</sub> emission under the EKC hypothesis. The outcomes showed that it has a considerable and positive contact with CO<sub>2</sub> emission, which confirms that biomass energy caused environmental degradation in Pakistan. Also, the study revealed that FDI has a positive relationship with CO<sub>2</sub> emission. Nonetheless, trade openness showed an insignificant association with CO<sub>2</sub> emission. Park et al. (2018) evaluated the enforcement of electricity utilization, FDI, GDP, trade, and financial development on the environment eminence through the time of 1980–2016 in BRI countries. The results of the study illustrated that economic development, trade openness, and financial growth have a significant and negative effect on CO<sub>2</sub> emission. However, ICT and electricity use has a positive effect on CO<sub>2</sub> emission. Chai-Arayalert and Nakata (2011) investigated green ICT practices and their impact on the environment quality for the nation of the United Kingdom (UK). The study explored that with the use of green ICT practices, considerable changes were noted in the UK, such as the reduction in universities' computing and enterprise computing, printing devices, and other consumables, which refers to minimize CO<sub>2</sub> emission in the environment.

The analysis confirmed that financial development, GDP, and ICT had a direct effect on CO<sub>2</sub> emission. However, urbanization has a negative impact on CO<sub>2</sub> emission. Ishida (2015) and Røpke and Christensen (2012) argued that ICT investment significantly reduces energy consumption. Asongu et al. (2018) considered the efficaciousness of ICT on environmental quality with the use of the generalized method of movements (GMM) model for 44 Sub-Saharan African states. The consequence exposed that ICT has a positive influence on CO<sub>2</sub> emission. Moutinho et al. (2018) considered the top 23 nations of the world and reported that financial development and renewable resources are the key factors that diminish the CO<sub>2</sub> emission. However, fossil fuel energy consumption has a positive and significant impact on CO<sub>2</sub> emission for these nations.

Consequently, the above-presented literature and summary of the current five years' studies presented in Table 1 showed mixed impacts of ICT on CO<sub>2</sub> emission. Moreover, from an ICT point of view, significant concern has been shown for developed nations, but research on the impacts of ICT on CO<sub>2</sub> emission in developing nations is still insufficient, especially in Pakistan. Further, the author could not find a study that investigates the impacts of ICT on CO<sub>2</sub> emission after considering the modest influence of FDI and international trade, in the context of Pakistan. Also, this article analyzed the existence of EKC in Pakistan.

## Data and methodological path

### Data

This study has used annual data through the period of 1990–2018 to analyze the liaison between climate change and ICT. The examination has utilized the CO<sub>2</sub> emission as the dependent variable. This analysis used the data of mobile cellular subscribers per hundred people as a proxy variable for ICT. The trade (% of GDP) and foreign direct investment (% of GDP) are used as the nominator of trade variable and FDI, respectively. Additionally, the linkage between ICT and Trade, and ICT and FDI is calculated as ICT\*Trade and ICT\*FDI, respectively. The investigation has collected the data from the World Bank database. The complete data is deformed into a natural log to avoid the problem of heterogeneity.

### Methodology

The current investigation employed the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model established by Dietz and Rosa (1997) to observe the nexus among ICT and CO<sub>2</sub> secretion. The STIRPAT model is flexible, and some additional factors can be integrated into this model (Ahmed et al. 2019). The general form of this model is as follows:

$$I_t = aP_t^b A_t^c T_t^d \mu_t \quad (1)$$

Here  $P$  denotes the population size,  $A$  indicates the affluence measured as GDP growth,  $I$  is the environmental impact indicated by CO<sub>2</sub> emission, and  $\mu$  is the error term. Moreover,  $T$  nominates the technology factor. However,  $T$  and  $P$  are not only two variables but consist of different factors that manipulate environmental effects; it can be disaggregated by adding further variables in the STIRPAT model (York et al. 2003; Ahmed et al. 2019). This examination disaggregated the  $T$  factor into ICT, the interface between ICT and FDI (ICTF), and the interaction between trade and ICT (ICTT). Moreover, this study disaggregated the  $P$  into the total population, trade, and FDI. The linear relationship between these variables can be illustrated as follows:

$$\begin{aligned} \ln CO_{2t} = & \beta_0 + \beta_1 \ln ICT_t + \beta_2 \ln FDI_t + \beta_3 \ln GDP_t \\ & + \beta_4 \ln TR_t + \beta_5 \ln ICTT_t + \beta_6 \ln ICTF_t \\ & + \beta_7 \ln POP_t + \varepsilon_t \end{aligned} \quad (2)$$

Here,  $\ln$  and  $t$  represent the natural log and time, respectively. While  $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$  are the coefficients. Moreover, ICT defines information and communication technology, FDI nominates the foreign direct

**Table 1** The current studies on the relationship between ICT, GDP, FDI, Trade, and CO<sub>2</sub> emission

Author (year)	Country	Methodology	Variables	Results
Zhang and Liu (2015)	Chinese provinces	STIRPAT, panel data analysis	ICT industry, CO <sub>2</sub> emission, energy consumption, and urbanization	The study found a negative impact of the ICT industry on CO <sub>2</sub> emission. The examination made known that energy intensity has an impressive favorable influence on CO <sub>2</sub> emission
Salahuddin and Alam (2015)	Australia	ARDL, Granger causality	Internet usage, economic growth, CO <sub>2</sub> emission, and electricity consumption.	The study found that the use of the internet and economic growth are two primary sources of electricity consumption in Australia
Ozcan and Apergis (2018)	20 emerging economies	Panel data analysis, and panel Granger causality	ICT, CO <sub>2</sub> emission, GDP, energy consumption, trade, and financial development.	The study reported that GDP, energy consumption, and trade significantly affect environmental quality, while there was a negative connection between financial development and CO <sub>2</sub> emission.
Dogan et al. (2019)	Indonesia, Mexico, Turkey, and Nigeria	ARDL, Granger causality	Ecological footprints, exports, fossil fuel, energy consumption, financial development, and urbanization.	The investigation found that exports have the contrary, but imports exhibited positive liaison with environmental degradation. The study concluded that exports, fossil fuel energy consumption, financial development, and urbanization are the very conventional sources of environmental degradation.
Lu (2018)	12 Asian countries	Pedroni cointegration	ICT, economic growth, energy consumption, financial development, and CO <sub>2</sub> emission.	The examination found that ICT has a negative relationship with CO <sub>2</sub> emission, but financial development, energy consumption, and GDP significantly increased the level of CO <sub>2</sub> emanation.
Salahuddin et al. (2018)	Kuwait	ARDL	Energy consumption, GDP, FDI, and CO <sub>2</sub> emission.	The study concluded that energy consumption, GDP, and FDI factors had long-term affiliation with CO <sub>2</sub> emission.
Danish et al. (2018)	Emerging economies	Panel ARDL	GDP, trade, urbanization, and CO <sub>2</sub> emission.	The investigation stated that a decrease in per capita income caused an increase in CO <sub>2</sub> emission. The research also noted that a large proportion of carbon dioxide production in the country is due to fossil fuel energy consumption, whereas trade has no significant influence on CO <sub>2</sub> emission.
Ahmed et al. (2015)	Pakistan	ARDL and VECM Granger causality	Deforestation, GDP, trade openness, energy use, and population.	The investigation found that GDP and energy consumption positively influenced the deforestation. However, trade openness has an insignificant and adverse effect on deforestation.
Dogan and Inglesi-Lotz (2020)	European countries	Panel FMOLS, and OLS	GDP, industrial share, and CO <sub>2</sub> emission.	The examination used the industrial share as a nomination factor of economic structure and found an insignificant EKC hypothesis for the European nation, but the U-shaped association was confirmed. However, the use of GDP growth confirmed the EKC hypothesis for European countries.
Dogan and Turkekul (2016)	USA	ARDL	GDP, the square of GDP, energy consumption, trade openness, financial development, and urbanization.	The assessment found that there was a bidirectional liaison between energy consumption and CO <sub>2</sub> , GDP and CO <sub>2</sub> , urbanization and CO <sub>2</sub> , trade openness and GDP, and urbanization and GDP. Further, the study could not find a significant EKC hypothesis for the USA.
Mahmood et al. (2019)	Pakistan	ARDL	Biomass energy, GDP, FDI, trade openness, and CO <sub>2</sub> emission.	The outcomes showed that it has a considerable and positive contact with CO <sub>2</sub> emission, which confirms that biomass energy caused environmental degradation in Pakistan. Also, the study revealed that FDI has a positive relationship with CO <sub>2</sub> emission.
Park et al. (2018)	BRI countries	ARDL	ICT, FDI, GDP, electricity consumption, trade, financial development, and CO <sub>2</sub> emission.	The results of the study illustrated that economic development, trade openness, and financial growth have a significant and negative effect on CO <sub>2</sub> emission. However, ICT and electricity use has a positive effect on CO <sub>2</sub> emission.
Asongu et al. (2018)	Sub-Saharan African states	GMM	ICT, economic growth, and CO <sub>2</sub> emission	The consequence exposed that ICT has a positive influence on CO <sub>2</sub> emission

investment, TR stands for the trade, and ICTT and ICTF indicate the interface between ICT and trade and interaction between ICT and FDI, respectively. Further, GDP specifies the growth of the gross domestic product, and POP is the total population.

The on-hand examination utilized the autoregressive distributed lag (ARDL) model introduced by Pesaran et al. (2001) to evaluate the cointegration among the variables. The ARDL can be used apart from either the data is stationary at level, first difference, or else

varied of integration (Ahmad et al. 2018), and it is more suitable for a small set of data. Moreover, in the ARDL model, the dependent factor is explained through its previous and the past values of other independent instruments (Cherni and Essaber Jouini 2017). This study evaluates the ARDL bound testing cointegration equation for each variable as:

$$\begin{aligned} \Delta \ln CO2_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln CO2_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln ICT_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln FDI_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln GDP_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln CO2_{t-i} + \phi_2 \ln ICT_{t-i} + \phi_3 \ln FDI_{t-i} \\ & + \phi_4 \ln GDP_{t-i} + \phi_5 \ln TR_{t-i} + \phi_6 \ln ICTT_{t-i} \\ & + \phi_7 \ln ICTF_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta \ln ICT_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln FDI_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln GDP_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln ICT_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln FDI_{t-i} \\ & + \phi_4 \ln GDP_{t-i} + \phi_5 \ln TR_{t-i} + \phi_6 \ln ICTT_{t-i} \\ & + \phi_7 \ln ICTF_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \quad (4)$$

$$\begin{aligned} \Delta \ln FDI_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln FDI_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln GDP_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln FDI_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln ICT_{t-i} \\ & + \phi_4 \ln GDP_{t-i} + \phi_5 \ln TR_{t-i} + \phi_6 \ln ICTT_{t-i} \\ & + \phi_7 \ln ICTF_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \quad (5)$$

$$\begin{aligned} \Delta \ln GDP_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln GDP_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln ICT_{t-i} \\ & + \phi_4 \ln FDI_{t-i} + \phi_5 \ln TR_{t-i} + \phi_6 \ln ICTT_{t-i} \\ & + \phi_7 \ln ICTF_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta \ln TR_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln GDP_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln ICT_{t-i} \\ & + \phi_4 \ln FDI_{t-i} + \phi_5 \ln GDP_{t-i} + \phi_6 \ln ICTT_{t-i} \\ & + \phi_7 \ln ICTF_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta \ln ICTT_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln ICTT_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln TR_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln GDP_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln ICT_{t-i} \\ & + \phi_4 \ln FDI_{t-i} + \phi_5 \ln GDP_{t-i} + \phi_6 \ln TR_{t-i} \\ & + \phi_7 \ln ICTF_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \quad (8)$$

$$\begin{aligned} \Delta \ln ICTF_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln TRR_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTT_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \phi_1 \ln GDP_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln ICT_{t-i} \\ & + \phi_4 \ln FDI_{t-i} + \phi_5 \ln GDP_{t-i} + \phi_6 \ln TR_{t-i} \\ & + \phi_7 \ln ICTT_{t-i} + \phi_8 \ln POP_{t-i} + \mu_t \end{aligned} \tag{9}$$

$$\begin{aligned} \Delta \ln POP_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln POP_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln TRR_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTT_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln ICTF_{t-1} \\ & + \phi_1 \ln GDP_{t-i} + \phi_2 \ln CO2_{t-i} + \phi_3 \ln ICT_{t-i} \\ & + \phi_4 \ln FDI_{t-i} + \phi_5 \ln GDP_{t-i} + \phi_6 \ln TR_{t-i} \\ & + \phi_7 \ln ICTT_{t-i} + \phi_8 \ln ICTF_{t-i} + \mu_t \end{aligned} \tag{10}$$

where  $i$  indicates the lag values and  $\Delta$  specifies the first difference operator,  $\delta_1 - \delta_8$  represents the short-term parameters, and  $\phi_1 - \phi_8$  are the long-term coefficients, while  $\mu_t$  signifies the residual parameter. In order to guesstimate the long-run cointegration among variables, the ARDL model hinges on the joint F-statistics. Hence, the investigation examined the null hypothesis of no assimilation exists against the alternative assumption of cointegration exists. Pesaran et al. (2001) quantified the lower critical bound (LCB) value and upper critical bound (UCB) value to reckon the validity of the ARDL model. If the projected F-statistics value is lesser than LCB, then the null hypothesis of the ARDL model is accepted, whereas, if the estimated value of F-statistics is higher than UCB, then the null hypothesis of the ARDL model is rejected, which infers that cointegration among variables is present. Besides, if the F-statics value falls between UCB and LCB, then the ARDL model is considered to be indecisive. Once the long-run cointegration among variables is confirmed through examining Eqs. 3–10, the next step is to find a long-term and short-term causality among the variables. If there is no indication of cointegration among the variables examined in this study, then vector autoregressive (VAR) will be specified to

ascertain the Granger causality. Nonetheless, if the investigation found confirmation of cointegration, then Granger causality will be subtracted through one period lagged error correction term ( $ECT_{t-1}$ ) as follows (Engle and Granger 1987):

$$\begin{aligned} \Delta \ln CO2_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln CO2_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln ICT_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln FDI_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln GDP_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \tag{11}$$

$$\begin{aligned} \Delta \ln ICT_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln FDI_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln GDP_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \tag{12}$$

$$\begin{aligned} \Delta \ln FDI_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln FDI_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln GDP_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \tag{13}$$

$$\begin{aligned} \Delta \ln GDP_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \tag{14}$$



$$\begin{aligned} \Delta \ln TR_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln TR_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln ICTT_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \quad (15)$$

$$\begin{aligned} \Delta \ln ICTT_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln ICTT_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln TR_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \quad (16)$$

$$\begin{aligned} \Delta \ln ICTF_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln ICTF_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln TR_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTT_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln POP_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \quad (17)$$

$$\begin{aligned} \Delta \ln POP_t = & \delta_0 + \delta_1 \sum_{i=1}^p \Delta \ln POP_{t-1} + \delta_2 \sum_{i=1}^p \Delta \ln CO2_{t-1} \\ & + \delta_3 \sum_{i=1}^p \Delta \ln ICT_{t-1} + \delta_4 \sum_{i=1}^p \Delta \ln FDI_{t-1} \\ & + \delta_5 \sum_{i=1}^p \Delta \ln GDP_{t-1} + \delta_6 \sum_{i=1}^p \Delta \ln TR_{t-1} \\ & + \delta_7 \sum_{i=1}^p \Delta \ln ICTT_{t-1} + \delta_8 \sum_{i=1}^p \Delta \ln ICTF_{t-1} \\ & + \psi_1 ECT_{t-1} + \mu_t \end{aligned} \quad (18)$$

Here  $ECT_{t-1}$  denotes the error-correction term, which quantifies the speed of adjustment of a series to attain long-run equilibrium. The investigation utilized the heteroskedasticity and serial correlation techniques to assess the appropriateness of the examined model. Furthermore, the study utilized the cumulative sum of recursive residuals (CUSUM) test and the square of the cumulative sum of

recursive residuals (CUSUMSQ) test (Brown et al. 1975) to analyze the constancy of the model.

## Results and discussions

### Descriptive statistics, correlation, unit root, and cointegration test

The descriptive statistics of the complete data are specified in Table 2, which shows that all the variables are normally distributed except FDI and ICTF, as the probability value of the Jarque-Bera test is highly significant for them. Table 3 demonstrates the correlation analysis, which indicates that most of the factors have a direct and worth mentioning correlation with CO<sub>2</sub> emission; however, TR and ICTF showed a negative association with CO<sub>2</sub> emission. The study has applied ADF, PP, and KPSS tests for the evaluation of the stationary level of the variables. The results of the unit root test are demonstrated in Table 4. The results of ADF (Dickey and Fuller 1979) indicate that most of the factors are stationary at I(1), but the results of PP (Phillips and Perron 1988) and KPSS (Kwiatkowski et al. 1992) illustrate that the integration level of the variables is assorted, e.g., I(0) and I(1), though no one variable is included at I(2). Hence, it allows the author to apply the ARDL bound test approach to ascertain the long-run, short-run, and cointegration affiliation among the variables with the use of bound test approach (Pesaran et al. 2001).

The next step of the evaluation process is to evaluate the cointegration liaison among variables. For this purpose, the investigation used each factor as the dependent variable and employed the bound test technique of Pesaran et al. (2001). Table 5 exhibited the results of Eqs. 3–10 based on the Akaike information criterion. The fallouts stated that long-run cointegration subsists among the variables employed in this investigation as the F-statistics values of all models are higher than UCB value (3.9) at 1% level of significance.

### ARDL reckoning

Table 6 displayed the outcomes of the long-run and short-run ARDL model. The long-run results revealed that there is a negative and momentous affiliation between ICT and CO<sub>2</sub> emission. The study indicated that one unit growth in ICT significantly decreases the CO<sub>2</sub> emission by 0.322 units. These results indicate that the use of ICT plays a significant role in alleviating the level of CO<sub>2</sub> emission in Pakistan. It can be confirmed through determining, supervising, managing, and enabling efficient utilization of resources (Houghton 2010), e.g., e-mail as compared with mail, e-book in place of the book, e-newspaper instead of a printed newspaper; hence, it curtails waste. Further, video conferences and online shopping in lieu of traveling outside, which can hoard the

**Table 2** Descriptive statistics

	CO <sub>2</sub>	ICT	FDI	TR	GDP	ICTF	ICTT	POP
Mean	0.82062	24.4276	20.7680	3.49329	6.84227	12.2324	1.457347	18.8218
Median	0.83247	1.84078	20.6460	3.49436	6.82231	12.5279	2.063393	18.8287
Maximum	0.99103	73.1688	22.4442	3.65706	7.10867	92.8472	14.80755	19.0939
Minimum	0.61629	0.00185	19.3570	3.23105	6.62515	− 121.72	− 22.5987	18.5156
Std. Dev.	0.11559	29.7265	0.86810	0.10412	0.13807	71.0538	12.06679	0.16794
Skewness	− 0.2326	0.58228	0.26597	− 0.7145	0.18289	− 0.2197	− 0.29183	− 0.1074
Kurtosis	1.70423	1.50140	2.01753	3.10953	1.60239	1.49009	1.578763	1.85795
Jarque-B	2.2114	4.1466	15.210***	1.00386	2.15572	10.9***	3.425961	1.59432
Prob.	0.3309	0.1258	0.00050	0.60541	0.34031	0.00424	0.258445	0.45061

Source: author’s calculation. \*\*\*, \*\* and \* denote 1%, 5%, and 10% significance, respectively

consumption of fossil fuel, accordingly reduce the CO<sub>2</sub> emission.

Moreover, building automation, domotics<sup>1</sup> or home automation and intelligent transportation system (ITS) are the factors that help to get better energy efficiency; thus, it diminishes the CO<sub>2</sub> emission. Also, the involvement of ICT helps to save energy in some areas of life, which exceeds the extra energy use caused by ICT in other areas, such as the utilization of smaller ICT apparatus, laptops, smartphones, and others which are energy-efficient tools. Therefore, the government of Pakistan should spread more awareness about the use of ICT in the general public. Moreover, this information is also crucial for policymakers to introduce new environment-friendly ICT equipment, a possible way to reduce CO<sub>2</sub> emission.

The study also found an indirect and generous liaison between trade and CO<sub>2</sub> emission for Pakistan. The coefficient of ICTT is found − 0.0890, which specifies that trading of one unit of ICT goods significantly helps to decrease the level of CO<sub>2</sub> emission by 0.089 units. However, the interaction between ICT and FDI (ICTF) showed a constructive and foremost relationship with CO<sub>2</sub> emission. These outcomes described that trading and usage of ICT imperatively improve the environment quality of Pakistan. However, the study showed that the production techniques of ICT goods in Pakistan are not so advanced that they can produce products without affecting environmental quality. The government of Pakistan should introduce and adopt the production techniques that utilize green technology. Thus, the policymakers need to implement high environmental policies to restrict the old production techniques that harm the environment quality. These results point towards that the emergence of green technology in industries and daily life

plays a significant and positive role in climate change in Pakistan. Lu (2018) investigated the data of twelve Asian nations and explored that ICT and CO<sub>2</sub> emission have a negative relationship with each other. Moreover, the examination illustrated that ICT improves environmental quality, and it can be used as an effective strategy to emit CO<sub>2</sub> emission. Danish et al. (2018) assured that ICT with a combination of GDP (ICTxGDP) significantly decreases the level of CO<sub>2</sub> emission. Chai-Arayalert and Nakata (2011) also explored that the use of ICT lessens the use of energy, which improves climate quality. However, Park et al. (2018) documented an encouraging collision of ICT with CO<sub>2</sub> emission.

In addition, this examination evaluates the EKC hypothesis with the use of Narayan and Narayan (2010) approach. According to this approach, if the value of GDP is lesser in the long run instead of the short run, then the EKC hypothesis is accepted. This technique evades the problem of multicollinearity linked with GDP and its square if they are regressed as determinants of CO<sub>2</sub> emission (Amri 2018). Several studies have utilized this technique (e.g., Jaunky 2011; Amri 2018; Zambrano-Monserrate et al. 2018; Al-Mulali et al. 2015a, b). The investigation explains that GDP has an affirmative and significant affiliation with CO<sub>2</sub> emission. Also, the coefficient of GDP, in the short run, is higher than that in the long run. Hence, this study corroborates the veracity of EKC in Pakistan. Saud et al. (2018) also stated that economic growth has a positive relationship with CO<sub>2</sub> emission. The study revealed that TR has a negative but inconsequential connection with CO<sub>2</sub> emission. Nonetheless, in the short run, TR exposed positive and substantial rapport with CO<sub>2</sub> emission, implying that trade has a hostile impact on environmental quality for the short-term period. The analysis also publicized that FDI has a positive attachment with CO<sub>2</sub> emission, but the first lag value of FDI has shown a negative link with CO<sub>2</sub> emission. Besides, the population showed a positive liaison with CO<sub>2</sub> emission. The

<sup>1</sup> Domotics is a term that refers to a system to control home devices and automation through ICT. More at <http://www.easydom.com/en/discover/what-is-domotics>

**Table 3** Correlation analysis

	TR	FDI	CO <sub>2</sub>	GDP	ICTF	ICTT	POP	ICT
TR	1							
FDI	0.202689 0.2917	1						
CO <sub>2</sub>	- 0.531593 0.003	0.396032 0.0334	1					
GDP	- 0.215679 0.2612	0.022831 0.9064	0.046042 0.8125	1				
ICTF	0.336694 0.0741	0.587741 0.0008	- 0.14659 0.448	- 0.02086 0.9144	1			
ICTT	- 0.590038 0.0008	0.25858 0.1756	0.96905 0	0.048992 0.8007	- 0.26478 0.1651	1		
POP	- 0.717301 0	0.1089 0.5739	0.92308 0	0.102758 0.5958	- 0.38796 0.0376	0.967879 0	1	
ICT	- 0.599662 0.0006	0.251849 0.1875	0.967552 0	0.05671 0.7701	- 0.27066 0.1556	0.999526 0	0.972951 0	1

Source: author’s calculation

coefficient of  $ECT_{t-1}$  indicated that the previous year’s deviation of this model would move back to equilibrium with a speed of 0.82 units in the current year. These results are in line with Zhang (2011), Dar and Asif (2006), Siddique (2017), Anser (2019), Javid and Sharif (2016), Nazir et al. (2018), and Rahman and Ahmad (2019). Further, the negative and significant coefficient value of  $ECT_{t-1}$  describes that the previous year’s deviation of the CO<sub>2</sub> emission from the long-term equilibrium is adjusted with the speed of 0.82 units in the recent time. Additionally, the coefficient of R-squared and Adj.R-squared stipulates that 90% variation in CO<sub>2</sub> emission is due to the variables used in this study, and 83% changes in CO<sub>2</sub> emission are due to significant variables among them, respectively. The value of Durbin-Watson is found 2.094, which clearly states that there is no autocorrelation in the data.

The lag selection of this study is based on the Akaike information criterion with a maximum lag of 3.

**Time-series causality**

The outcomes of Granger causality based on the vector error correction model are presented in Table 7. The fallouts termed that in the short run, there is bidirectional causality between CO<sub>2</sub> emission and ICT, and CO<sub>2</sub> emission and ICTT. Besides, the study discovered that unidirectional causality is running from ICT and ICTT to GDP. However, the null hypothesis of GDP does not Granger-cause CO<sub>2</sub> emission could not be rejected. The study indicated that ICT, GDP, and ICTT have significant causality flow on ICTF, implying that changes in ICT, GDP, and ICTT have a significant impact on ICTF.

**Table 4** Unit root test

Variables	ADF		PP		KPSS	
	Level T-STAT	1st diff T-STAT	Level T-STAT	1st diff T-STAT	Level LM-STAT	1st diff LM-STAT
CO <sub>2</sub>	- 1.22664	- 5.51330***	- 1.22664	- 5.49260***	0.624221	0.149786**
GDP	- 3.676386**	- 7.02430***	- 3.646928**	- 9.82238***	0.133357**	0.311283
ICT	- 1.221272	- 3.611692**	- 2.591747	- 3.629161**	0.658754	0.473705*
FDI	- 3.85559***	- 4.50365***	- 2.302988	- 4.50664***	0.102918**	0.07706***
TR	- 1.894595	- 5.84684***	- 1.894595	- 5.84115***	0.47299	0.07812***
ICTF	- 2.620589	- 3.678055**	- 2.189213	- 3.644619**	0.212749	0.06568***
ICTT	- 1.283288	- 4.07182***	- 2.730046*	- 4.03014***	0.653427	0.491216*
POP	- 0.736189	- 5.44099***	- 9.85932***	- 0.888178	0.693604	0.623071

Source: author’s calculation. \*\*\*, \*\* and \* denote 1%, 5%, and 10% significance, respectively

**Table 5** ARDL bound test results (cointegration)

Equations 3–10	Model(lag)	F-stat.	Cointegration exists
FCO2 (CO2/Yt ICT,FDI,GDP,TR,ICTT,ICTF,POP)	ARDL(3,2,2,2,0,0,2,0)	4.7***	Yes
FICT (ICT/Yt CO2,FDI,GDP,TR,ICTT,ICTF,POP)	ARDL(2,0,2,0,2,2,2,1)	11.9***	Yes
FFDI (FDI/Yt CO2,ICT,GDP,TR,ICTT,ICTF,POP)	ARDL(3,2,2,2,2,2,2,2)	72.3***	Yes
FGDP (GDP/Yt CO2,ICT,FDI,TR,ICTT,ICTF,POP)	ARDL(3,2,1,2,2,2,2,2)	5.2***	Yes
FTR (TR/Yt CO2,ICT,FDI,GDP,ICTT,ICTF,POP)	ARDL(1,0,2,2,2,2,2,1)	8.0***	Yes
FICTT (TR/Yt CO2,ICT,FDI,GDP,TR,ICTF,POP)	ARDL(3,0,2,2,1,2,0,2)	9.8***	Yes
FICTF (TR/Yt CO2,ICT,FDI,GDP,TR,ICTT,POP)	ARDL(2,2,1,2,2,2,2,2)	6.7***	Yes
FPOP (TR/Yt CO2,ICT,FDI,GDP,TR,ICTT,ICTF)	ARDL(3,2,2,1,0,2,2,2)	154.***	Yes
Critical bound value		I(0)	I(1)
10%		1.92	2.89
5%		2.17	3.21
2.50%		2.43	3.51
1%		2.73	3.9

Source: author’s calculation. \*\*\*, \*\* and \* denote 1%, 5%, and 10% significance, respectively

Furthermore, the examination exposed one-way causality moving from (1) CO<sub>2</sub> emission to TR, (2) ICTF to TR, (3)

CO<sub>2</sub> emission to ICTT, and (4) TR to POP. Finally, in the long run, the investigation found three significant causality association from (1) ICT, FDI, GDP, TR, ICTT, ICTF, and POP to CO<sub>2</sub> emission; (2) CO<sub>2</sub> emission, ICT, FDI, TR, ICTT, ICTF, and POP to GDP; and (3) CO<sub>2</sub> emission, ICT, FDI, GDP, TR, ICTT, and ICTF to POP.

**Table 6** Long-run and short-run parameters of ARDL model

Variable	Coefficient	Std. error	t-statistics	P values
<b>Long-run</b>				
ICT	− 0.322184	0.135387	− 2.379723	0.0489
FDI	0.101344	0.041103	2.465586	0.0431
GDP	0.086482	0.044877	1.927107	0.0953
TR	− 0.284984	0.212898	− 1.338596	0.2225
ICTT	− 0.089019	0.033338	2.670231	0.032
ICTF	0.005947	0.007808	0.761598	0.4712
POP	0.434354	0.275096	1.578917	0.1584
C	− 7.158021	5.340074	− 1.340435	0.222
<b>Short-run</b>				
D(CO2(-1))	− 0.374826	0.112041	− 3.345442	0.0123
D(CO2(-2))	− 0.654839	0.134255	− 4.877571	0.0018
D(FDI)	0.014721	0.007419	1.984291	0.0876
D(FDI(-1))	− 0.068903	0.011934	− 5.773536	0.0007
D(GDP)	0.091996	0.007344	5.718615	0.0007
D(GDP(-1))	− 0.032749	0.007214	− 4.539632	0.0027
D(TR)	0.086128	0.051503	1.672306	0.1384
D(TR(-1))	0.222623	0.048022	4.63586	0.0024
D(POP)	34.00687	8.620542	3.944864	0.0056
D(POP(-1))	− 42.78084	9.05034	− 4.726987	0.0021
ECT <sub>t-1</sub>	− 0.827908	0.086272	− 9.59652	0.0000
R-squared	0.90115			
Adj.R-squared	0.835192			
Durbin-Watson	2.0942535			

Source: author’s calculation

### Diagnostic techniques

In order to evaluate the accuracy of the ARDL model, this study applied the Breusch-Godfrey (Breusch and Pagan 2006) test to appraise the serial correlation and heteroskedasticity, Jarque-Bera test to determine normality, Ramsey RESET test to determine functional misspecification, and CUSUM and CUSUMSQ (Brown et al. 1975) test to ascertain the constancy of parameters. Table 8 articulates the upshots of these analytical tools, which stated that the ARDL model is accurately fitted, and no serial correlation and heteroskedasticity is found in the variables. As well, the results of the CUSUM and CUSUMSQ tests are flaunted in Fig. 2. These figures make clear that recursive residuals stay inside the borders of 5% critical lines, which means parameters of the ARDL model are stable.

### Conclusion, recommendations, and policy implications

The world has faced technological affluence that enormously revolutionized the lives of humankind. Today, the entire manufacturing process of the energy sector, production sector, agriculture sector, and service sector is entirely or partially based upon ICT tools. The current investigation extended

**Table 7** Short-run and long-run Granger causality fallouts

Dependent variable	Short-run								Long-run ECT <sub>t-1</sub>
	CO2	ICT	FDI	GDP	TR	ICTT	ICTF	POP	
CO2	-	2.7466*	0.104	0.5531	1.4855	2.8027*	0.8968	0.2162	0.015*
ICT	4.012**	-	1.513	0.19	1.807	0.126	0.326	0.437	0.085
FDI	0.080	1.284	-	0.8010	0.104	0.944	0.2535	0.05	0.026
GDP	1.87	4.279**	1.735	-	0.65	4.51**	0.7529	0.001	0.081*
TR	4.92**	0.253	0.779	0.182	-	0.71	4.52**	0.156	0.028
ICTT	6.62**	0.62	1.76	0.027	1.722	-	0.146	0.367	0.704
ICTF	1.05	5.62**	0.877	2.87*	0.078	5.30**	-	0.549	0.218
POP	1.97	2.62	0.025	1.934	3.6**	1.86	0.051	-	0.002**

Values are based on the chi-square distribution. \*\* and \* denote 5% and 10%, respectively

Source: author's calculation

the STIRPAT model and analyzed the liaison among ICT, FDI, trade, the interface between ICT and trade, economic growth, the interaction between ICT and FDI, and population, in the context of Pakistan. The study employed annual data through the time of 1990–2018. The results of this study stated that ICT has a sanguine affiliation with the environment quality of Pakistan. Moreover, the study identified bidirectional causality between ICT use and CO<sub>2</sub> emission. The investigation reported that the utilization of ICT-based electrical devices, home automation, and intelligent transportation system significantly improves energy efficiency. Also, the optimum use of resources and inefficient use of energy can be controlled through the emergence of ICT in the production process of industries. Further, the application of ICT built-in technologies will help to save fuel consumption through online banking, online bookings, and online shopping; thus, it will decrease the CO<sub>2</sub> emission. Moreover, the green energy plan, with the use of ICT, can minimize the dependence on gasoline exploitation. Thus, the policymakers and technology ministry of Pakistan should not only introduce most new ICT tools but also spread more awareness in the general public about the use of ICT-based equipment.

The study also concluded that ICT apparatus manufactured in Pakistan might produce electronic waste due to old

production techniques; thus, it increases the CO<sub>2</sub> emission. Hence, the government of Pakistan needs to adopt advanced manufacturing techniques, strengthen her environmental standards, and construct the other significant policies to limit the production of pollutant ICT goods. Nevertheless, technology transferred through trade showed an adverse impact on CO<sub>2</sub> emission, which gives the impression that importing ICT equipment is more beneficial for the environment quality in Pakistan. Hence, the government of Pakistan must maintain the policies that provide significant opportunities for trade in the ICT sector; consequently, it will ensure sustainable development.

The study also examined the EKC on the insinuation of ICT for the nation of Pakistan. The examination exposed that GDP has an inverted U-shaped affiliation with CO<sub>2</sub> emanation, which verified the subsistence of the EKC hypothesis in Pakistan. Moreover, the investigation showed that there is a negative rapport between trade and CO<sub>2</sub> emission, while FDI has a positive and significant relationship with CO<sub>2</sub> emission. In addition, the population showed a positive and significant link with CO<sub>2</sub> emission; accordingly, the environment control authorities should use ICT tools to monitor the circumstances of the environment and to assess the effect of human activities on the environment. The findings of this investigation have an

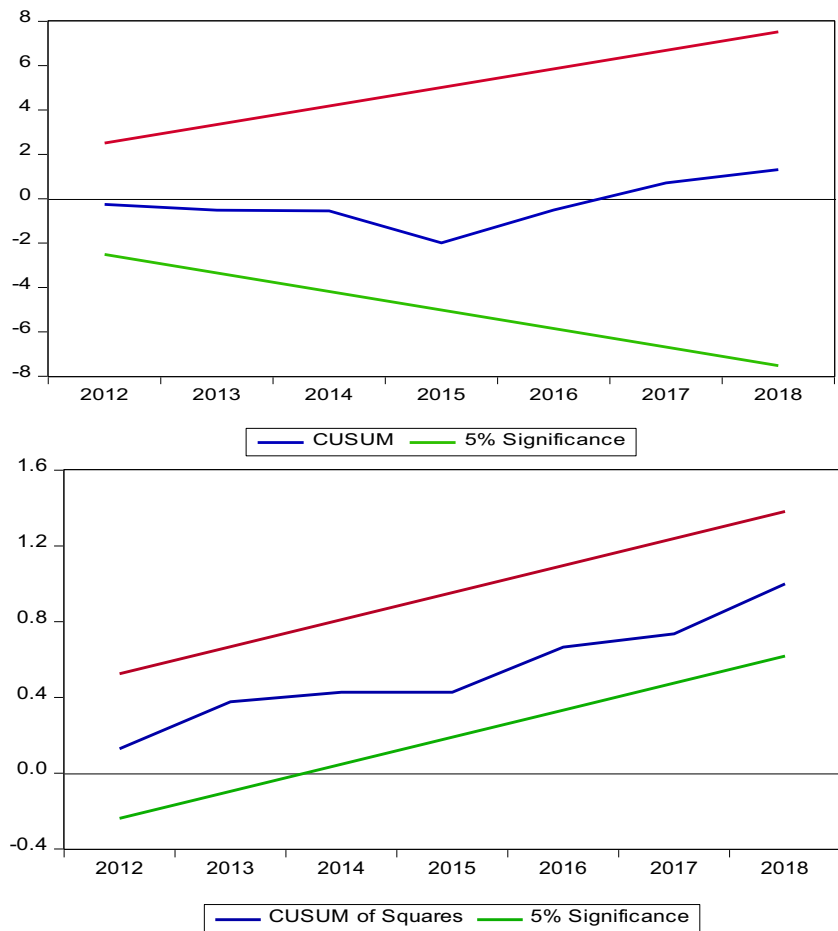
**Table 8** Diagnostic test results

Breusch-Godfrey heteroskedasticity results				Breusch-Godfrey serial correlation LM results			
F-statistic	0.853666	Prob.	0.6298	F-statistic	1.996114	Prob.	0.2305
Obs*R-squared	16.76062	Prob.	0.4707	Obs*R-squared	0.341286		0.5591
Ramsey RESET results				Normality test			
T-statistics	0.130481	Prob.	0.9005	Jarque-Bera	0.6958591	Prob.	0.706137
F-statistic	0.017025	Prob.	0.9005				

Source: author's calculation



**Fig. 2** CUSUM and CUSUMSQ graph



identical implication for China, India, Malaysia, Bangladesh, Indonesia, Thailand, Sri Lanka, and other developing nations. This study has some limits; first, other proxies for ICT can be used under the ARDL approach to determine the validity of results. Additionally, other potential variables such as institutional performance, globalization, energy consumption, financial development, urbanization, and industrialization can be added to provide detailed insight for policymakers.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

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