Environment, Development and Sustainability (2022) 24:1761–1780
https://doi.org/10.1007/s10668-021-01506-w

Asymmetric impact of information and communication technologies on environmental quality: analyzing the role of financial development and energy consumption

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Received: 16 October 2020 / Accepted: 6 May 2021 / Published online: 12 May 2021

Abstract

The development of information and communication technologies (ICT) positively contributes to economic growth; however, their environmental implications cannot be ignored. Therefore, it is imperative to investigate the impact of ICT, energy consumption, economic growth, and financial development on the air quality in Pakistan. Drawing on the data set from 1976 to 2018, we employed Nonlinear Autoregressive Distributed Lag model. The results revealed that there is a substantial presence of asymmetric cointegration between ICT and CO_2 emissions. The empirical results unfold that positive shocks in ICT negatively affect CO_2 emissions, implying that an increase in ICT brings a decrease in CO_2 emission; negative shocks in ICT publicized a negative association with CO_2 emissions, inferring that a decrease in ICT will bring an upsurge in CO_2 emissions. Moreover, on the dark side, energy consumption and financial development degrade the environmental quality by increasing the CO_2 emissions in Pakistan. Additionally, the existence of the Environmental Kuznets Curve hypothesis in Pakistan was confirmed. Our key findings emphasize the importance of ICT development and several environmental implications in attaining the sustainable development goal.

Keywords CO_2 emissions · ICT · Economic growth · Financial development · Energy consumption · Pakistan · NARDL

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JEL Classification C52 · O38 · O40 · O55 · P37

1 Introduction

From the last two decades, global warming and environmental degradation posed severe challenges for developed and developing countries. However, developing countries are more vulnerable due to their poor environmental policies and priorities of economic growth over the environment (Ahmad et al., 2020a, 2020b). Since the start of the revolution in industrialization, the developing countries have been making great efforts to accomplish the maximum possible economic development (Munir & Ameer, 2020). This race has led to an unprecedented increase in greenhouse gases (GHGs) in general and carbon dioxide (CO_2) emissions in particular, which caused global warming (Zeraibi et al., 2020). The impact of climate change, global warming, and environmental degradation is already noticeable, such as severe weather events, enlarged storm intensity, and changes in rainfall patterns (Chandio et al., 2019; Dar & Asif, 2006; Shahbaz et al., 2013). These variations have an adequately substantial effect on the ecosystem, the sustainability of forests, and human health (Boutabba, 2014). The growing carbon footprint is a global concern and part of economic, political, and social choices (Ben Ayeche et al., 2016). Therefore, environmental degradation received more attention from researchers and policymakers due to its severe threat to human and economic development. As a result, numerous studies have been devoted to probing the determinants of CO_2 emissions.

Information and communication technology (ICT) initiatives, financial development, energy consumption, trade, urbanization, income, foreign direct investment (FDI), and economic growth are found to be an essential determinant of CO_2 emissions (Haseeb et al., 2019; Sharif Hossain, 2011; Danish et al., 2018a; Omri et al., 2015; Sharma, 2011; Tang & Tan, 2015; Hnatyshyn, 2018). The effects of ICT on CO_2 emissions have gained more attention from analysts and academicians in the recent era. In the modern era of globalization, countries are actively adopting ICT to boost output and energy efficacy in various economic sectors of developed and developing countries over the past few decades. However, the position of ICT for environmental excellence is ambiguous. Several researchers (Chavanne et al., 2015; Mathiesen et al., 2015) originated that ICT has a discouraging impression on environmental quality. Salahuddin and Alam (2015) reported that the fast evolution in ICT amplified the utilization of electricity, which eloquently upsurge the carbon emissions (Hamdi et al., 2014) and degrade the quality of the environment. Conversely, Amri (2018) documented that ICT has an insignificant impact on CO_2 emissions. Añón Higón et al. (2017) illustrated that ICT and CO_2 emission have an inverted U-shaped bonding with each other.

On the contrary, Asongu et al. (2018) found that ICT harms CO_2 emissions. Thus, the impact of ICT on environmental excellence needs to be elucidated in-depth, predominantly in emerging nations, i.e., Pakistan. The ICT sector in Pakistan has documented an inexhaustible increase during the last few years (Sheikh, 2013). Moreover, more than 250 cities in Pakistan are now linked via a fiber-optic cable network. In January 2020, there were 76.38 million Internet subscribers, which is 17% greater than in 2019. Additionally, 37 billion people are using social media in Pakistan (Kemp, 2020). Pakistan telecommunication authority earned revenue of Rs555,759 million in 2018–2019 (PTA 2019). Recently, Pakistan's government presented new goals related to ICT development in Pakistan called "Digital Pakistan." This strategy's fundamental purpose is to develop ICT in the manufacturing and service sectors working under government control and private ownership. It also aims to increase Pakistan's ranking in the ICT sector and delivers the new benchmark for economic innovations, technological innovations, and environmental innovations (Ministry of Information Technology, 2018). Hence, the rapid development of the ICT sector in Pakistan encouraged the author to reveal its impact on Pakistan's environmental quality.

Further, the financial sector is a crucial factor that possesses an active role in economic development. This sector encourages firms to adopt and utilize advanced tools in the various sectors, which imperatively decrease CO_2 emissions. Further, the emergence of advanced technologies in the financial industry can upgrade environmental excellence (Danish et al., 2018b; Latif et al., 2017; Wang et al., 2015). The usage of modern technologies has a positive interrelationship with economic development. Moreover, Latif et al., (2018) stated that foreign investment (FDI) and globalization have a long-run association with economic growth. Sharif Hossain (2011) explored that in the long-run, economic development and energy consumption significantly influence CO_2 emissions in Thailand and the Philippines, while it remains insignificant in Malaysia. Likewise, Chandio et al. (2019) found that financial development and FDI improve the quality of the environment, while the consumption of electricity and economic growth degrades the environmental quality in Pakistan. In the context of emerging nations like Pakistan, many research works have been done to see the effect of financial development, energy consumption, economic growth, deforestation, globalization, tourism, and urbanization on CO_2 emissions. Nonetheless, the studies on the asymmetric affiliation between ICT and CO_2 emissions in Pakistan's context are insufficient.

Summing up, the above discussion brings forth the insufficiency of previous studies on the relationship between ICT and CO_2 emissions. Evidently, there are limited studies with contradictory findings (Ahmed et al., 2015; Ali et al., 2019; Khan et al., 2019; Sharif et al., 2017; Siddique, 2017). However, the present empirical study differs from previous studies. We investigate the impact of ICT on CO_2 emissions in Pakistan by using various traditional and advanced econometrics techniques from 1976 to 2018. This empirical study fills this gap by investigating the effect of several factors, including ICT, financial development, energy consumption, and economic growth on CO_2 emissions in Pakistan. Particularly, an asymmetric impact of ICT on the environmental quality in Pakistan is evaluated. Moreover, various studies used the mobile phone subscription/Internet subscription data as a proxy factor of ICT; though, we utilized an index of computer communications and other services such as worldwide telecommunication and technical services as the nomination of ICT. As per the author's knowledge, no study considered this variable before to measure the impact of ICT on CO_2 emissions in Pakistan. Moreover, the existence of the Environmental Kuznets Curve (EKC) theory in Pakistan is evaluated by incorporating GDP and square of GDP in the Nonlinear Autoregressive Distributed Lag (NARDL) model. The examination accounts for the following domineering queries of policymakers and academicians. First, does ICT possess nonlinear effect on CO_2 emissions? Second, do positive and negative shocks in ICT have same/different impact on CO_2 emissions? Third, does energy consumption reveal positive association with CO_2 emissions? Fourth, does an increase in the financial advancement damage/improve the environmental excellence? Fifth, does EKC exist in Pakistan in the framework of ICT, financial development, and energy consumption? The fundamental findings of revealed that positive and negative shocks have indirect affiliation with CO_2 emissions, implying that use of built-in ICT devices and working online reduce environmental pollution. However, financial development and energy consumption do not favor the environmental quality in Pakistan. Additionally, U-shaped association between economic growth and environmental degradation was confirmed in Pakistan, implying that EKC exist there.

The remaining research study is systematized as follows: Sect. 2 deals with the concise literature reviewing, Sect. 3 designates the data and methodological path. Moreover, Sect. 4 offers the long-run and short-run asymmetric results and discussions, and finally, Sect. 5 wraps up as a conclusion of the paper with policy implications.

2 Theoretical mechanism

ICT's impact on the environment is either positive or negative because ICT can increase or decrease environmental degradation in two ways, i.e., use effect and substitution effect (Danish, 2019). First, during the use effect, the manufacturing of technologies (ATMs, ICT equipment, Vehicles, Robots, etc.) stimulates the rebound effect of energy consumption, extraction of rare earth elements, and e-waste, increasing environmental degradation in turn (Añón Higón et al., 2017). It is estimated that only the ICT sector produces 2% GHG annually (Cancino et al., 2018), and the electricity consumption from this sector is increasing 7% annually. More precisely, the process of installation and operation of ICT devices are considered highly energy-intensive (Ozcan & Apergis, 2018). On the other hand, technological innovation may increase the extraction and consumption of natural resources (Acemoglu et al., 2012), which increases the carbon footprint. However, innovation in the transportation sector, such as planes, cars, trains, and ships, increased fossil fuel energy consumption. According to the estimates, the worldwide transportation sector consumes about 20% of global energy use and accounted for around 19.34% of carbon emissions (Ajanovic et al., 2012; Alshehry & Belloumi, 2017).

The second effect of ICT is the substitute effect, including automation, mobilization, and de-carbonization (Salahuddin et al., 2016). Innovation in the ICT sector substituting physical goods such as E-mails are replacing paperwork, e-books are substituting printed books, e-business, and e-commerce reduce transportation activities. The emergence of ICT in the manufacturing sector significantly reduces energy consumption. Furthermore, the use and development of ICT reduce CO_2 emissions. ICT emergence in the energy sector increases energy efficiency, which in turn contributes to alleviating environmental degradation (Danish et al., 2018b). Godil et al. (2020) analyzed the impact of ICT by using the QARDL approach in Pakistan. The investigation elaborated that ICT has nonlinear negative impact on CO_2 emissions in Pakistan. Murshed (2020) explored the nonlinear links among ICT trade, renewable energy consumption, improving energy efficiencies, and CO_2 emissions for the south Asian nations, i.e., Pakistan, Bangladesh, India, Sri Lanka, Maldives, and Nepal. It is exposed that ICT trade directly upsurges the use of renewable energy but diminishes the energy use intensity. Moreover, it was found that ICT trade indirectly reduces CO_2 emissions by improving energy efficiency and promoting renewable energy use.

3 Literature review

The literature regarding the impact of ICT on CO_2 emissions can be categorized into two categories, i.e., linear impact and nonlinear impact. In the linear structure, Danish et al. (2018a) investigated the effect of ICT on carbon emission in 11 emerging countries from

1990 to 2015. Their results unveil that ICT degrades the environmental quality by increasing CO_2 emissions. However, the interaction term of ICT and economic growth decreases carbon emissions, while the interaction of ICT and financial development add to CO_2 emissions. Likewise, Zhang and Liu (2015) quantified the effects of ICT on environmental quality by employing the STIRPAT technique in China. The empirical findings suggested that ICT increased the level of pollution. Moreover, energy intensity and economic growth are responsible for decreasing the environmental quality; while, urbanization across the different provinces of China increases the environmental quality. Dehghan Shabani and Shahnazi (2019) examined the effect of ICT on CO_2 emissions in different sectors of Iran. They find that ICT reduces the emission in service and transport sector but increase in industrial and agriculture sector. Similarly, using the quantile and FMOLS approach, Nguyen et al. (2020) explore the effect of ICT and innovations in selected G-20 countries. Their outcome exposed that import and export of ICT goods (proxy of ICT) intensify the carbon emissions. However, innovation helps to curb environmental degradation. In another study on 21 SSA countries, Avom et al. (2020) found evidence that ICT poses a direct and indirect positive effect on carbon emission through financial development, trade openness, and energy consumption.

However, Salahuddin et al. (2016) investigated the effect of ICT on environment in OECD countries during the period of 1991–2012. By using the PMG approach, their results indicate that ICT does not harm the environmental quality. Likewise, Asongu et al. (2017) used the GMM approach to examine the effect of ICT on environment quality in 44 sub-Saharan African (SSA) countries from 2000 to 2017. They highlighted that ICT complements CO_2 emissions from liquid fuel consumption to increase inclusive development. Additionally, ICT can be a useful tool to curb the negative effect of carbon emission on inclusive development. Lu (2018) investigated the effects of economic growth, financial development, energy consumption, and ICT on CO_2 emission in Asian economies. The increasing trend of ICT in Asian countries reduced the CO_2 emissions although energy consumption, financial development, and economic growth positively contribute to CO_2 emissions. Danish (2019) also endorses the mitigating effect of ICT on environmental degradation in 59 belt and road countries. The author recommended investment in ICT, innovation, and trade for a smoother pathway to achieve a sustainable environment.

The second category verifies the nonlinear linkage between ICT and CO_2 emissions; for instance, Godil et al. (2020) employed the quarter data through 1995Q1–2018Q4 for Pakistan's nation. The investigation utilized the QARDL approach and discovered that financial development and ICT ominously decrease Pakistan's environmental pollution. The investigation reported that institutional quality and economic growth play a perilous role in Pakistan's environmental quality and EKC significantly exists in Pakistan. Similarly, Añón Higón et al. (2017) explored that ICT has an inverted U-shaped relationship with CO_2 emissions in most of developed and developing countries. Additionally, Xu and Lin (2017) analyzed the impact of the high-tech industry on CO_2 emissions in different regions of China. The investigation found that high-tech industry has an inverted U-shaped nonlinear affiliation with CO_2 emissions in the eastern districts of China. However, in the western and central regions, it revealed a positive U-shaped impact. Recently, Razzaq et al. (2021) used the QARDL approach and examined the asymmetric impact of technological innovations on CO_2 emissions. The findings discovered that technology significantly alleviates the CO_2 emissions in the long run in China. Moreover, Ahmed et al. (2021) also found ICT decreases environmental degradation by reducing carbon emissions, while economic growth and urbanization degrade the environment in Latin American and Caribbean (LCA) regions. Hence, the given literature proved that ICT is an important determinant of environmental degradation in various countries. Moreover, no one study is found which examined the non-liner impact of ICT in the framework of energy consumption, financial development, and economic growth for the nation of Pakistan.

4 Data and methodological path

In order to investigate the liaison between Information and Communication Technology and environmental excellence, this examination employed annual data from 1976 through 2018. The dependent variable is CO_2 emissions, which is used as a proxy of environmental degradation. This examination employed an index of computer communications and other services such as worldwide telecommunications and technical services as a proxy of ICT. Also, Shehzad et al. (2019) consider this factor for the nomination of ICT. Moreover, the investigation used domestic credit to the private sector (% of GDP) as the financial development nominator. Alom et al. (2017) used the same proxy to analyze the impact of financial development on CO_2 emissions in Tunisia. Moreover, energy consumption (kg of oil equivalent per capita) as an exogenous variable was included. Also, Zeraibi et al. (2020) utilized energy use (kg of oil equivalent per capita) to nominate the energy consumption in China. Furthermore, the investigation included GDP per capita (constant 2010 US$) and quadratic terms of GDP to analyze the EKC hypothesis. Ahmad et al. (2020a), Bozoklu et al. (2020) and Ulucak and Bilgili (2018) utilized the GDP and its square to analyze the U-shaped affiliation among environmental degradation and economic growth. The data utilized in this analysis are extracted from the World Bank and British Petroleum Energy Statistical Review database. All the variables are transformed into a natural log to avoid the problem of heterogeneity. The linear relationships among these factors can be exemplified as follows

$$\Delta \mathrm{CO2}_t = \beta_0 + \beta_1 \ln \mathrm{ICT}_t + \beta_2 \ln \mathrm{FD}_t + \beta_3 \ln \mathrm{GDP}_t + \beta_4 \ln \mathrm{GDP}_t^2 + \beta_5 \ln \mathrm{EC}_t + \varepsilon_t \quad (1)$$

here ln denotes the natural log, and t signifies the time factor. While $\beta_{0,}\beta_{1,}\beta_{2,}\beta_{3,}\beta_{4,}\beta_{5,}$ are the coefficients. Moreover, Information and Communication Technology is nominated by ICT, FD designates financial development, and EC indicates energy consumption. Whereas GDP and GDP^2 specify the Gross Domestic Product and its square, respectively. This analysis affianced the NARDL methodology. The NARDL model is more appropriate for less number of observations, and it also documents asymmetries and cointegration in the same equation. Since NARDL is the nonlinear form of the ARDL approach (Pesaran et al., 2001), first, the examination follows (Pesaran et al., 2001) and readjusts Eq. (1) into an error correction model to capture both long-run and short-run dynamics. The error correction form of the ARDL model can be defined as follows,

$$\begin{aligned}\Delta \ln \mathrm{CO2}_t = {} & \delta_0 + \delta_1 \sum_{i=1}^{p} \Delta \ln \mathrm{CO2}_{t-1} + \delta_2 \sum_{i=1}^{p} \Delta \mathrm{ICT}_{t-1} + \delta_3 \sum_{i=1}^{p} \Delta \mathrm{FD}_{t-1} + \delta_4 \sum_{i=1}^{p} \Delta \mathrm{GDP}_{t-1} \\ & + \delta_5 \sum_{i=1}^{p} \Delta \ln \mathrm{GDP}_{t-1}^2 + \delta_6 \sum_{i=1}^{p} \Delta \ln \mathrm{EC}_{t-1} + \phi_1 \ln \mathrm{CO2}_{t-i} + \phi_2 \mathrm{ICT}_{t-i} + \phi_3 \mathrm{FD}_{t-i} \\ & + \phi_4 \mathrm{GDP}_{t-i} + \phi_5 \mathrm{GDP}_{t-1}^2 + \phi_6 \ln \mathrm{EC}_{t-i} + \mu_t \end{aligned} \quad (2)$$

$$\Delta \mathrm{lnCO2}_t = \delta_0 + \delta_1 \sum_{i=1}^{p} \Delta \mathrm{lnCO2}_{t-1} + \delta_2 \sum_{i=1}^{p} \Delta \mathrm{lnICT}_{t-1} + \delta_3 \sum_{i=1}^{p} \Delta \mathrm{lnFD}_{t-1} + \delta_4 \sum_{i=1}^{p} \Delta \mathrm{lnGDP}_{t-1} + \delta_5 \sum_{i=1}^{p} \Delta \mathrm{lnGDP}^2_{t-1} + \delta_6 \sum_{i=1}^{p} \Delta \mathrm{lnEC}_{t-1} + \psi_1 \mathrm{ECT}_{t-1} + \mu_t \tag{3}$$

where i and Δ symbolize the lags and first difference, respectively. In addition, $\delta_1 - \delta_6$ represents the short-run parameters and $\phi_1 - \phi_6$ are the long-run coefficients. μ_t and $\psi_1 ECT_{t-1}$ indicate the coefficient of error term and error correction term, respectively. Thus, the long-run affiliation among study parameters in Eq. (2) through the F-test approach was estimated. The null hypothesis of the F-test explained that there is no cointegration among study parameters. The conclusion is made through the comparison of projected values estimated by following the methodology of Pesaran et al. (2001) with the F-test statistics. If the F-test statistics are higher than upper critical bound values, then the alternative hypothesis of cointegration exists is accepted. On the other hand, if an estimated F-test value remains between the upper critical bound values and lowers critical bound values, then it means the model's findings are inadequate. Further, if the F-test value remains low compared to lower critical bound statistics, then it is concluded that the underlying parameters have no long-run affiliation with each other. This investigation is based on the assumption that ICT has a nonlinear association with CO_2 emanations in Pakistan. Accordingly, this inspection splits ICT into two categories, i.e., $\mathrm{ICT}^+_\mathrm{t}$ and $\mathrm{ICT}^-_\mathrm{t}$. The $\mathrm{ICT}^+_\mathrm{t}$ and $\mathrm{ICT}^-_\mathrm{t}$ parameters guesstimate the impact of positive and negative shocks on CO_2 emanations, respectively;

$$\mathrm{ICT}^+_t = \sum_{j=1}^{t} \Delta\ \mathrm{ICT}^+_j = \sum_{j=1}^{t} \max(\Delta\ \mathrm{ICT}_j, 0) \tag{4}$$

$$\mathrm{ICT}^-_t = \sum_{j=1}^{t} \Delta\ \mathrm{ICT}^-_j = \sum_{j=1}^{t} \min(\Delta\ \mathrm{ICT}_j, 0) \tag{5}$$

In order to obtain the NARDL equations, we substitute the ICT_t with ICT^+_t and ICT^-_t in Eqs. (2) and (3).

$$\Delta \mathrm{lnCO2}_t = \delta_0 + \delta_1 \sum_{i=1}^{p} \Delta \mathrm{lnCO2}_{t-1} + \delta_{2a} \sum_{i=1}^{p} \Delta \mathrm{ICT}^+_{t-1} + \delta_{2b} \sum_{i=1}^{p} \Delta \mathrm{ICT}^-_{t-1} + \delta_3 \sum_{i=1}^{p} \Delta \mathrm{FD}_{t-1} + \delta_4 \sum_{i=1}^{p} \Delta \mathrm{GDP}_{t-1} + \delta_5 \sum_{i=1}^{p} \Delta \mathrm{lnGDP}^2_{t-1} + \delta_6 \sum_{i=1}^{p} \Delta \mathrm{lnEC}_{t-1} + \phi_1 \mathrm{lnCO2}_{t-i} + \phi_{2a} \mathrm{ICT}^+_{t-1} + \phi_{2b} \mathrm{ICT}^-_{t-1} + \phi_3 \mathrm{FD}_{t-i} + \phi_4 \mathrm{GDP}_{t-i} + \phi_5 \mathrm{lnGDP}^2_{t-1} + \phi_6 \mathrm{lnEC}_{t-i} + \mu_t \tag{6}$$

$$\Delta \mathrm{lnCO2}_t = \delta_0 + \delta_1 \sum_{i=1}^{p} \Delta \mathrm{lnCO2}_{t-1} + \delta_{2a} \sum_{i=1}^{p} \Delta \mathrm{ICT}^+_{t-1} + \delta_{2b} \sum_{i=1}^{p} \Delta \mathrm{ICT}^-_{t-1} + \delta_3 \sum_{i=1}^{p} \Delta \mathrm{lnFD}_{t-1} + \delta_4 \sum_{i=1}^{p} \Delta \mathrm{lnGDP}_{t-1} + \delta_5 \sum_{i=1}^{p} \Delta \mathrm{lnGDP}^2_{t-1} + \delta_6 \sum_{i=1}^{p} \Delta \mathrm{lnEC}_{t-1} + \psi_1 \mathrm{ECT}_{t-1} + \mu_t \tag{7}$$

The investigation employed the Wald test to discover the short term $\delta^+_{2a}/\delta_1 = \delta^-_{2b}/\delta_1$ and long-term $\phi^+_{2a}/\phi_1 = \phi^-_{2b}/\phi_1$ asymmetric impact of ICT on CO_2 emission.

5 Results and discussion

5.1 Descriptive statistics, correlation and unit root test

Table 1 presents the results of descriptive statistics. The outcomes discovered that the variables examined in this investigation are normally distributed; however, financial development revealed abnormality because the probability statistics of the Jarque–Bera approach for FD is highly significant. Moreover, economic growth and energy consumption show very high mean values of 6.689 and 6.036, respectively. It shows a great extent of environmental degradation caused by economic growth and energy consumption. The ICT has an average value of 3.527, with a 3.030 minimum and 4.208 maximum value. Results of correlation analysis are given in Table 2, which indicates that all the variables positively and significantly correlate with CO_2 emissions; however, FD shows a negative relationship with CO_2 emission. In order to evaluate the stationary level of variables, the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979), Philips and Perron (PP) test (Phillips & Perron, 1988), and Kwiatkowski Phillips–Schmidt–Shin (KPSS) test (Kwiatkowski et al., 1992) were applied. Table 3 demonstrates the results of the unit root test. The investigation indicates that CO_2 and EC are stationary at level, while others are stationary at the first difference. The results of KPSS show that FD is stationary at level. Hence, the investigation discovered the variables' mixed integration order, such as $I(0)$ and $I(1)$. Consequently, the NARDL approach impeccably fits the study.

5.2 NARDL analysis

Table 4 shows the findings of the long-run NARDL model. The long-run outcomes disclosed that ICT parameters are negative and significant for both ICT increase and decrease in the model. The coefficient of ICT increase (ICT_POS) mentioned that one unit growth in ICT brings −0.088 units to decrease in CO_2 emissions. Moreover, the ICT decrease (ICT_NEG) coefficient illustrates that adverse shocks in ICT imperatively raise the CO_2 emissions by −0.13 units. Here, the sign of the ICT_NEG parameter is negative, which showed the negative relationship between ICT_NEG and CO_2 emissions. Hence, these outcomes

Table 1 Descriptive statistics. *Source*: Author's calculation

	CO_2	GDP	GDP^2	FD	EC	ICT
Mean	−0.406	6.689	44.817	3.141	6.036	3.527
Median	−0.306	6.711	45.048	3.185	6.102	3.527
Maximum	−0.009	7.108	50.533	3.394	6.261	4.208
Minimum	−1.102	6.197	38.405	2.733	5.701	3.030
SD	0.325	0.253	3.371	0.174	0.172	0.278
Skewness	−0.660	−0.304	−0.245	−0.987	−0.601	0.585
Kurtosis	2.263	2.152	2.114	3.183	1.986	2.792
Jarque-B	4.002	1.907	1.793	6.879	4.326	2.473
Probability	0.135	0.385	0.407	0.032	0.114	0.290

Here, CO_2, FD, EC, and ICT nominate the carbon emissions, financial development, energy consumption, and information and communication technology, respectively. Moreover, GDP and GDP^2 refer the gross domestic product and its square

Table 2 Correlation analysis. *Source*: Author's calculations

Correlation	CO_2	EC	FD	GDP	GDP^2	ICT
CO_2	1					
Probability	–					
EC	0.9876***	1				
Probability	0	–				
FD	−0.2856*	−0.220284	1			
Probability	0.0779	0.1778	–			
GDP	0.9943***	0.9747***	−0.3205**	1		
Probability	0	0	0.0467	–		
GDP^2	0.9943***	0.9747***	−0.3205**	0.9998***	1	
Probability	0	0	0.0467	0	–	
ICT	0.6934***	0.6634***	−0.4874***	0.7160***	0.7160***	1
Probability	0	0	0.0016	0	0	–

*, **, and *** denotes the 10%, 5%, and 1% level of significance. Here CO_2, FD, EC, and ICT nominate the carbon emissions, financial development, energy consumption, and information and communication technology, respectively. Moreover, GDP and GDP^2 refers the gross domestic product and its square

confirmed the importance of Pakistan's renowned policies that deal with ICT and its impact on environmental quality, such as "Digital Pakistan" policy. It aims to use technology for the social welfare of the country, which further improves the horizons for achieving environmental sustainability (Nizam et al., 2020). Also, this policy aims to improve Pakistan's international ICT ranking and serve as a benchmark for business and environmental innovations, socioeconomic impact, low cost, infrastructure, and skills development. In addition, by making ICT strategically important to Pakistan, the vision has made ICT a fast-growing domain in the country. Specifically, this policy helps the digitalization of socioeconomic sectors in Pakistan, i.e., E-energy, E-agriculture, E-education, and E-commerce (Ministry of Information Technology, 2018). Moreover, In terms of energy, Pakistan is committed to realizing the potentials of renewable energy used in hydro, solar, and wind and to shift its energy mix to 60% clean energy by 2030 (World Economic Forum, 2021). Consequently, the examination verified that the emergence of ICT built-in technologies in the energy sector could improve its productivity. ICT built-in technologies can help to manage the distribution of electricity smartly as most areas of Pakistan faced non-schedule load-shedding due to an inefficient distribution system. These findings are aligned with various studies, i.e., C. Zhang and Liu (2015) assessed the effect of the ICT business on environmental quality in China. The findings unveils that ICT played a useful role in minimizing CO_2 emissions. Lu (2018) analyzed 12 Asian states' information and exposed that there was a negative liaison between CO_2 emissions and ICT. Additionally, the analysis reported that ICT does not harm the environmental quality, and it could be utilized as a reliable strategy to reduce CO_2 emissions. Danish et al. (2018b) verified that amalgamation of ICT and GDP (ICT × GDP) momentously improved environmental excellence. Also, Shehzad et al. (2020) documented that the application of Information and Communication Technology helps to save the additional energy consumption that eloquently upsurges environmental excellence. However, Khan et al. (2019), Asongu et al. (2018) and Park et al. (2018) documented a positive relationship between ICT and CO_2 emissions.

Table 3 Unit root test. *Source*: Author's calculation

Variables	ADF				PP				KPSS	
	Level		1st difference		Level		1st difference		Level	1st difference
	T-stat	Prob	T-stat	Prob	T-stat	Prob	T-stat	Prob	LM-stat	LM-stat
CO_2	− 3.130**	0.030	− 6.3***	0.000	− 3.130**	0.03	− 6.401***	0.000	0.7662	0.49**
GDP	− 1.527	0.501	− 4.6***	0.000	− 1.318	0.61	− 4.734***	0.000	0.8038	0.17***
FD	− 1.208	0.660	− 5.4***	0.000	− 1.284	0.62	− 5.401***	0.000	0.348*	0.18***
EC	− 2.729*	0.070	− 4.9***	0.000	− 2.630*	0.09	− 4.923***	0.000	0.7528	0.517**
ICT	0.518	0.980	− 6.7***	0.000	0.774	0.99	− 6.807***	0.000	0.6869	0.395**
GDP^2	− 1.527	0.500	− 4.6***	0.000	− 1.318	0.61	− 4.713***	0.000	0.8038	0.17***

***, ** and * denote significance level at 1%, 5% and 10%, respectively. Here, ADF nominates augmented Dickey–Fuller (Dickey & Fuller, 1979), PP nominate Philips & Perron (Phillips & Perron, 1988), and KPSS nominates Kwiatkowski–Phillips–Schmidt–Shin (Kwiatkowski et al., 1992). Moreover, Prob. define the probability values. Here CO_2, FD, EC, and ICT nominate the carbon emissions, financial development, energy consumption, and information and communication technology, respectively. Moreover, GDP and GDP^2 refers the gross domestic product and its square

Table 4 Long-run fallouts of asymmetric ARDL approach. *Source*: Author's calculation

Dependent variable = CO_2 emissions				
	Coefficient	SE	T-stat	Prob
lnICT_POS	– 0.088*	0.0488	– 1.802	0.087
lnICT_NEG	– 0.137**	0.0501	– 2.732	0.013
lnGDP	0.151*	2.003	1.756	0.087
$lnGDP^2$	– 0.025**	0.149	– 2.688	0.010
lnFD	0.084**	0.032	2.639	0.016
lnEC	1.182***	0.199	5.941	0.000
C	– 10.054	6.134	– 1.638	0.117

***, ** and * denote significance level at a 1%, 5% and 10%, respectively. Here, Prob. nominates the probability values

The long-run results also revealed that energy consumption (EC) has a positive and significant relationship with CO_2 emissions in Pakistan. According to a report published by Pakistan's Ministry of Finance, the energy sector grew by 5.78% during the 2017–2018 financial year (PEC 2018). In the case of Pakistan, renewable energy sources are still not fully utilized. Hence, fossil fuels are the main source, followed by hydropower plants (Nizam et al., 2020). However, with the help of ICT built-in technologies, one can efficiently control the use of electricity, such as home automation and smart building concepts. Consequently, the emergence of ICT-built-in technologies in homes and private offices can reduce electricity consumption. Moreover, Pakistan is moving toward clean energy and has introduced its first Electric Vehicle Policy (2020), which aims to have 30% of its vehicles by 2030. In addition, electric buses have already been approved for Karachi, the world's first "zero emissions" metro line project designed to convert cattle dung into methane. Recently, Pakistan also moved its transport fuel quality from Euro 2 to Euro-V. All of these initiatives demonstrate unwavering commitment to environmentally friendly, sustainable, and climate-friendly development (World Economic Forum, 2021). Park et al. (2018) documented that electricity use expressively increases CO_2 emissions. Dehghan Shabani and Shahnazi et al. (2019) confirmed that CO_2 emissions and energy consumption have a direct affiliation with each other. Also, Anser (2019) inveterates that energy consumption has a positive influence on CO_2 emissions in Pakistan. Additionally, investigation shows that GDP revealed a direct effect on CO_2 emissions, while the square of GDP publicized negative liaison with CO_2 emissions in Pakistan, inferring that the EKC hypothesis momentously exists in Pakistan. On the other hand, the inspection confirmed that financial development brings an increase in Pakistan's CO_2 emissions. Hence, green financing must be adopted to achieve environmentally friendly and sustainable development. Recently, the National Bank of Pakistan has launched a green banking policy aimed at dropping the susceptibility of banks to environmental risks, accomplishing their obligation to guard the environment, and providing financing to build a green economy (Zubair Mumtaz & Alexander Smith, 2019). Saud et al. (2018) reported that CO_2 emission and GDP have a direct affiliation with each other. The analysis of Huang and Zhao (2018) revealed that financial development has a significant and positive impact on CO_2 emissions. Moreover, these results are also in line with Dar and Asif (2006) and Zhang (2011).

The fallouts of the short-run NARDL model are disclosed in Table 5. The short-term parameters of ICT are positive and negative. The first lag of ICT_POS shows that one

Table 5 Short-run findings of NARDL approach. *Source*: Author's calculation

Dependent variable = CO_2 emissions				
	Coefficient	SE	T-stat	Prob
Δ(lnICT_POS)	−0.012	0.029	−0.443	0.662
Δ(lnICT_POS(−1))	0.113***	0.0321	3.544	0.002
Δ(lnICT_NEG)	−0.067	0.043	−1.573	0.131
Δ(lnGDP)	6.315	3.705	1.704	0.104
Δ(lnGDP(-1))	10.769**	4.231	2.544	0.019
Δ(lnGDP^2–	−0.437	0.282	−1.549	0.137
Δ(lnGDP^2(−1))	−0.857**	0.323	−2.653	0.015
Δ(lnEC)	0.814***	0.175	4.649	0.000
ECT_{t-1}	−0.118***	0.131	−9.017	0.000
R-squared	0.872			
Adj. *R*-squared	0.826			
Durbin–Watson	2.038			

***, ** and * denote significance level at a 1%, 5% and 10%, respectively. Here, Prob. nominates the probability values

unit growth in ICT brings 0.113 units significant upsurge in CO_2 emissions in Pakistan. While the coefficient of ICT_NEG shows that a one unit decrease in ICT brings 0.064 units growth in CO_2 emissions, but these results were inconsequential. Nonetheless, the first lag of ICT_POS revealed a strong direct affiliation with CO_2 emission in Pakistan, implying that ICT intensifies the pollution in Pakistan in the short run. Even so, in the long run, it improves the environmental quality in Pakistan. The examination also revealed that the first lag of GDP and square of GDP is significantly positive and negative, respectively. The GDP coefficient stated that a one unit increase in per capita income boosts carbon emissions by 10.76 units. Thus, in the short run, the EKC hypothesis is present in Pakistan. Therefore, an inverted U-shaped relationship exists between GDP and CO_2 emissions. In the first phase, the carbon emissions will increase with the increase in income until attainment of fixed points; this relationship moved toward negative as ICT-based and energy-proficient tools, and structure is implemented for the period of the nation's development. These results are matched with **(Javid & Sharif, 2016; Nazir et al., 2018; Rahman & Ahmad, 2019).

The investigation exposed that energy consumption has a positive and significant relationship with CO_2 emission in the short run. Thus, EC has proved a strong determinant of carbon dioxide emissions. The ECT_{t-1} parameter contained negative and significant value, implying that past year disequilibrium of CO_2 emissions will achieve equilibrium with a speed of 11.8% this year. Additionally, the *R*-squared factor revealed that the variables utilized in this analysis have the power to predict 87% variation in CO_2 emissions. This investigation engaged the Akaike information criterion to select the best lags, i.e., (1, 2, 1, 2, 2, 2, 1, 0). Further, the Durbin–Watson test indicated the value of 2.03, which enlightens that the data has no autocorrelation problem. Table 6 exhibits the results of the F-Bound test. The F-statistic value is 6.45, which is higher than the upper critical bound value *I*(1) at a 1% level of significance. Therefore, the alternative hypothesis is accepted.

Table 7 presents the Wald test findings for both the short-run and long-run results of the NARDL model. The purpose of this test is to examine either the ICT has an asymmetric effect or not. The null hypothesis of the Wald test purposed that there is no asymmetry

Table 6 Outcomes of F-bound test. *Source*: Author's calculation

Test statistic	Value	Significance (%)	I(0)	I(1)
F-statistic	6.454	10	1.92	2.89
K	7	5	2.17	3.21
		2.5	2.43	3.51
		1	2.73	3.9

Table 7 Results of Wald test. *Source*: Author's calculation

Exogenous variables	Long-run asymmetry		Short-run asymmetry	
	F-stat	Prob	F-stat	Prob
ICT	2.665	0.0941	2.799	0.084

Here, Prob. nominate the probability values

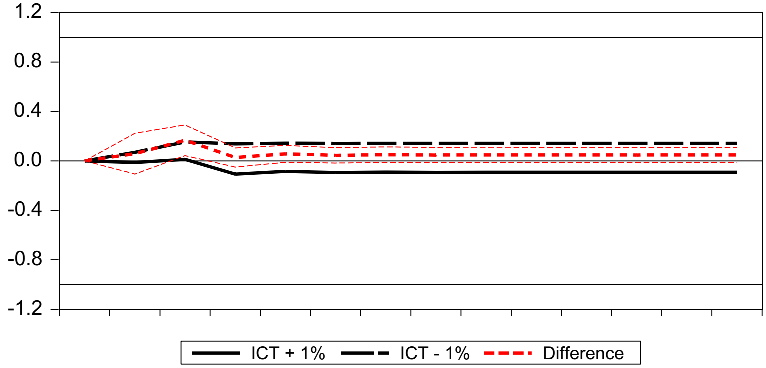

Fig. 1 Dynamic multiplier

between ICT and CO_2 emission. However, the alternative hypothesis assured the existence of the asymmetric effect. The long-term and short-term Wald results confirmed an asymmetric impact on ICT's positive and negative mechanism for a short time and long term period. Hence, the NARDL model is perfect for evaluating the impact of ICT on environmental quality in Pakistan. Moreover, dynamic multiplier plots given in Fig. 1 also showed that positive shocks in ICT decrease the CO_2 emissions, while negative shock increase it.

5.3 Diagnostic tests

The investigation utilized the methodology explained by Breusch and Pagan (2006) to determine the serial correlation and heteroscedasticity in the model's residuals. Additionally, the Ramsey RESET test is applied to evaluate functional misspecification in the NARDL model. In contrast, the cumulative sum of recursive residuals (CUSUM) and its square (CUSUMSQ) model established by Ploberger and Kramer (2006) is engaged in examining the constancy of the NARDL model. Table 8 expresses the outcomes of these diagnostic implements. These findings elaborate that the NARDL approach is correctly

Table 8 Diagnostic test. *Source*: Author's calculation

Heteroscedasticity findings				Serial correlation findings			
F-statistic	0.574	Prob	0.879	F-statistic	0.219	Prob	0.644
Ramsey test findings							
T-statistics	0.1860	Prob	0.854				
F-statistic	0.034	Prob	0.854				

Here, Prob. nominates the probability values

fixed, and there were no heteroscedasticity and serial correlation in the residuals of the model. In addition, the consequences of the CUSUM and CUSUMSQ tests are displayed in Figs. 2 and 3, respectively. These upshots classify that recursive residuals remain inside the 5% critical lines, implying that the NARDL model is appropriately fitted and its coefficients revealed correct information.

6 Conclusion and policy implications

The ICT sector in Pakistan has documented an inexhaustible increase during the last few years. The government of Pakistan is also struggling to make Pakistan a digital economy. This investigation analyzed the renowned impact of ICT on environmental quality in Pakistan. This inspection makes use of the NARDL model with year-wise information over the age of 1976–2018. Our key contribution of is to analyze the nonlinear impact of ICT on the carbon emissions (CO_2) in Pakistan. Furthermore, the role of financial development and energy consumption for the environmental degradation in Pakistan has been ascertained. Additionally, the existence of Environmental Kuznets Curve in the framework of asymmetric impact of ICT and symmetric impact of financial development and energy consumption for the nation of Pakistan is verified. The findings

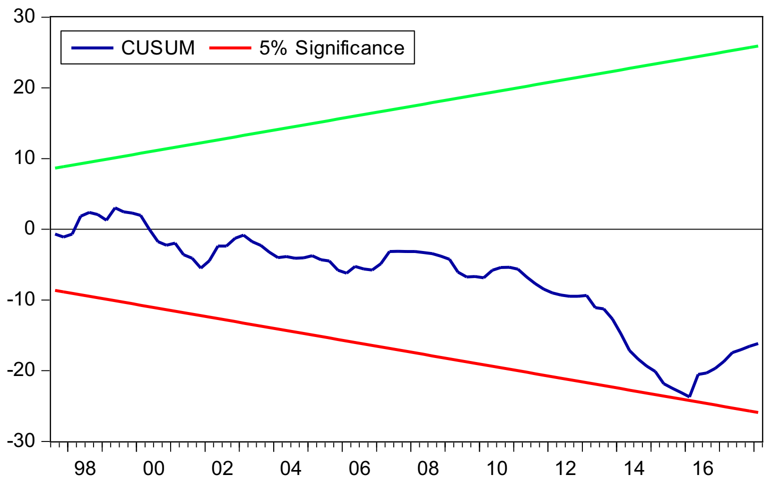

Fig. 2 CUSUM plot

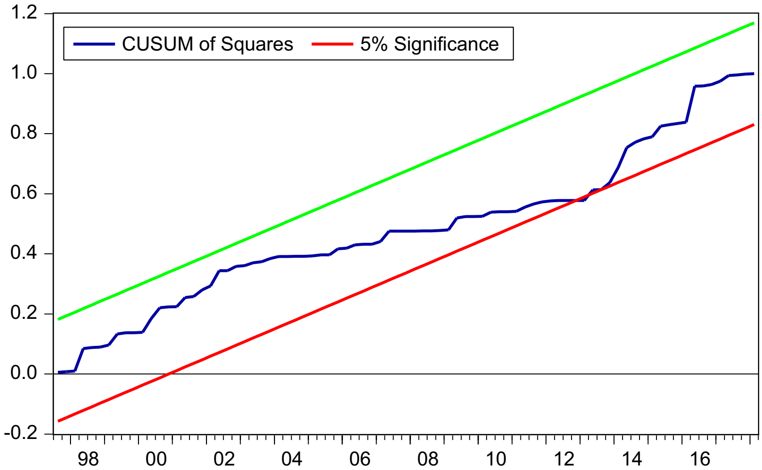

Fig. 3 CUSUM of square plot

indicate that the critical reason for CO_2 emissions in Pakistan is energy consumption. However, the investigation found that the emergence of ICT in the daily life and energy sector plays a vital role in mitigating carbon emissions. The inspection stated that both positive and negative shocks have a significant effect on carbon emissions. The utilization of a smart grid, ICT-based electrical devices, smart electricity services, smart home appliances, and intelligent transportation can drastically improve environmental quality. The exertion of ICT built-in technologies will also bring innovation to smartphones, such as online banking, bookings, and shopping which will decrease CO_2 emissions. Furthermore, ICT intrusion linked with load shifting and demand response should be considered to facilitate more renewable production resources. The administration should formulate policies that focus on up-to-date technology for electrical energy production and industrial production. They should also pay attention to the energy-effective structure and utilization of green energy. Moreover, the Ministry of Science and Technology of Pakistan should educate the people related to the usage of environment-friendly and ICT built-in home appliances to emit carbon emissions. This approach will decrease environmental hazards. The analysis elaborated that GDP growth degrades the environment at the first stage, but after reaching a peak point, it improves environmental conditions, as GDP and the GDP's square have a positive and negative sign, respectively. Finally, the growth of Pakistan's financial sector also increases CO_2 emissions, but this impact is lower compared to energy consumption. These days, Pakistan's government is facing challenges to achieve a high level of financial development and keep a balance in financial growth and environmental quality. In this regard, recently, Pakistan's government has made amendments in the tax system and planted 1 billion trees under a project named Billion Tree Tsunami (BTS). However, this is the best time to think about green economics by initiating the green concept. This investigation reported some limitations; first, another suitable proxy for Information and Communication Technology and financial development could be applied under the NARDL model to ascertain outcomes' legitimacy. Other possible factors, i.e., institutional performance, industrialization, and globalization, can be employed to present a detailed understanding for policymakers.

Authors' contributions KS contributed to conceptualization, analysis, writing, software. UZ was involved in writing revised draft and analysis. MA was involved in analysis, writing and proofreading. XL was involved in supervision.

Funding The study was supported by National Natural Science Foundation of China (No. 71673043).

Data availability The data utilized in this investigation are openly available in https://databank.worldbank.org/source/world-development-indicators.

Declarations

Conflict of interest The authors reported no potential conflict of interest.

Ethics approval and consent to participate This investigation does not involve human and animal data.

Consent for publication This study does not include any individual person's data.

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