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Digitalization, Financial Development, Trade, and Carbon Emissions; Implication of Pollution Haven Hypothesis During Globalization Mode

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In the modern era of globalization, information and telecommunication technologies (ICTs) have become an important factor influencing carbon dioxide (CO_2) emission; however, the specific effect produced by ICTs is still not clear. Therefore, the study examines the nexus between ICTs, foreign direct investment, globalization, and CO_2 emission in 77 developing countries. The novel attribute of this research is the ICTs with financial development and the international trade interaction term. The results of this study are based on the pooled regression and generalized method of moment (GMM) techniques from 1990 to 2016. The subsequent empirical findings are established as follows: first, the ICTs positively contribute to reducing CO_2 emission. Second, globalization significantly increases the CO_2 emission; third; the interaction between ICTs and financial development increases CO_2 emissions, and the moderating effect of ICTs and international trade performs the similar role. Fourth, the empirical finding verifies the presence of the pollution haven hypothesis. Fifth, our robustness tests confirmed that our empirical results were consistent. We suggest that policymakers should be using ICTs as a policy tool to mitigate CO_2 emission and should invite such investments in ICT sectors, which help maintain the environment quality.

Keywords: CO_2 emission, globalization, ICTs, pollution haven hypothesis, developing countries

1 INTRODUCTION

During the globalization mode, rising trends in information and communication technologies (ICTs), energy consumption, sustainable development, and environmental changes are becoming vital areas of interest (Qader et al., 2021; Qiang et al., 2021). Over the past 3 decades, the usage of ICT led to develop energy efficiency and productivity in various sectors in developing economies (Dagar et al., 2021). On the other hand, its consequence on the environment is uncertain and cannot be overlooked in the globalization-ICT and environmental deliberation. The junction of innovation and technology in the field of ICTs has enabled industries to achieve production in more efficient and effective ways not only at the industrial level but also at the aggregate firm's level. The financial sector is measured as a vital feature in the economic growth that plays a considerable role in the monitoring of funds, mobilization, and utilization of the connections for production activities (Amna Intisar et al., 2020; Jahanger et al., 2021a; Kamal et al., 2021). Carbon dioxide (CO_2) emission can be reduced through the use of ICT technologies in the financial system because a well-developed financial firm

motivates the organization to use modern technology in the energy sectors, which results in reducing CO_2 emission and increasing the environmental quality (Balsalobre-Lorente et al., 2021; Ramzan et al., 2021; Zhang et al., 2021; Ramzan et al., 2022).

ICTs help in reducing the carbon emission with the usage of the Internet, but we have some suggestions about developing economies that increase investment in the ICT sector especially the in-retailer sector when they have their own distribution network and feels insecure about sharing personal information openly due to competitors (Jahanger et al., 2021b; Usman and Hammar, 2021; Huang et al., 2022). The main advantages of ICT development are that it encourages the volume of imports and exports through E-trade. ICTs have rapidly increased in developing economies. The various types of ICTs, such as the Internet, mobile phones, and satellites, address challenges about temperature change sustainable growth. ICTs impact the environment in three ways, namely, 1) direct means the ICT influence through e-waste and energy consumption. 2) Indirect means ICT application such as smart grids, building, and intelligent transport systems. 3) Rebound means ICTs supporting both direct and indirect ways. After a keen evaluation of a plethora of empirical literature, we conclude that the ICT impact on environmental quality is not only ambiguous but also complex in nature both in developing and developed economies. No one exactly knows how the present day decisions about the adoption of ICTs will influence the quality of the environment, leading to variation in the sustainability of economic development. Therefore, examining the impact of ICTs on environmental quality is a hot research topic that needs to be addressed. In addition, climate change has now become a global challenge that disrupts the economies and people's lives severely. Some other environmental challenges facing the world include waste management, improvement in energy efficiency, biodiversity, loss of natural habitat, water quality, and carbon dioxide emissions. Along with the rapid increase in the FDI and trade activities, the trend of ICT development has increased swiftly across the world. So, there is a need to find the answer to the question; does ICT improve or deteriorate the environmental quality?

The nexus between globalization, ICTs, and CO_2 emission impacts *via* three channels. First, the use effect, which means the installation of ICT equipment during the production process significantly contributes to reducing CO_2 emission (Shahnazi and Dehghan Shabani, 2019). The second channel is the substitution effect which is distinct as the reformation of the production procedure, such as decarburization, detribalization, dematerialization (Danish et al., 2018; Ozcan and Apergis, 2018; Usman and Makhdum, 2021), intelligent traffic control, and GPS system to overcome the CO_2 emission (Shahnazi and Dehghan Shabani, 2019). The third is cost-effectiveness, which means increased production at a minimum price. Meanwhile, the development of ICTs assists new communication channels and increases trade actions and flows (Ozcan and Apergis, 2018). ICT supplies such as digital equipment transfer through globalization mean knowledge transfer through foreign direct investment (FDI), usage of updated machinery, communication among people building an awareness among people that guides to a minimization of carbon emission (Danish et al., 2018; Yang et al., 2021b; Jahanger, 2021a; Jahanger, 2021b).

The trend of global ICT development from the period 2001 to 2019 shows that the use of mobile cellular subscription is higher than other subscriptions that can be seen in **Figure 1**. Globalization is a worldwide phenomenon; it has a substantial impact on the political, economic, and social surfaces of human welfare (Jahanger, 2021a; Yang et al., 2021a; Bilal et al., 2022). Globalization linked economies *via* capital flows, culture, innovative opportunities, and trade. Globalization has a positive effect on the environmental excellence of any economy. Developed economies also take advantage of it in the course of the usage of sophisticated energy-saving equipment that has significant influences on the pattern of energy consumption and help reduce CO_2 emission (Usman et al., 2021a; Khalid et al., 2021; Ahmad et al., 2022; Yang et al., 2022).

Globalization improves the economic scale through market liberalization that enhances market competition. Such forces make the ICT industry become globalized, for example, multinational enterprises have been used as an instrument for encouraging globalization which depicts that high productivity can be attained in those firms which are extremely based on ICTs (Huang et al., 2022). Only 34% of the population of developing economies has access to the usage of the Internet as compared to 80% in developed economies. (Khan et al., 2018). The positive impact of FDI on economic growth may be harmful to the environment. Some parts of FDI inflow to developing economies due to careless environmental rules and regulations. If the FDI inflow positively affects the environment, it is called the pollution haven hypothesis (PHH).

Many existing studies examined the influence of ICTs on the environment (Asongu et al., 2018; Ramzan et al., 2021; Huang et al., 2022). These research articles ignored the nexus between globalization, ICTs, and CO_2 emission. In order to plug this breach, this study looks for the effect of globalization and ICTs on CO_2 emission for developing economies. According to our best knowledge, we are the first ones to inspect the association between ICTs, globalization, and CO_2 emission. We used balanced panel data of 77 developing countries from 1990 to 2016 by applying the pooled regression and generalized method of moment (GMM) method to scrutinize the impact of ICTs and globalization on CO_2 emission. Our results indicate that ICTs have the ability to reduce CO_2 emissions, but globalization has a negative impact on the environment. The study is anticipated to contribute to the literature in different ways; the current study also used the moderation role of ICTs with trade-in CO_2 emission. This moderation effect may help improve ICT through financial development. In addition, it is well-identified that panel static methods, such as pooled OLS, random effect, and fixed effect, are inappropriate in the non-stationary occurrence of data as they would have reasoned an endogeneity issue and could not offer accurate outcomes. To resolve this endogeneity issue, we have pragmatically used the GMM method. Furthermore, our robustness tests confirm these findings. Our results also suggest that increasing the level of investment in the ICT

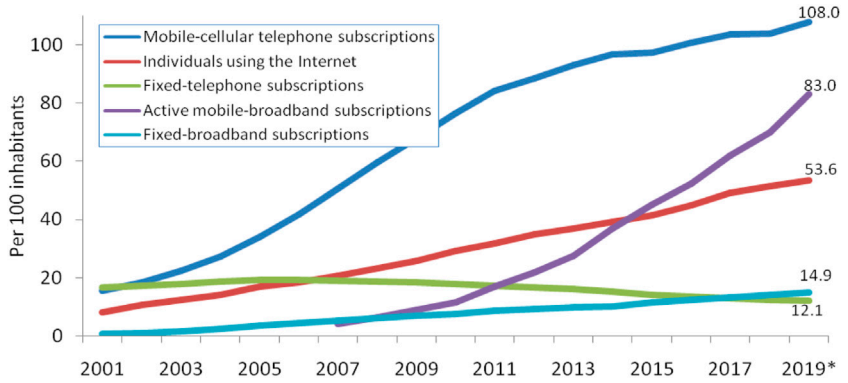

FIGURE 1 | Global ICT developments; source: ICT indicator database.

sector will boost the level of economic growth and also help reduce CO_2 emission.

The remaining sections of this study are set in the following manner. **Section 2** provides a literature review; **Sections 3** describes the data sample and empirical strategy; **Section 4** provides the empirical findings and their detailed discussion; **Section 5** outlines the conclusion and policy suggestions.

2 REVIEW OF PREVIOUS LITERATURE

The empirical nexus between globalization, ICT, and CO_2 emission has been recognized in several research articles. Nevertheless, the literature has been separated into pairwise connections based on past estimated results among the series that have been indicated in the following paragraphs.

2.1 Nexus Between ICTs and CO_2 Emission

A noteworthy increase in ICT sectors over the span from 2000 to 2013 increased the function of the Internet as a vital part of real economic (GDP) growth. In this regard, Faisal et al. (2020) studied the link between economic growth, financial development, electricity consumption, trade, ICTs, and CO_2 emission with a second-generation panel co-integration technique and the panel data of fast-emerging economies from the period 1993–2014. The estimated findings explore that financial development and electricity consumption have a constructive impact on which trade and economic growth have a significant adverse impact on environmental degradation. Furthermore, ICTs and CO_2 emission have a U-shape relationship. Amri et al. (2019) investigated the impact of ICTs, total factor productivity (TFP) on CO_2 emission based on autoregressive distribution delay (ARDL), and the time series data of Tunisia from 1975 to 2014. They conclude that TFP plays a positive role in environmental disclosure, while ICTs have an insignificant impact on CO_2 emission. According to world-system theory (WST), information and telecommunication technologies (ICTs) are seen as one of several solutions to a variety of societal, environmental, and economic troubles. Furthermore, Anwar et al. (2022) used quantile regression to examine the impact of institutional quality, trade openness, and technological innovation and population on environmental degradation. The empirical conclusions confirm that institutional quality and technological innovation have played a major role in minimizing environmental pollution. In addition, the empirical outcomes of the study by Guo et al. (2021) mention that environmental innovation and renewable energy use are key contributors in explaining environmental pollution. Noted that a positive (negative) shock in technological innovation causes a decrease (increase) in environmental pollution.

Based on the individual country time-series data from 29 developing countries during 2010–2014 and by using the two-step system generalized method of moments (S-GMM) approach, Mirza et al. (2019) found that ICT has significantly increased environmental pollution. Moreover, Asongu et al. (2018) studied the relationship between ICTs and CO_2 emission with a similar approach and used the data of 44 sub-Saharan African (SSA) countries for the period of 2000–2012. Their findings reveal that ICTs have an adverse impact on carbon emissions in the long run. Using the generalized method of moments (GMM) methods, Bansal (2017) researched the relationship between ICTs, trade openness, and CO_2 emission based on panel data of 44 sub-Saharan countries from 2000 to 2012. They found that ICTs have an insignificant negative impact on CO_2, while trade openness has a positive influence on the environment. Park et al. (2018) observed the dynamic connection between ICTs, trade openness, economic growth, and financial expansion on carbon emissions with the pooled mean group (PMG) method and used the panel data of 23 different European Union (EU) countries from 2001 to 2014. Their observed results point out that ICTs positively contribute to the high carbon emissions while trade, financial development, economic growth, and trade have an adverse influence on environmental degradation.

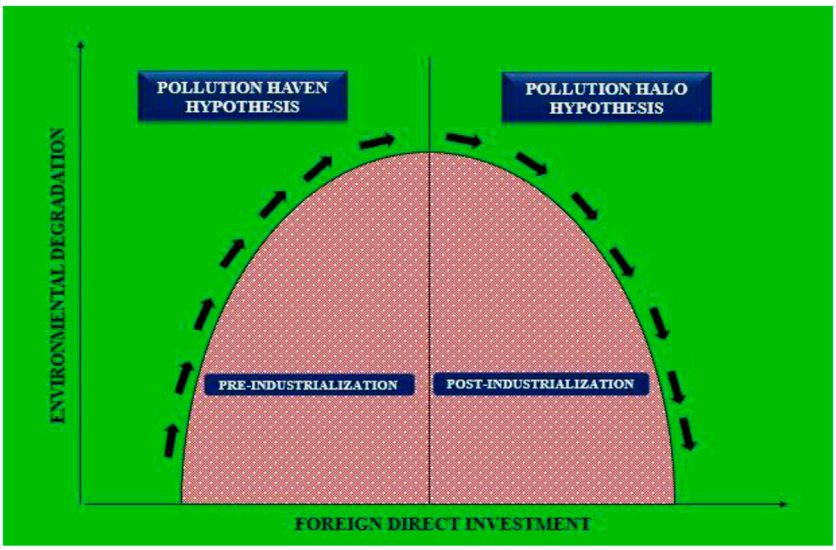

FIGURE 2 | Inverted U-shaped relationship between FDI and environmental degradation.

2.2 Nexus Between Foreign Direct Investment and CO_2 Emissions

Xie et al. (2019) investigated the association between foreign direct investment and carbon emission in 11 emerging economies from 2005–2014 with the panel smooth transition regression (PSTR) model and concluded that FDI has a positive and negative impact on carbon emission, thereby confirming the pollution haven (PHH) and pollution halo hypotheses (PHHH). Ali et al. (2020) inspected the asymmetric impact of FDI, trade openness, and institution performance on environmental quality in 57 OIC countries with dynamic common correlated effect (DCCE) methods. The results indicate that trade openness and FDI have a positive impact on the ecological footprint that hence PHH, while institution performance has a negative impact on the environmental deficit. Bildirici and Gokmenoglu, 2020 studied the causality of the relationship between energy consumption, terrorism, economic growth, terrorism, FDI, and CO_2 emission in nine developing economies with the ANOVA and panel trivariate causality tests, and the empirical outcomes show that economic growth, energy use, FDI, and terrorism have a significant impact on CO_2 emission that is confirmed by PHH. The graphical presentation of the inverted U-shaped link between FDI and environmental degradation is presented in **Figure 2**.

Bildirici and Gokmenoglu (2020) studied the causality between foreign direct investment, energy consumption, terrorism, and CO_2 emission based on the ANOVA test and the panel data of nine developing economies from 1975 to 2013. The empirical results have confirmed the existence of PHH. Zmami and Ben-Salha (2020) examined the influence of GDP, urbanization, FDI, and international trade on CO_2 emission in six GCC countries based on a PMG-ARDL approach and the annual time series data for the period of 1980–2017. They discovered a positive relationship between FDI and CO_2 emission in the short term while in the long term, FDI reduces CO_2 emission. In accordance with this, the PHHH is verified in the short run, while in the long term, the PHH is conformed for the Gulf Cooperation Council (GCC) countries.

2.3 Nexus Between Financial Development and CO_2 Emissions

Qayyum et al. (2021) explored the interaction between financial development, renewable energy consumption, technological innovations, and CO_2 emissions in India from 1980 to 2019. According to the study's conclusions, financial development has a considerable positive impact on environmental degradation, while renewable energy consumption and technical innovations show a negative association with environmental pollution. In the financially resource-rich economies, Usman et al. (2022a) investigated the dynamic association between financial development, globalization, natural resources, and non-renewable and renewable energy use on the environmental deficit from 1990 to 2018. The outcomes reveal that financial development helps increase the ecological footprint level, while renewable energy and globalization processes significantly diminish environmental pollution. Furthermore, Yang et al. (2021c) examined the impact of technological innovations and financial development on environmental decay in the case of BICS nations. The outcomes of this study reveal that financial development significantly deteriorates environmental performance, while technological innovations are an essential factor for the decrease of the environmental degradation level. Moreover, Jahanger et al. (2022) explored that financial development significantly raises environmental degradation, while technological innovations help inhibit them. Usman et al. (2020a) scrutinized the dynamic influence between financial development, GDP growth, and renewable and non-renewable energy in boosting economic growth and reducing the

ecological footprint level for the 15 most polluted countries. The outcomes of the augmented mean group (AMG) estimation method explored that renewable energy, financial development, and trade significantly improve environmental quality, while GDP growth and non-renewable energy increase environmental damages. Furthermore, financial development and non-renewable and renewable energy significantly boost economic growth. Kamal et al. (2021) noted that financial development is considered one of the most crucial indicators to increased pollution levels. In addition, empirical outcomes mention that financial development, economic growth, urbanization, and agriculture impact CO_2 emissions positively. However, Usman et al. (2021b) discovered an insignificant effect of financial development on the ecological footprint in the case of the 20 Asian countries. In the 20 highest polluted economies, Usman et al. (2020b) established a long-run association between ecological footprint, energy utilization, and financial development under the EKC framework from 1995 to 2017. The empirical results of the AMG discovered that energy consumption and financial developments increase the ecological footprint. Moreover, the empirical outcomes do not authorize the EKC hypothesis in the long run.

2.4 Nexus Between Globalization and CO_2 Emissions

The theoretical relation between globalization and CO_2 emission can be clarified all the way through the following two hypotheses, ecological modernization hypothesis and world polity hypothesis, which suggest that globalization advances the institutionalization of ecological practices and culture around the world (Hamalainen, 2007), resulting in reducing the levels of CO_2 emissions worldwide. Akadiri et al. (2020) studied the connection between GDP growth, electricity utilization, globalization, and CO_2 emission with an ARDL-bound testing approach and the time series data of Turkey from 1970 to 2014. They found that in electricity consumption, economic growth plays a positive role in reducing CO_2 emission, while globalization has no statistical indication of impacts on CO_2 emission. Shahbaz et al. (2020) investigated the influence of electricity use, economic growth, financial expansion, and economic globalization on carbon emission based on the Toda–Yamamoto causality test and the time series data of the United Arab Emirates from 1975 to 2014. The results show that financial development and economic globalization have a negative impact on atmosphere pollution, while economic growth and electricity consumption improve CO_2 emission. Shahbaz et al. (2019) examined the dynamic relationship of globalization and CO_2 emission with the cross-correlation approach and the panel data of 87 countries. The results indicate that globalization will decrease CO_2 emissions in the future. Yang et al. (2020) have supported the view that globalization decreases environmental decay due to eco-friendly technologies. The empirical findings of Wan et al. (2022) demonstrate the globalization process, and renewable energy consumption plays a dominant role in minimizing environmental degradation.

Khan et al. (2019) investigated the impact of economic growth, globalization, FDI, and energy consumption on CO_2 emission based on the dynamic ARDL simulation model by using the time-series Pakistani data from 1971 to 2016. The empirical outcomes specify that energy utilization, globalization, and economic growth have a constructive impact on CO_2 emission, while FDI will increase CO_2 emission. Ahmed et al. (2019) examined the asymmetric impact between globalization and ecological footprint using the ARDL-bound test and the data of Malaysia for the period 1971–2014. The results show that globalization will increase CO_2 emissions. Using second-generation panel data, Destek, (2019) researched the dimensions of globalization (i.e., total globalization, political globalization, economic globalization, and social globalization) on CO_2 emissions based on panel data of 12 Central and Eastern European Countries (CEEs) from 1995 to 2015; they found that economic globalization, social globalization, and overall globalization increase the CO_2 emissions, while political globalization will help reduce the CO_2 emission. However, there is no empirical evidence above the literature review between the association of ICTs and globalization on CO_2 emissions, so this point has motivated to fill the gap in the empirical literature by examining the dynamic role of globalization and ICTs on CO_2 emissions across the developing economies. The empirical outcomes of Fatima et al. (2021) mention that an increase in income moderates the ratio of utilization of renewable energy to environmental pollution. Miao et al. (2022) noted that financial globalization leads to a sustainable environment.

Table 1 reviews some of the existing literature that emphasizes the association among information and communication technology, globalization, economic growth, foreign direct investment, financial development, trade openness, urban population, and gross capital formulation. Several studies have highlighted the information and communication technology–environment nexus, globalization–economic growth–environment nexus, foreign direct investment, financial development–environment nexus, trade openness, urban population, and gross capital formation–environment nexus, but none of them has discovered the information and communication technology, globalization, economic growth, foreign direct investment, financial development, trade openness, urban population, and gross capital formulation in the context of developing economies.

3 EMPIRICAL STRATEGY AND DATA

3.1 Data

The main purpose of this empirical research was to examine the influence of ICT development on CO_2 emission. This research used balanced panel data of 77 developing countries from the period 1990 to 2016. In order to categorize the developing countries, we have used the United Nations Classification (2019) to classify the developing economies. In Appendix (see **Appendix Table A1**) the details of the countries that had been studied in

TABLE 1 | Summary of the published literatures between ICT, TGL, FDI, FD, TRD, URP, and GLF-environment nexus.

Authors	Countries	Period	Variables	Methods	Findings
A) Information and communication technology–environment nexus					
Faisal et al. (2020)	Four fast-emerging countries	1993–2014	CO_2, GDP, FD, TRD, and ICT	FMOLS, DOLS	GDP and TRD have a negative and significant impact on CO_2 emissions. In addition, an inverted U-shaped link between ICT and CO_2 emissions was found
Amri et al. (2019)	Tunisia	1975–2014	CO_2 and ICT	ARDL	The outcome indicates an insignificant influence of ICT on CO_2 as a measure of pollution
Asongu et al. (2018)	44 Sub-Saharan Africa	2000–2012	CO_2 and ICT	GMM	ICT does not significantly affect the environment
Batool et al. (2022)	East and South Asia	1985–2020	CO_2, ICT, and FD	PMG	ICT and FD positively contribute to the degradation of the environment
Bilal et al. (2022)	OBOR countries	1991–2019	CO_2 and ICT	Second-generation tests	ICTs negatively contribute to the degradation of the environment
B) Globalization–economic growth-environment nexus					
Yang et al. (2021a)	Top ten health expenditure countries	1995–2018	GLO, URB, GDP, and EF	Second-generation tests	GLO and the URB process significantly decrease environmental damage while GDP is more responsible for increasing the pollution level
Yang et al. (2021b)	GCC countries	1990–2016	GLO, FD, ENG, and EF	CCEMG, FMOLS	GLO, FD, and ENG are significantly worsening the environmental excellence
Usman et al. (2021c)	Eight Arctic countries	1990–2017	GLO, GDP, NENG, and GHG	Second-generation tests	GLO, GDP, and NENG contribute to amplified environmental pollution
Yang et al. (2020)	97 countries	1990–2016	RMT, ENG, GLO, and CO_2	GMM	RMT and ENG increases environmental pollution; however, GLO decreases the pollution level
Jahanger (2021a)	78 developing economies	1990–2016	GDP, GLO, and CO_2	GMM	Empirical results support the inverted U-shaped EKC hypothesis. Furthermore, GLO decreases the environmental quality
C) Foreign direct investment and financial development–environment nexus					
Kamal et al. (2021)	105 countries	1990–2016	FPI, GLO, FDI, and CO_2	FMOLS, DOLS, and ARDL	FPI and GLO significantly increase environmental pollution. The empirical outcomes approve the existence of the pollution haven hypothesis
Bildirici and Gokmenoglu (2020)	9 Countries	1975–2017	FDI, CO_2, and TRIM	PTCT tests	One-way causal nexus from TRIM to CO_2 and from FDI to CO_2
Shahbaz et al. (2022)	39 RECAI countries	2000–2019	FD, RENG, and FDI	Second-generation tests	FD found to increase RENG, while FDI and RENG are positively linked
Usman and Balsalobre-Lorente (2022)	Top ten newly industrialization countries	1990–2019	FD, NNR, RENG, and EF	Second-generation tests	FD is significantly driving environmental degradation, while NNR and RENG significantly mitigate environmental decay
Usman et al. (2022b)	Pakistan	1990–2017	CO_2, FD, NREN, REN, TRD, and GDP	ARDL-bound test	FD and REN accelerate the environmental quality, while GDP, NREN, and TRD reduce it
D) Trade openness, urban population, and gross capital formulation–environment nexus					
Azam et al. (2022)	Six OPEC countries	1975–2018	URB, IND, TRD, ENG, and CO_2	Fixed effect	URB, IND, TRD, and ENG significantly increase environmental pollution in the long run
Etokakpan et al. (2020)	Malaysia	1980–2014	GDP, REN, and CO_2	NCCIT tests Novel	Empirical analysis confirmed the growth energy–driven hypothesis
Rahman and Ahmad (2019)	Pakistan	1980–2016	GCF and CO_2	NARDL test	Result approves the existence of an asymmetric effect of GCF shocks on environmental pollution in the short and long term
Muhammad et al. (2020)	65 BRI Countries	2000–2016	FDI, URB, and CO_2	2SLS regression	Results confirmed an inverted U-shaped relationship between URB and CO_2, while FDI increased CO_2 emissions
Usman et al. (2020c)	33 Upper-middle income countries	1994–2017	FDI, GDP, EFP, TRD, and NREN	FMOLS, DOLS, FGLS, and AMG	The results explored that TRD adversely affects ecological footprint in the case of African and American upper–middle income countries

FD stands for financial development; CO_2 denotes the carbon emission; TRD expresses the trade openness; GDP stands for economic growth; URB stands for urbanization process; ICT stands for information and communication technology; GMM stands for generalized method of moments; CCEMG stands for common correlated effect mean group; FPI stands for fiscal policy; EF stands for ecological footprint; GLO stands for globalization; GCF shows the gross capital formulation; FMOLS represents the Full Modified Ordinary Least Square; DOLS represents the Dynamic Least Square; ARDL represents the Autoregressive Distributed Lag; NNR represents the natural resources; CCEMG stands for Common Correlated Effects Mean Group; NREN stand for non-renewable energy consumption; REN stands for renewable energy consumption; FDI stands for foreign direct investment; TRIM stands for terrorism; NARDL stands for Non-Linear Auto Regressive Distribution Lag, 2SLS stands for 2-stages least square) regression; NCCIT stands for novel combined co-integration test; PTCT stands for panel trivariate causality tests; PMG stands for Pooled Mean Group.

TABLE 2 | Variables, acronyms, and data sources.

Variables	Acronyms	Unit and data sources
CO_2 per capita	CO_2	CO_2 emission (metric tons per capita); https://data.worldbank.org/
Information and communication technologies	ICT_{mobile}	Mobile cellular subscriptions (per 100 people); https://data.worldbank.org/
Information and communication technologies	ICT_{int}	Internet users (per 100 people); https://data.worldbank.org/
Total globalization index	TGL	KOF index (0–100); https://kof.ethz.ch/en/forecasts-and indicators/indicators/kof-globalisation-index.html
Financial development	FD	Domestic credit provided by the financial sector (% of GDP); https://data.worldbank.org/
Trade	TRD	Trade (% of GDP); https://data.worldbank.org/
Urban population growth	UPG	Urban population growth % of annual; https://data.worldbank.org/
Gross capital formation	GLF	Gross capital formation is the percentage of total GDP; https://data.worldbank.org/
Foreign direct investment	FDI	Foreign direct investment is the net inflow (BoP, current US$); https://data.worldbank.org/

this research are shown. Carbon dioxide emission (CO_2) as a dependent variable, information and communication technologies (ICTs), TGL (overall globalization), foreign direct investment (FDI), financial development (FD), trade openness (TRD), gross capital formulation (GCF), and urban population (URP). All the data for the candidate variables are attained from the World Bank Indicators (2020) database, except the globalization index, which has been obtained from the KOF Swiss Economic Institute (2020), (Dreher, 2006). Detailed descriptions of each variable are given in **Table 2**.

3.2 Model Specification

The function form of the econometric model based on past studies by Asongu et al. (2018); Amri et al. (2019); Akadiri et al. (2020); Faisal et al. (2020); Shahbaz et al. (2020)can be illustrated in **Eq. 1** as follows.

$$CO_2 = f(ICTs, TGL, LF, FDI, TRD, URP, GCF), \quad (1)$$

where CO_2 emission (metric tons per capita) and ICTs is measured mobile cellular subscription (per 100 people). The weight of the globalization index was categorized into three parts. Social globalization has a weight of 38%; economic dimension has a weight of 36%; and political globalization has 26% Dreher, (2006). FD (financial development) is measured by domestic credit provided by financial sectors (% of GDP); FDI is the foreign direct investment; TRD is (trade) is the % of GDP; URP is a measure of urban population growth, that is, the percentage of annual, and last, GEF is a gross capital formulation that is the percentage of total GDP The definitions of all variables and data sources are provided in **Appendix Table A1**. We will convert all variables into their nature logarithmic shape's main objective to attain more reliable results (Manning, 1998; Usman and Jahanger, 2021). The log-linear specification as explained in **Eq. 2** is as follows:

$$\ln CO_2 = \beta_0 + \beta_1 \ln ICTs_{it} + \beta_2 \ln TGL_{it} + \beta_3 \ln FD_{it} + \beta_4 \ln FDI_{it} + \beta_5 \ln TRD_{it} + \beta_6 \ln URP_{it} + \beta_7 \ln GCF_{it} + \varepsilon_{it}, \quad (2)$$

where subscripts ***i*** represent cross-sections ($i = 1, 2. . ..77$) and t shows time dimensions (1990–2016); ε_{it} depicts the error terms. The term β_0 is constant, $\beta_1 \rightarrow \beta_7$ are the parameters to be anticipated. Next,, we will introduce the interaction terms between ITCs and FDI included in the function of CO_2 emission. The major objective of this research is to investigate the increasing fact of foreign direct investment (FDI) toward a high usage of ICTs in various sectors to increase economic growth. The development of ICTs with growing financial development (FD) may affect environment positively and negatively. The second purpose of our study is to investigate the interaction terms between ICTs and TRD that may shift and the use of advanced technology that may boost up energy efficiency that could be helpful in reducing the CO_2 emission. Similarly, an increase in trade actions leads to increased usage of ICT goods, which may help reduce the CO_2 emission. **Eq. 3** is an extended form of **Eq. 2**; the interaction terms between FDI, TRD, and ICTs can be written as

$$\ln CO_2 = \beta_0 + \beta_1 \ln ICTs_{it} + \beta_2 \ln TGL_{it} + \beta_3 \ln (\text{ICTs X FD})_{it} + \beta_4 \ln (\text{ICTs X TRD})_{it} + \beta_5 \ln FD_{it} + \beta_6 \ln FDI_{it} + \beta_7 \ln TRD_{it}. + \beta_8 \ln URP_{it} + \beta_9 \ln GCF_{it} + \varepsilon_{it} \quad (3)$$

TABLE 3 | Descriptive statistics.

Variables	LCO_2	LICTmob	TGL	Lgdp	LFDI	LFD	LTRD	LURP	LGCF
Mean	0.0263	0.77328	1.7067	3.42023	8.62132	1.5387	1.8018	0.45372	1.34367
Std. Dev	0.7149	1.02163	0.11	0.5978	1.08492	0.35329	0.30378	0.25853	0.16306
Minimum	–1.6796	–2.0682	1.33519	2.21733	2	–0.4404	–0.7762	–2.1712	–0.5333
Maximum	1.84536	2.32764	1.93117	4.8431	11.4637	2.39603	2.64081	1.2495	1.78865
VIF		1.87	4.4	1.92	2.26	1.4	1.4	1.29	1.26
(1/VIF)		0.53552	0.22736	0.5216	0.44209	0.71283	0.71497	0.77529	0.79206

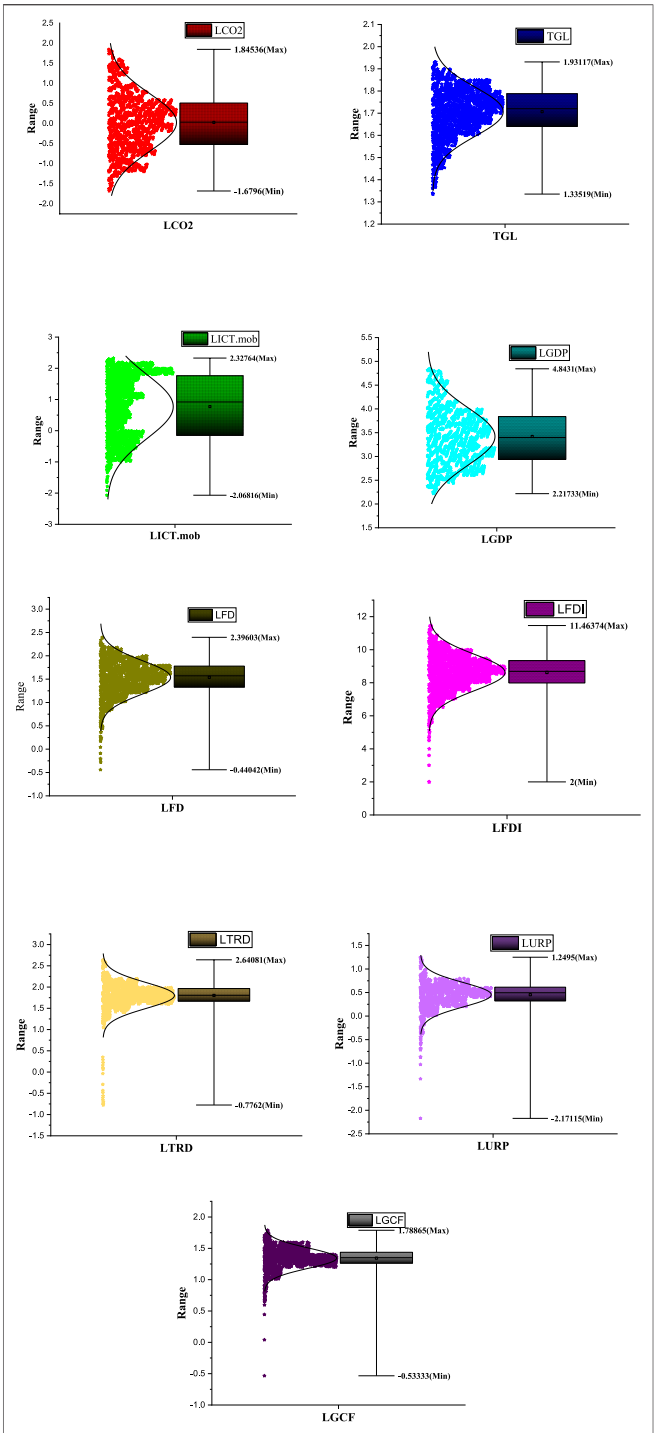

FIGURE 3 | Box–plot summary for the selected variables.

3.3 Methodology

This study began estimations of our model by applying a panel OLS estimator (fixed-effects and random-effects models). The Hausman test was chosen to analyze whether the fixed effects or random effects are most suitable for our model. Overall, the fixed-effect model was more suitable because it controls overlooking the country-specific effects and alleviate the problem of multicollinearity. The OLS estimator is inappropriate in the presence of non-stationary data as they would have been consistently an endogenous problem. Therefore, the generalized method of moments (GMM) (Arellano and Bond, 1991) was applied to overcome the endogeneity problem. Furthermore, compared with the one-step GMM, the two-step system GMM estimator produces more asymptotic well-organized values, especially in conditions where autocorrelation and heteroscedasticity problems. Therefore, we implemented two system GMM techniques to estimate the empirical model. We adopted the "Xtabond2" command to include the estimation models. Furthermore, the Hansen test was used to corroborate the effectiveness of the instrument variable instead of the Sargan test. Roodman, (2009) investigated that the Sargan test is not robust to deal with autocorrelation or heteroscedasticity problems.

4 EMPIRICAL RESULTS AND DISCUSSION

The main purpose was to understand the impact of information and communication technologies (ICTs) and globalization on CO_2 emission across the 77 developing countries. **Table 3** presents the descriptive statistics of the variables for our main model. The summary statistics of the concerned variables from 1990 to 2016 through Plot-boxes is shown (see **Figure 3**).

Table 4 presents the correlation metric that is used to identify the severity of multicollinearity. According to Lee, (2006), when all variable coefficients are less than 0.85, then there is no issue of multicollinearity. Furthermore, the results of the variance inflation factor (VIF) test verify that there is no multicollinearity. The value of VIF for each variable is less than 0.85.

Table 5 presents the full sample of the empirical results of the effect of ICTs and globalization on CO_2 emission. The first-order serial correlation AR 1) is significant at the 1% level, and second-order serial correlation AR 2) and Hansen test were insignificant. These misspecification tests proved the correctness of the GMM specification. The results of the regression showed that ICTs had a negative impact and were significantly linked to CO_2 emission. Specifically, a 1% increase in ICTs results in 0.105% decrease for developing economies. The finding is consistent with that by Asongu et al. (2018), who showed the negative relationship between ICTs and CO_2 emission. This means the rapid use of the Internet along with the mobile cellular subscription; these economies are generating energy-efficient ICT devices, which additionally alleviate energy consumption and improve environmental quality. According to the World Bank, ICTs could help reduce 6–15% CO_2 emission in 2030 through smart applications, dematerialization, and well-organized use of energy. Despite contributing to economic growth, the quick transformation to industrialization has caused environmental pollution and severely influences the health standards of the general public. A strand of literature postulates that the ICT contributes both directly and indirectly to social, economic, and

TABLE 4 | Correlation matrix.

	LCO_2	$LICT_{mobile}$	TGL	LFD	LFDI	LTRD	LURP	LGCF
LCO_2	1							
$LICT_{mobile}$	0.3640*	1						
TGL	0.6786*	0.6779*	1					
LFD	0.4752*	0.2446*	0.5136*	1				
LFDI	0.5057*	0.4916*	0.6501*	0.3485*	1			
LTRD	0.3001*	0.2581*	0.3855*	0.1784*	0.0795*	1		
LURP	−0.2442*	−0.2026*	−0.3496*	−0.2664*	−0.2320*	0.0703*	1	
LGCF	0.2886*	0.1957*	0.2780*	0.1673*	0.3955*	0.2286*	0.02	1

****, **, and * explore that the coefficients are significant at the 1%, 5%, and 10% level of significance, respectively.*

TABLE 5 | Static and dynamic elasticity evidence.

Variables	OLS		FE		GMM	
	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
$LICT_{mobile}$	−0.116***	0.0152	−0.0193***	0.0044	−0.105***	0.0039
TGL	0.0717***	0.0040	0.0129***	0.0015	0.0616**	0.0128
LFD	0.307***	0.0383	0.1192**	0.0122	0.293***	0.0021
LFDI	0.0978***	0.0154	0.0043***	0.0048	0.101**	0.0411
LTRD	0.225***	0.0507	0.0302**	0.0201	0.139***	0.0003
LURP	−0.1103**	0.0478	−0.0107**	0.0148	−0.0502	0.1831
LGCF	0.2827*	0.0755	0.0757**	0.0202	0.3367	0.2212
Constant	−8.2722	0.3212	−1.5373	0.1195	−7.7724	0.8143
Observations	1,869		1,869		1,869	
No of Countries	77		77		77	
R-squared	0.5262		0.6386			
F-stats	294.88	0.0000	154.93	0.0000		
AR (1)					−2.88	0.0413
AR (2)					−1.5	0.2558
Hansen					24.08	0.5713

The Hausman test of the fixed pooled model was selected. The values in parentheses are the p*-values. ***, **, and * point out significance at 1%, 5%, and 10% levels, respectively.*

TABLE 6 | Dynamic elasticity evidence (estimation of moderating effect).

Variables	Model 1		Model 2		Model 3	
	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
$LICT_{mobile}$	−3.375**	0.0324	−0.421**	0.0187	−2.556***	0.0006
TGL	0.0788***	0.0092	0.0598***	0.0000	0.0660***	0.0000
$LICT_{mobile}$*LTRD	0.7625**	0.0153			0.4937**	0.0231
$LICT_{mobile}$*LFD			0.0800*	0.0504	0.1013*	0.0685
LFD	0.1292	0.1512	0.1299	0.1361	0.0008	0.1728
LFDI	0.1249*	0.0702	0.102*	0.0563	0.1322**	0.0219
LTRD	−0.9941	0.6212	0.0765	0.1473	−0.6319	0.4215
LURP	−0.2008	0.2153	−0.1735	0.1572	−0.2667	0.2123
LGCF	0.1094	0.3423	0.4001	0.2442	0.2923	0.2495
Constant	−3.0312	2.556	−7.184***	0.0041	−4.107**	0.0280
Observations	1,869		1,869		1,869	
No of Countries	77		77		77	
AR (1)	−2.3890**	0.017	−3.1364***	0.0027	−3.0694***	0.0025
AR (2)	−0.0792	0.9443	−0.9927	0.3682	−0.3929	0.6954
Hansen	23.7294	0.6462	30.3	0.3012	37.4	0.0889

*The Hausman test of the fixed effect model was selected. Furthermore, ***, **, and * point out significance at 1%, 5%, and 10% levels, respectively.*

environmental aspects of sustainable development goals (SDGs) set by the United Nations (UN). Regarding the other variable TGL (overall globalization), it has a statistically positive and significant impact on CO_2 emission. It is noted that 1% increase in TGL leads to a 0.0616% increase in CO_2 emission. This result is consistent with that of Destek, (2019) who revealed that globalization has a positive influence on CO_2 emission. Due to globalization, mostly pollution-intensive industries are

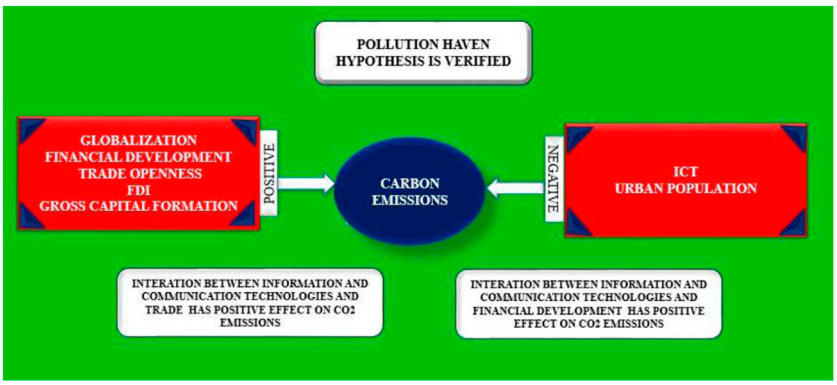

FIGURE 4 | Graphical presentation of empirical results.

TABLE 7 | Dynamic elasticity evidence (alternative proxy applied).

Variables	Model 1		Model 2		Model 1		Model 2	
	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
$LICT_{mobile}$	−0.1054***	0.0009			−2.556**	0.0406		
$LICT_{int}$			−0.0688*	0.0578			−1.3302**	0.0351
$LICT_{mobile}$*LTRD					0.4931**	0.0242		
$LICT_{int}$*LTRD							0.2618*	0.0637
$LICT_{mobile}$*LFDI					0.1013*	0.0685		
$LICT_{int}$*LFDI							0.0554*	0.0702
TGL	0.0616***	0.0000	0.0577**	0.0233	0.0660***	0.0000	2.5543**	0.0273
LFD	0.2937***	0.0000	0.2835	0.1748	0.0008	0.9774	0.2246	0.2137
LFDI	0.1017**	0.0411	0.254***	0.0000	0.1322**	0.0419	0.1408*	0.0725
LTRD	0.1394	0.1505	0.4593	0.3267	−0.6317	0.4217	0.0628	0.3304
LURP	−0.0502	0.1836	−0.0443	0.1945	−0.2665	0.2127	−0.1784	0.2728
LGCF	0.3362	0.2216	−1.397***	0.0000	0.2924	0.2349	0.0172	0.2860
Constant	−7.772***	0.0000	−6.662***	0.0000	−4.107**	0.0482	−13.97***	0.0000
Observations	1,869		1,511		1,869		1,511	
Number of ID	77		77		77		77	
AR (1)	−2.8849	0.0046	−2.6118	0.0091	−3.0664	0.0002	−2.0983	0.0376
AR (2)	−1.5982	0.1357	−1.0933	0.7317	−0.3982	0.6935	−0.4276	0.6742
Hansen	24.0893	0.5714	15.7729	0.7892	37.4628	0.0898	27.3274	0.6196

*The Hausman test of the fixed pooled model was selected. Furthermore, ***, **, and * point out significance at 1%, 5%, and 10% levels, respectively.*

migrated to developing countries because there are weaker environmental rules and regulations, which could be harmful to environmental quality (Usman et al., 2021a). The policymakers should encourage foreign direct investment to only encourage those investors through globalization that brings eco-friendly technologies and pollution-free industries. The sign of financial development (FD) appears consistently positive and has a significant impact on CO_2 emission. The value of the coefficient discloses that a 1% increase in FD leads to a 0.293% increase in CO_2 emission. This finding is consistent with that of Jiang and Ma (2019) who showed a positive relationship between financial development and CO_2 emission. Sadorsky (2010) investigated that FD increases CO_2 emission due to the following reasons: expanding financing channels to allow the enterprises to get lending capitals with minimum costs, which make possible their development of the production scale such as renting more equipment and building a new production line that may increase carbon emission. However, Shoaib et al. (2020) explored those two channels (stock market and Investment) through financial development on the environment. Initially, the stock market channel provides less financing costs for installation/fixing of heavy industries and enhances inefficiency of energy utilization, which leads to increased environmental degradation. Second, the investment channel enhances the economic growth through increased income capital formation, and it demands fossil fuel energy which could be harmful to environmental efficiency, hence having a positive influence on CO_2 emissions.

According to **Table 6**, the coefficient of FDI comes into sight with a consistently significant and positive impact on CO_2 emission. Specifically, a 1% augmentation in FDI leads to a 0.101% rise of the environmental pollution in the region that

conforms to the existence of the PHH. This outcome is also in line with that by Balsalobre-Lorente et al. (2019), who revealed that FDI positively impacts CO_2 emission in the long run. The possible reason is developing countries using dirty industries for generating economic growth, which mainly depends on conventional energy sources such as coal power and oil; besides that, low environmental regulations lead investors set to polluted industries due to trade openness in that countries, hence causing greater amount of pollution. The trade coefficient appears positive and has an insignificant effect on CO_2 emission; it is noted that a 1% change in TRD leads to a 0.139% enhancement in the pollution level. This result is in line with the study of Destek and Sinha, (2020) who show a positive impact on CO_2 emission. Developing nations adopt such trade openness policies to ensure the interest of environmental quality and to minimize the risk for global warming (Usman et al., 2021d). It is extended that free trade is not only responsible for mitigating CO_2 emissions by adapting environmental law and carbon tax. Developing nations should focus on encouraging trade of environmentally friendly technologies and green financing approaches, which could be helpful in reducing ecological hazards. The urban population (URB) coefficient appears negative and insignificant on CO_2 emissions. The value of the coefficient discloses that a 1% increase in URB leads to a 0.0502% decrease in CO_2 emission. However, the coefficient of GCF appears positive and insignificant on CO_2 emissions. The graphical presentation of empirical findings is presented in **Figure 4**.

As presented in model (1), **Table 6** shows that the coefficient of ICTs was negative and insignificant on CO_2 emission at the 5% level, but TGL was found significant and positive at the 1% level. However, the innovation of the study, the interaction between TRD and ITCs, was a positive and considerable blow on carbon emissions at the 5% level. This can be recognized to the truth that ICT equipment shift through trade openness could increase CO_2 emission. As represented in model (2), the coefficient of ICTs and TGL, we can readily notice that the coefficient of TGL was greater but more closely with each other, while the coefficient of ICTs is large than model (1). According to model 2, the positive coefficient of the interaction term ($LICT_{mobile}$*LTRD) shows that ICT positively moderates the association between TRD in enhancing CO_2 emissions, which means that ICT decreases the environmental quality due to promotion of TRD. Furthermore, it is surprising to find that the interaction term between FD and ICTs was positive but significant on CO_2 emissions. It means that investment in ICTs could increase CO_2 emission. In model 3), the interaction terms between FD, TRD, and ICTs were positive, but we can note that due to interaction terms, the coefficient of ICTs and TGL was less as compared to model 2) but greater as compared to model (1).

5.1 Robustness Checks

The earlier empirical investigation demonstrated that ICTs could decrease CO_2 emission, while TGL can increase CO_2 emission in developing economies; in this part, we performed robustness checks to confirm the reliability of the abovementioned empirical findings. We chose the two-step system GMM with the alternative proxy of Information and communication technologies, ICT_{int} (internet users per 100 people) over the period 1995–2016 for the robustness tests. **Table 7** shows that ICTs had a negative impact, but the TGL has a positive impact on the CO_2 emission, which was relatively analogous to the abovementioned experiential findings. Furthermore, the interaction terms between ICTs, FD, and TRD results were also similar to the abovementioned empirical finding. Finally, our robustness test had verified the stability of the abovementioned estimated findings.

5 CONCLUSION AND POLICY IMPLICATION

The major purpose of this econometric research is to investigate the effect of information and communication technologies (ICTs) on CO_2 emission based on the data of 77 developing economies over the period 1990–2016. After applying OLS regression and generalized method of moments (GMM), our empirical results demonstrate that the increase in mobile cellular subscriptions (ICTs) likely reduces CO_2 emission. In other word, mobile cellular usage and ICTs positively contribute to environmental quality. In addition, we further investigated the effect of overall globalization (TGL) on CO_2 emission. Following the estimated results, we accomplished that overall; globalization could enhance carbon emissions from developing economies. Primary studies mainly focused on the dynamic link between ICTs and CO_2 emission that integrate trade and financial development. However, previous studies ignored the interaction of international trade and financial development with ICTs on CO_2 emissions, which is declared in this empirical study. The finding recommends that the moderating effect of international trade and financial development deepens the negative role of ICTs in CO_2 emission. The robustness checks verified that the beyond empirical results are consistent and efficient.

It is evident from the abovementioned discussion that ICTs can play an important role in reducing carbon emission by decreasing the expenditures on transport and dematerialization and increasing commercial activities by giving e-communication services between the buyer and seller, which expand the business hub. It also helps increase the number of healthy and educated persons through e-learning and e-health programs in secluded areas of developing states. There is a need to develop policies to encourage investment in the ICT sector. The policymaker should increase the usage and access of ICT equipment in industries, education, and business sectors that will be helpful in reducing pollution and environmental degradation. It is anticipated that ICT implementation should minimize transportation costs and help reduce CO_2 emissions. The developing economies should encourage smart ICT infrastructure through FDI. There is also a need to advance economic policies to promote investment in the ICT sector. Easy access to the bank credit must be confirmed for those firms that inspire the green equipment of the ICT sector to certify effectiveness by consuming less energy. Moreover, developing economies can upgrade their industrial structure and increase economic green productivity through ICTs. The policymakers should

dent policies to grow smarter cities, transportation systems, electrical grids, industrial processes, and energy-saving gains *via* ICT on a macro level. Furthermore, policymakers should implement authoritarian rules and regulations (R&R) to both domestic and foreign companies to put into practice eco-friendly manufacturing organizations. The present research also suggests that the central authority and their respective governments should give confidence to exporter businesses to increase utilization of cleaner and alternative energy resources and efficient energy combustion. In addition, the inducement should be given to tourism companies and tourism hotels to increase the share of alternative and cleaner energy utilization contained by the energy mix procedure. Furthermore, checking the environmental impact of all ICT index (the individual by means of the Internet, fixed telephone contribution, fixed telephone subscription, active mobile-broadband contribution, and fixed-broad subscription) and its impact on the CO_2 emission is another interesting area of future research. Policymakers of developing nations recommended that the government should make an investment in the public/private education sector because skilled laborers boost economic growth and also improve the environmental quality.

One of the important limitations of the study is that we could not find the institutional quality and ICT on environmental pollution; we left this question for future research. In addition, this study does not investigate the Environment Kuznets curve (EKC) hypotheses of CO_2 emissions with these analyzed variables. In the future, a similar study can be augmented to analyze developed economies by using the advanced nonlinear ARDL method.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization, AJ, MU, and JK; methodology, AJ and MU; software, AJ and MU; formal Analysis, AJ, JK, and MU; data Collection, AJ, MU, and JK; writing—original draft preparation, AJ, MU, FR, BY, and JK; revised draft, MU, AJ, and BY; writing—review and editing AJ, MU, FR, JK, BY, and SL; supervision, BY; project administration, JK and FR. All authors have read and agreed to the published version of the manuscript.

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APPENDIX

TABLE A1 | Developing countries list.

Algeria	China	India	Mali	Paraguay	Togo
Angola	Colombia	Indonesia	Mauritania	Peru	Tunisia
Argentina	Congo, Rep	Iran	Mauritius	The Philippines	Turkey
Bahrain	Costa Rica	Israel	Mexico	Qatar	The UAE
Bangladesh	Ecuador	Jamaica	Morocco	Rwanda	Venezuela, RB
Benin	Egypt, Arab Rep	Jordan	Mozambique	Saudi Arabia	Vietnam
Bolivia	El Salvador	Kenya	Myanmar	Senegal	Zambia
Botswana	Gabon	Kuwait	Nepal	Sierra Leone	Zimbabwe
Brazil	Gambia, The	Lesotho	Nicaragua	Singapore	
Burkina Faso	Ghana	Liberia	Niger	South Africa	
Burundi	Guatemala	Madagascar	Nigeria	Sri Lanka	
Cameroon	Haiti	Malawi	Pakistan	Sudan	
Chile	Honduras	Malaysia	Panama	Thailand	

Source: Country classification (U.N, classification, 2019).