ORIGINAL RESEARCH
published: 09 June 2022
doi: 10.3389/fenvs.2022.875932

Do Information Communication Technology and Economic Development Impact Environmental Degradation? Evidence From the GCC Countries

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The environmental variations compel global countries for restructuring economic growth policies to ensure reliable energy usage. Ecological sustainability is a leading concern of the world for adequate and smooth survival of human beings. The inefficiency of technology is a focal hindrance to attaining the sustainable environment goal. This research aims to probe the cointegration and causal relationship among information communication technology, CO_2 emission, economic development, trade, and total population for GCC countries, namely, the United Arab Emirates, Saudi Arabia, Qatar, Oman, Kuwait, and Bahrain, from 2000 to 2018. This research approached the unit-root tests, cointegration test, and FMOLS and DOLS test to determine stationarity of data series, cointegration relationship among variables, and the short- and long-run relationship among variables, respectively. The results of the analytical procession by employing FMOLS and DOLS confirmed that CO_2 emission, ICT, and ED are positively significant, while POP was negatively substantial at a 1% level. No relation has been observed between trade and CO_2 emission. The long-run relationship among variables is confirmed by FMOLS and DOLS analyses. A negative relationship between population growth and CO_2 emission is observed. It is ideal for enhancing environmental sustainability by awareness of people's importance to the environment. The GCC countries should transform or divide their economic growth sectors instead of only the fossil fuel sector. This research also enlightened the way to reduce environmental destruction by the attraction of foreign investments in other sectors compared to entire fossil fuel industries, and the information communication technologies also move toward green technology using environmentally friendly energy resources.

Keywords: environmental sustainability, ICT, economic growth, GCC countries, FMOLS, DOLS

OPEN ACCESS

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Specialty section:
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

Received: *14 February 2022*
Accepted: *25 April 2022*
Published: *09 June 2022*

Citation:
Al-shammari ASA, Muneer S and Tripathi A (2022) Do Information Communication Technology and Economic Development Impact Environmental Degradation? Evidence From the GCC Countries. Front. Environ. Sci. 10:875932. doi: 10.3389/fenvs.2022.875932

INTRODUCTION

The Gulf Cooperation Council (GCC) countries suffer from severe environmental challenges, i.e., biosphere, hydrosphere, lithosphere, and atmospheric pollution. The last few years are evidence of environmental pollution, particularly military conflicts, constructive infrastructure, and demolition debris. Global warming has changed the picture of the globe, and this alteration comes from climate change. The increasing behavior of radioactive greenhouse gases, especially CO_2 emission in the atmosphere, is the leading cause of global environmental destruction (Warrick, 1988). The WWF/ecological footprint report "Our Living Planet," a visualizer of 150 countries' ecological states, declared that the UAE was putting the most significant footprint globally. The per capita income of the UAE countries is becoming the reason for placing heavy stress on the planet. The per person (hectares/person) total ecological footprint (TEF) for UAE is 1.8, and the aggregate figure was 11.9 global ha/person (hectares/person). In comparison, Kuwait and the Kingdom of Saudi Arabia also have enormous footprints—7.6 and 4.6 international ha/person, respectively.

The conventional monotonic reliance on the consumption of non-renewable fossil fuels has eventually generated a global agreement for guaranteeing energy security, while also minimizing the environmental consequences of fossil fuel combustion. Historically, such a heavy reliance on fossil fuels has resulted in the rapid depletion of their reserves, putting global energy sustainability goals in jeopardy. Furthermore, the finite nature of these primary energy resources has contributed to the unreliability of secondary energy supply (Kasayanond, 2019; Kunkel and Matthess, 2020). One possible explanation for this phenomenon is that worldwide power generating volumes frequently lag behind comparable installed capacity, owing to severe primary energy supply constraints. Aside from the continued depletion of non-renewable energy (NRE) reserves, rising global energy demand has also contributed to global energy crises. Furthermore, in particular, developing economies have been steadfastly unable to meet their distinct energy demands with domestic energy supplies. As a result, energy resource diversification is widely regarded as a vital energy sector reform for guaranteeing global energy security (Kasayanond, 2019; Kunkel and Matthess, 2020). The energy inputs are undisputedly necessary for economic expansion and achieving economic welfare. However, incorporating renewables into energy systems is critical to ensure the long-term viability of socioeconomic and environmental growth. Furthermore, improving energy use efficiency, particularly in third-world countries, has become a top priority.

The word "environmental sustainability" refers to preserving natural resources and the continuous improvement of environmental quality (Kasayanond. 2019; Murshed et al., 2020). As a result, the United Nations (UN) has asked for international commitments from global stakeholders to ensure greater access to affordable, reliable, sustainable, and contemporary energy supplies worldwide, taking into account global energy security and environmental sustainability concerns (Khan et al., 2020; Murshed, 2020; Gul et al., 2021). In this regard, the seventh Sustainable Development Goal (SDG 7) aimed to significantly increase the share of renewables in global final energy consumption while also doubling energy-use efficiencies. However, multidimensional constraints often obstruct the achievement of these targets, particularly in developing economies; among these, technological redundancy in these economies is frequently hypothesized to play a negative role in bottlenecking the achievement of energy and environmental sustainability targets (Mirza et al., 2009; Urmee et al., 2009).

This research aims to contribute to the existing literature in divergent aspects. This research focused on the impact of information communication technology on environmental sustainability in GCC countries. In the last 5 years, a significant change has been observed in traditional fossil energy sources, digitalization, renewable energy, and climate change. The GCC group of countries also moves toward energy diversification to overcome the toxic emissions and make a positive contribution to environmental quality with research and initiative in digitalization, renewable energy, and economic growth. This research will help measure the change and provide fundamental structural changes to enhance the quality of the environment with the growth of the economy and global competencies by acknowledging digitalization. The cointegration and causal relationship between variables are determined by employing the FMOLS and DOLS methods. The existing literature usually focused on South Asian countries (Murshed et al., 2020) with trade openness and renewable energy. This research purposely observed GCC countries observing the potential impact of ICT on environmental sustainability and economic growth. The CO_2 emission is considered an ecological representative in GCC countries, selected based on previous studies with confirmation that CO_2 emission is an aggregated top portion of greenhouse gas emissions globally (Pachauri et al., 2014; Murshed et al., 2020).

LITERATURE REVIEW

The traditional reliance on environmentally unfriendly non-renewable energy (NRE) resources to meet global energy demand has elicited international consensus for achieving socioeconomic and environmental sustainability, mainly through optimal use of the relatively cleaner renewable energy (RE) alternatives (Khan et al., 2020; Murshed, 2020). The constant reliance on the burning of NRE resources has resulted in overexploitation of these finite resources, putting global energy security in jeopardy to a great extent. In addition, the poor supply of primary NRE resources has harmed the reliability of secondary energy supplies, particularly electricity, forcing global power plants to run at or below their installed capacity (Agyekum et al., 2021; Iqbal et al., 2021). Simultaneously, a sustained increase in global energy demand has exacerbated the worldwide energy crisis. Today, humanity's two greatest obstacles are a lack of economic sustainability and environmental degradation (Aye and Edoja, 2017). Technology usage causes environmental degradation to consume resources, continuous economic development (GDP), and energy consumption (Huesemann and Huesemann, 2008). The current millennium will reduce distances of geographic boundaries and closer up the sociocultural values of the world by using information communication technology (Nasir and Kalirajan, 2016; Latif et al., 2018; Mohsin et al., 2021b). The paradox of wealth and poverty is the creation of information communication technology (ICT) which has presented the two opposite phases of human life, i.e., a bridge between individuals and isolation. The dramatic transformation of the world via information communication technology has tied people and communities, enhanced their standard of life, and increased global opportunities, modern facilities, and up-trending productivity in the last quarter of the 21st century (Avom et al., 2020; Khan et al., 2020; Naseem et al., 2021a). The scholars and researchers consider the contribution of ICT to economic growth, gross domestic product (GDP), the better infrastructure of organizations, international trade, financial structure, employment opportunity, and systematic democracy in people of a country (Bon et al., 2016; Sarfraz et al., 2022). Undoubtedly, the ICT infrastructure has enhanced the competition for attracting foreign direct investment to reshape the growth map of the globe (Al Asbahi et al., 2019; Sun et al., 2020; Yang et al., 2021).

The developing countries have been contemplating the significant impact of FDI on economic growth and pillars of a positive picture of an individual country's growth since 1980. The modern monetary theory also confirmed the position of FDI as a catalyst and engine of economic growth aggregately and per capita growth of a country. The economic boom and energy-intensive sector is information communication technology (ICT), i.e., computers, laptops, and mobile devices, which emitted 2% of greenhouse gases worldwide. The positive and negative effects of ICT are still under discussion. The theoretical approach has approved that ICT contributes to an up-trending graph of CO_2 emission in terms of ICT machinery production, energy consumption and energy-based devices, and recycling of electronic wastage. Smarter cities, transportation systems, the grid of electricity, industrial procession, and energy-saving can help reduce CO_2 emissions by environmentally friendly information communication technology (Lee & Brahmasrene, 2014; Awan et al., 2021). The relationship among ICT, CO_2 emission, and economic growth is examined by designing the panel of nine ASEAN (Association of Southeast Asian Nations) countries from 1991 to 2009. A significant positive relationship between ICT, economic growth, and CO_2 emission was observed (Zhang et al., 2021; Irfan et al., 2022; Zhao et al., 2022). A bidirectional relationship is also confirmed between economic growth and CO_2 emission (Avom et al., 2020; Khan et al., 2020; Murshed, 2020; Mohsin et al., 20201b). A bulk of the research was conducted to determine the relationship between economic growth and CO_2 emission in a few decades. Globally, many countries are antagonized with the significant challenge of developing the economy and sustainability of the environment in parallel (Tucker, 1995; Chang, 2010; Fodha & Zaghdoud, 2010; Niu et al., 2011; Sarfarz et al., 2022; Mohsin et al., 2021a). A negative long-run relationship between GDP and CO_2 emission since the low-carbon emitted technology will allow output levels to be met at lower levels of CO_2 emissions in the long term (Naseem et al., 2019; Mohsin et al., 2022).

The short-run positive link between GDP and CO_2 emission is observed with rapid production growth and high energy consumption for technology use. The estimation of ECM declared that the GDP is negatively related to CO_2 emission and suggested that the low-carbon and environmentally friendly technology can achieve the same production level at lower emissions (Kasperowicz, 2015). Divergent research studies (Tucker, 1995; Chang, 2010; Fodha & Zaghdoud, 2010; Niu et al., 2011) determined the linear relationship between economic growth and environmental destruction. The findings of empirical analysis have acknowledged a causal relationship present among carbon emission, energy consumption, electricity production process, fossil fuels, and growth of GDP. The developing countries do not present a significant connection between CO_2 emission and GDP, while developed countries show a strong association between these variables.

DATA DESCRIPTION

Carbon dioxide (CO_2) emissions, economic development (ED), information communication technology (ICT), trade (TR), and total population (POP) of the Gulf Cooperation Council countries are all examined in this study on an annual basis. From 2000 to 2018, the World Bank (WB) has provided analytical data series retrieved from its website. The World Bank's official website offers data at several scales, which is why the data specifications for this research are presented in **Table 1**.

MATERIALS AND METHODS

The main model of this research is given as follows:

$$\boldsymbol{CO_{2t} = \beta_0 + \beta_1 ICT + \beta_2 ED + \beta_3 TR + \beta_4 POP + \varepsilon_t}, \quad (1)$$

In the aforementioned **Eq. 1**, the sign of delta Δ used for the first difference, while β_0, β_1, β_2, β_3, and β_4 are demonstrated as the independent parameters. The abbreviation of variables in the equation is representative of environmental degradation (CO_2), information communication Technology (ICT), economic development (ED), trade (TR), and total population (POP). ε_t is an error term with respect to time. The analytical process of this research will start to determine the stationarity of the panel data set by using four renowned panel unit root tests (PURTs), i.e., ADF, PP, LLC, and IPS. To obtain the stationarity of the data series, the cointegration technique is used to check the relationship among selected variables. The confirmation of cointegration allowed processing of the data series to determine the long-run elasticities by employing FMOLS. The dynamic OLS (DOLS) is used to observe the short- and long-run dynamic series. The last step of this analytical procession is variance decomposition which will check the cross contribution among all the variables, not only the behavior

TABLE 1 | Variable description used in the model.

Symbol	Explanation	Source
CO_2	CO_2 emissions (metric tons per capita)	World Bank
ICT	Information communication technology (ICT) (% of total goods)	World Bank
ED	GDP (current US$)	World Bank
TD	Trade (% of GDP)	World Bank
POP	Total population	World Bank

TABLE 2 | Unit root test based on individual intercept variables.

Variable	Level				First difference			
	ADF	PP	LLC	IPS	ADF	PP	LLC	IPS
CO_2	9.069	8.364	−1.649**	0.108	23.533**	38.256*	−2.029**	−1.438***
	0.697	0.756	0.050	0.543	0.024	0.000	0.021	0.075
ICT	14.411	20.116***	−1.943**	−1.088	46.651*	97.770*	−4.523*	−4.956*
	0.275	0.065	0.026	0.138	0.000	0.000	0.000	0.000
ED	18.128	9.435	−3.262*	−1.608***	26.688*	48.850*	−3.934*	−2.724*
	0.112	0.665	0.001	0.054	0.009	0.000	0.000	0.003
TR	23.237**	16.165	−2.761*	−1.985*	36.868*	53.154*	−4.719*	−3.896*
	0.026	0.184	0.003	0.024	0.000	0.000	0.000	0.000
POP	43.898*	6.957	−6.961*	−4.505*	55.796*	45.138*	−7.576*	−5.947*
	0.000	0.861	0.000	0.000	0.000	0.000	0.000	0.000

*Note: *, **, and *** denote 1%, 5%, and 10% level of significance.*
ADF, augmented Dickey–Fuller test.
PP, Phillips–Perron test.
LLC, Levin–Liu–Chu test.
IPS, Im–Pesaran–Shin test.

TABLE 3 | Cointegration tests.

	Within-dimension	Between-dimension
Panel v-statistic	0.994	—
	0.160	—
Panel rho-statistic	2.169	2.845
	0.985	0.998
Panel PP-statistic	−5.293*	−5.919*
	0.000	0.000
Panel ADF-statistic	−5.127*	−4.133*
	0.000	0.000

*Note: *, **, and *** denote 1%, 5%, and 10% level of significance.*

toward CO_2 emission (Streimikiene & Kasperowicz, 2016; Khan et al., 2019; Mohsin et al., 2020; Naseem et al., 2020).

Panel Unit-Root Tests

The panel unit root tests were used to investigate the stationarity variable under the null hypothesis of a unit root in a series. It was critical to identify the problem of spurious correlations. Generally, the intercept, constant, and trend are used to check the stability of time series with the following equations:

$$\Delta Y_{it} = \delta Y_{it-1} + \mu_{it}, \tag{2}$$

$$\Delta Y_{it} = \alpha + \delta Y_{it-1} + \mu_{it}, \tag{3}$$

$$\Delta Y_{it} = \alpha + \beta T + \delta Y_{it-1} + \mu_{it}, \tag{4}$$

Equation 2 is the equation without a constant and trend. The inclusion of α in **Eq. 3** and $\alpha + \beta T$ in **Eq. 4** declares their scaling with a constant and with a constant and trend, respectively. The hypothetical approach of the unit-root test is: null hypothesis = 0; alternative hypothesis ≠ 0. The stationarity of the data series should be attained after taking the first difference for further process. In this research, four unit-root tests, i.e., augmented Dickey–Fuller (ADF), Phillips–Perron (PP), Levin–Liu–Chu (LLC), and Im–Pesaran–Shin (IPS), are employed (see **Figure 1**).

Cointegration Test

The confirmation of variable sequence stability indicates the Pedroni intercept and trend coefficient heterogeneous panel cointegration test (Pedroni, 1999; Pedroni, 1999). The Pedroni–Engle–Granger-based cointegration test regression equation is as follows:

$$CO_{2it} = \alpha_i + \delta_i t + \beta_1 ICT_{it} + \beta_2 ED + \beta_3 TR_{it} + \beta_4 POP_{it} + \varepsilon_{it}, \tag{5}$$

The deterministic trend of each country is represented by α_i, δ_i; and the residuals as deviations from the long-run relationship are represented by ε_{it}. β_1 is the coefficient of information communication technology, β_2 for economic development, β_3 for trade, and β_4 for population. The residuals are computed under the null (no cointegration) and alternative (cointegration) hypotheses. $\varepsilon_{it} = I(1)$ and $\varepsilon_{it} = I(0)$, respectively. The integration of regression's residuals at first difference I(1) is computed by applying the auxiliary regression. The auxiliary regression is presented as follows:

TABLE 4 | Estimated FMOLS and DOLS.

Regressor	Fully modified OLS			Dynamic OLS		
	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
ICT	0.031*	0.007	0.000	0.025*	0.009	0.010
ED	0.192*	0.036	0.000	0.189*	0.052	0.001
TR	0.014	0.090	0.880	0.031	0.132	0.815
POP	−0.281*	0.054	0.000	−0.237*	0.073	0.002

*Note: *, **, and *** denote 1%, 5%, and 10% level of significance. OLS, ordinary least square.*

TABLE 5 | Variance decomposition of CO_2 emissions.

Period	SE	Ln CO_2	Ln ICT	Ln ED	Ln TD	Ln POP
1	0.048	100	0.000	0.000	0.000	0.000
2	0.069	98.265	0.016	0.500	0.591	0.627
3	0.083	95.977	0.440	0.604	0.916	2.064
4	0.094	93.003	1.243	0.586	0.986	4.182
5	0.104	89.233	2.413	0.587	0.928	6.841
6	0.113	84.666	3.996	0.653	0.829	9.857
7	0.121	79.449	5.966	0.823	0.729	13.033
8	0.129	73.829	8.211	1.135	0.643	16.181
9	0.136	68.081	10.575	1.615	0.581	19.147
10	0.144	62.449	12.907	2.269	0.553	21.823

$$\varepsilon_{it} = p_i\varepsilon_{i,\,t-1} + \mu_{it} \; OR \; \varepsilon_{it} = p_i\varepsilon_{i,\,t-1} + \sum_{j=1}^{p_i} \psi_{ij}\Delta\varepsilon_{i,t-j} + v_{it}, \quad (6)$$

Two alternative hypothetical frames are determined by the Pedroni cointegration, i.e., within-dimension $(p_i = p) < 1$ for all i (homogenous) and between-dimension $p_i < 1$ for all i (heterogeneous). The alternative hypothesis of within-dimension is a panel statistics, while the between-dimension is considered a group statistics test (Kao, 1999; Apergis and Payne, 2009; Apergis and Payne, 2015). Pedroni has seven asymptotically distributed statistics as ordinary, normal panel cointegration, i.e., P-v, P-rho, P-ADF, and P-PP for within-dimension and P-rho P-ADF, and P-PP for between-dimension.

FMOLS and DOLS Estimator

After employing panel cointegration to quantify parameters, McCoskey and Kao (1998) and Phillips and Moon (1999) developed the FMOLS. The OLS term measures the asymptotical biases. The FMOLS balanced panel framework is used to determine the long-run relationship between non-stationary variables (Kauffman & Riggins, 2012; Latif et al., 2018). Traditional OLS estimation is used to eliminate serial correlations in endogenous variables. The OLS estimator confirmed the significant skewness with N and T terms. The FMOLS enables the OLS panel setup to be extended as well as dynamic heterogeneity (Pedroni, 1999). The FMOLS estimator is as follows:

$$\beta^*_{NT} - \beta = \left(\sum_{i=1}^{N} L_{22i}^{-2}\sum_{i=1}^{T}(\chi_{it} - \bar{\chi}_{it})^2\right)\sum_{i=1}^{N} L_{11i}^{-2}L_{22i}^{-2}\left(\sum_{i=1}^{T}(\chi_{it} - \bar{\chi}_{it})\mu^*_{it} - T\hat{\gamma}_t\right), \quad (7)$$

$$\mu^*_{it} = \mu_{it} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}}\Delta\chi_{it},\ \hat{\gamma}_i = \hat{\Gamma}_{21i}\hat{\Omega}^0_{21i} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}}\left(\hat{\Gamma}_{22i}\hat{\Omega}^0_{21i}\right),\ \hat{L}_i \text{ was lower triangulation of } \hat{\Omega}_i,$$

The asymptotic distribution of FMOLS $\beta_{FMOLS} = [\sum_{i=1}^{N}\sum_{t=1}^{T} X_{it}X_{\overline{it}}^{\prime}]^{-1}(\sum_{i=1}^{T}(\chi_{it} - \bar{\chi}_{it})\mu^*_{\overline{it}} - T\hat{\gamma}_t)$ and DOLS $y_t = a + bX_t + \sum_{i=-k}^{i=k} \varnothing_i \Delta X_{t+i} + \varepsilon_t$ estimator is the same, which performed and confirmed the consistency of outcomes.

EMPIRICAL RESULTS

The results of the panel unit root tests (PURTs) are presented in **Table 2**, which confirmed the stability of the data series. Four unit root tests are applied to the selected data span of variables for assurance of result accuracy. The data series have gone through level and first difference by getting the mixture of results (Mohsin et al., 2021a). Some tests confirmed significance at level, but some tests denied it while all panel unit root tests show their significance at 1%, 5%, and 10% at first difference. The mixture of results is provided with a feasible and perfect condition to implement the cointegration test.

Table 3 shows the results of the Pedroni–Engle–Granger-based cointegration test. According to Engle and Granger (1987), the residuals of spurious regression were performed at first difference integration I(1) to examine variable integration. The cointegration of variables was performed at the first difference I(1), and then residuals should be integrated at level I(0) and vice versa (Mohsin et al., 2021b). Pedroni (1999) extended the Engle–Granger framework with the inclusion of two alternative hypotheses, i.e., within-dimension and between-dimension. The PP and ADF tests are significant at 1% under within-dimension and between-dimension. These alternative hypotheses in Pedroni cointegration are used to check homogeneity and heterogeneity among the variables.

The results of FMOLS and DOLS are presented in **Table 4**. Purposely, the FMOLS is used to check the long-run elasticity of the panel, and DOLS is applied for robust check of a small sample. The FMOLS eliminated the problems caused by the long-run correlation between the cointegration equation and stochastic regressor innovation. The leading feature of FMOLS is having an asymptotically unbiased estimator (Phillips and Hansen, 1990; Jamil et al., 2021; Ivascu et al., 2021). The DOLS is used to cross-

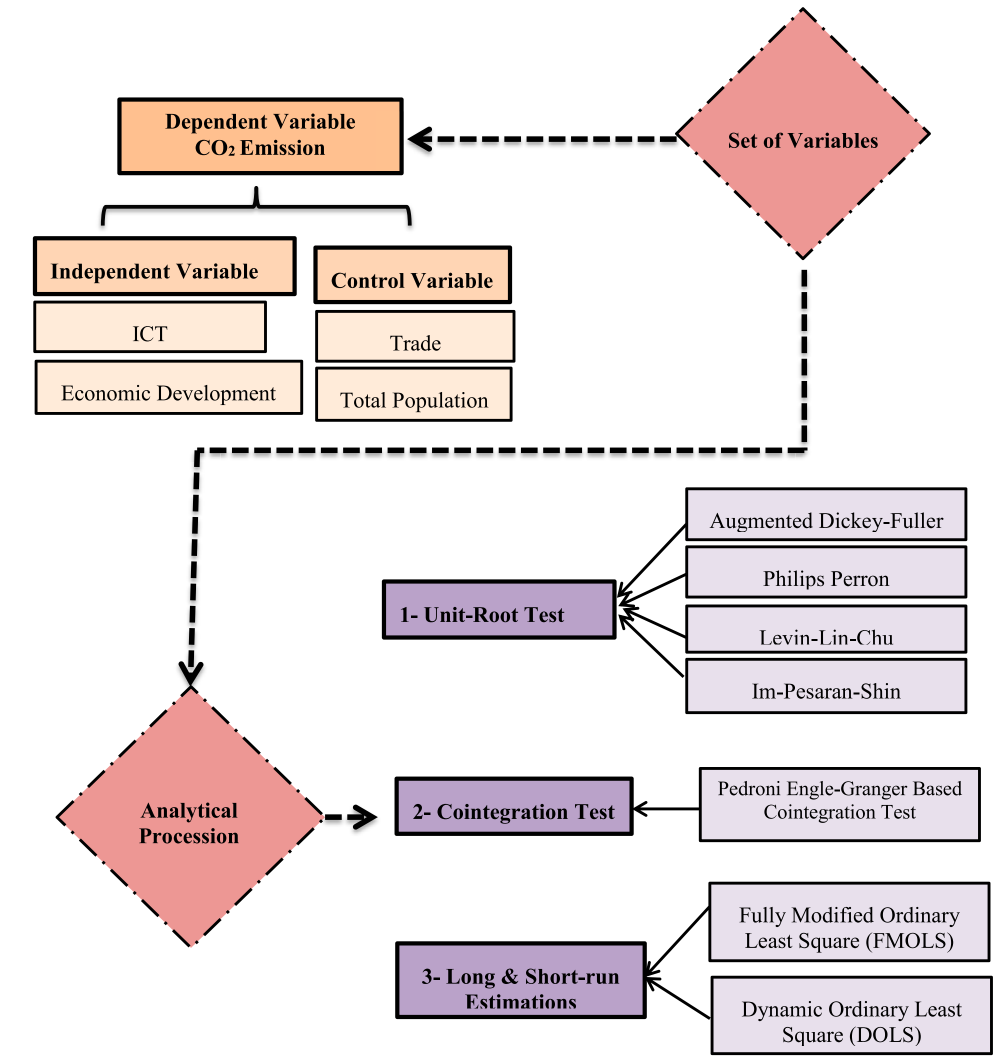

FIGURE 1 | Flowchart of variables and analytical techniques.

check OLS and FMOLS, and the endogeneity biases are also controlled by it. The FMOLS and DOLS estimators provide similar results for the variables, i.e., ICT, ED, and TR, across all sample countries regarding statistical significance. Still, the magnitudes of the predicted coefficients are slightly different.

Except for trade, all coefficients are statistically significant at the 1% significance level. The results declared a positive relationship between CO_2 emission, information communication technology, and economic development, while a negative relationship was confirmed for trade by FMOLS and DOLS. According to the results of FMOLS, 1% increase in ICT and ED will increase CO_2 emission by 0.0306% and 0.1920% , respectively, while a 1% increase in total population decreases CO_2 emission by 0.2809%. The total population decreases the CO_2 emission because people are beginning to realize the global environmental situation, and they are trying to reduce their carbon footprint as an individual body. They are more conscious of environmentally friendly technologies. The DOLS also confirmed the same results as FMOLS that a 1% increase in ICT and ED shows an increasing trend in CO_2 emission by 0.0245% and 0.1889%, respectively. Trade is shown as an insignificant behavior toward CO_2 emission, while a significant negative relationship between the total population and CO_2 emission is observed at a 1% level. In GCC countries, the population and trade are not directly affecting environmental sustainability. The information communication technology is based on energy, and the economic development of GCC countries is also based on oil consumption which are the main sectors of environmental degradation.

Table 5 contains the results of variance decomposition, which is used to determine the contribution of each variable to others or its counterpart (Helmut, 2005; Naseem et al., 2021b). CO_2 emission has shown a downward trend, while information communication technology, economic development, and total population have shown an upward trend. The behavior of trade shows a downward trend. The decomposition analysis results

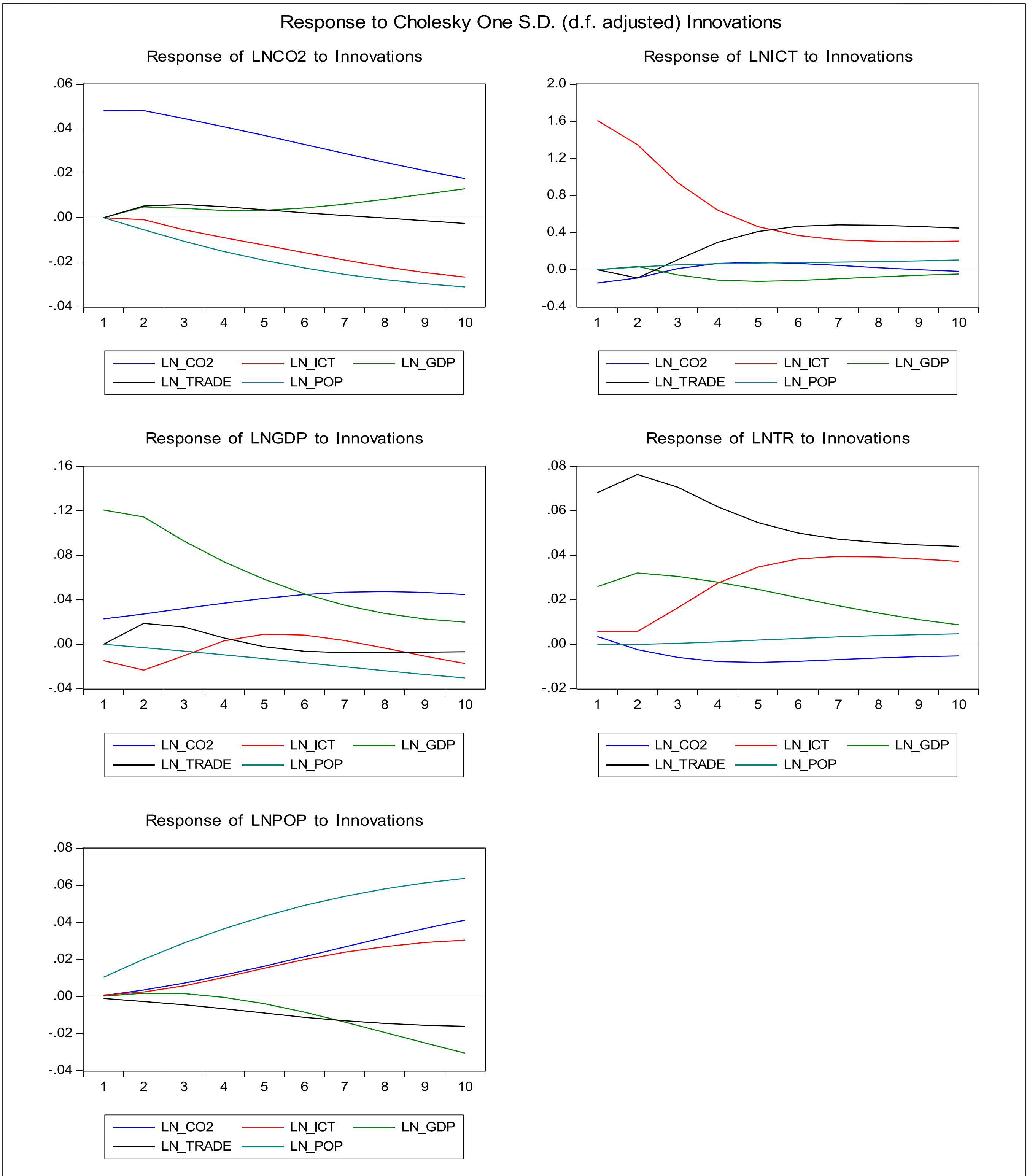

FIGURE 2 | Response to Cholesky One S.D Innovations.

confirmed the reduction in CO_2 emission concerning variability in the rest of the variables. The impulse response is used to measure the impact of one standard deviation shock on an independent variable that causes an upward (downward) reaction in dependent variables in a specific time period. The graphic representations of impulse response are available in

Figure 2. The behavior of individual variables toward other variables is easily visualized in **Figure 2**.

CONCLUSION AND DISCUSSION

This research examined the cointegration and causal relationship among information communication technology, CO_2 emission, economic development, trade, and total population for GCC countries, namely, the United Arab Emirates, Saudi Arabia, Qatar, Oman, Kuwait, and Bahrain, from 2000 to 2018. The cointegration among selected variables was examined by employing FMOLS and DOLS analyses. FMOLS results declared that CO_2 emission, ICT, and ED are positively significant, while POP was negatively substantial at the 1% level. No relation can be observed between trade and CO_2 emission. The long-run relationship among variables is confirmed by FMOLS and DOLS analyses. The population growth of GCC countries was inversely related to CO_2 emission because the people are conscious of environmental sustainability. They focused on environmentally friendly technology and renewable energy used as a replacement for fossil fuels, reducing the footprint of CO_2 emission. There is an increasing behavior of information communication technology and economic development toward CO_2 emission in GCC countries because the energy source of these countries is fuel consumption. The economic growth is also based on fossil fuels which comparatively enhance the CO_2 footprint. The impulse response also confirmed an upward relationship among variables and CO_2 emission, as confirmed by FMOLS and DOLS. The CO_2 emission can be reduced by transforming leading sectors of the economy. Renewable energy, green technology, and the transformation of energy sources compared to fuel consumption can reduce greenhouse gas emissions. As a result of the findings, it was concluded that the efficient utilization of renewable energy would minimize GHG emissions over time. As provided in the study's preceding parts, the prior literature has typically established a positive association between ICT, ED, and CO_2 emissions; however, few studies have examined the relationship between ICT and CO_2 emissions. This research gap was filled for the first time, and the overall link between information and communication technology and CO_2 emissions was negative. In the short run, the connection between ICT and CO_2 emissions for GCC countries was shown to be the same.

Official Environmental Protection Bodies in the GCC Countries

The GCC countries are keenly concerned about environmental protection and the enhancement of ecological preservation. The GCC countries designed divergent international and regional panels to maintain the environmental quality with the growth of the individual sector of the economy. The newly organized agencies, councils, and ministries, especially environmental check and balance, are significantly playing their roles. These institutional bodies have collaborated with governments, researchers, environmentalists, and policymakers by taking part in the decision-making process regarding environmental priorities, challenges, threats, and problems in GCC countries. The institutional bodies with the executive agency working on environmental sustainability in different GCC countries are given as follows:

In Bahrain—the Policy Institution of Environment and Wildlife affairs with the executive agency, the Public Commission for the Protection of Marine Resources, Environment, and Wildlife.

In Kuwait—the Policy Institute of Environment Public Authority with the executive agency, Environment Public Authority.

In Oman—the Council of Ministries' Policy Institute with the executive agency, Ministry Environment and Climate Change.

In Qatar—the Policy Institute of the Council of Ministries (Permanent Commission for Environmental Protection) with the executive agency Supreme Council for the Environment and Natural Reserves.

In Saudi Arabia—the Policy Institute of the Ministerial Committee on Environment with the executive agency, Presidency of Meteorology and Environment (PME).

In UAE—the Policy Institute of the Council of Federation with the executive agency, Federal Environment Agency/Ministry of Environment and Water Resources.

Recommendations, Future Direction, and Limitations

This research suggested that a rapid increase in information communication technology (ICT) and growth of the economy's activities can consequently increase CO_2 emissions. Renewable energy might be more expensive than fossil fuel energy in developed and developing countries, but renewable and environmentally friendly energy resources should be prioritized. Renewable energy and environmentally friendly resources are undoubtedly expensive but they can enhance environmental quality and lower pollution levels. Technically, the expensive renewable and low-carbon-emitted points and subordinate financing activities like reducing pollution and enhancing environmental quality are more beneficial. The inclusion of many factors can raise renewable energy as cost reductions due to renewable energy technologies, dedicated legislative initiatives, improved access to energy resources, environmental concerns, and emerging nations' expanding energy needs.

The Gulf Cooperation Council countries can be attained a sustainable environment by following pedagogical innovation and awareness of low carbon technology. The primary energy source of fossil fuels is decentralized with hydropower, solar power, wind energy, biomass, and geothermal energy. The CO_2 and ultraviolet greenhouse gas emissions are strengthened by fossil fuels and destroy environmental sustainability. The energy-saving and energy conservation program can practically enhance the ecological quality of GCC countries. The future direction of this research should focus on the circular economy's principle and clean energy development mechanisms integrated with renewable energy information communication technologies. The lack of experience in environmental authorities and institutional capacity became the hurdle to implementing most ecological precautions. Many approved policies and structural changings are in the pipeline to improve awareness, protection, and sustainability of the environment. The current need is to enhance the expertise and skillful environmentalists who can apply the new structural changing to attain the goal of green GCC countries. The green technology to enter digital economic growth with no carbon emission protocol should be followed by GCC countries. This research is limited in the methodological perspective, which can be explored in future with the second generation of econometric methodology. The GCC countries should be compared with different groups of countries such as BRICS, G-20, and random global countries.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. These data can be found at: https://databank.worldbank.org/source/world-development-indicators.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

ACKNOWLEDGMENTS

This is to acknowledge that this article is part of a research project number BA-2138 funded by the University of Ha'il, Saudi Arabia.

REFERENCES

Agyekum, E. B., Amjad, F., Mohsin, M., and Ansah, M. N. S. (2021). A Bird's Eye View of Ghana's Renewable Energy Sector Environment: A Multi-Criteria Decision-Making Approach. *Util. Policy* 70, 101219. doi:10.1016/j.jup.2021.101219

Apergis, N., and Payne, J. E. (2009). CO_2 Emissions, Energy Usage, and Output in Central America. *Energy Policy* 37 (8), 3282–3286.

Apergis, N., and Payne, J. E. (2015). Renewable Energy, Output, Carbon Dioxide Emissions, and Oil Prices: Evidence from South America. *Energy Sources B: Econ. Plan. Policy* 10 (3), 281–287.

Asbahi, A. A. M. H. A., Gang, F. Z., Iqbal, W., Abass, Q., Mohsin, M., and Iram, R. (2019). Novel Approach of Principal Component Analysis Method to Assess the National Energy Performance via Energy Trilemma Index. *Energy Rep.* 5, 704–713. doi:10.1016/j.egyr.2019.06.009

Avom, D., Nkengfack, H., Fotio, H. K., and Totouom, A. (2020). ICT and Environmental Quality in Sub-saharan Africa: Effects and Transmission Channels. *Technol. Forecast. Soc. Change* 155, 120028. doi:10.1016/j.techfore.2020.120028

Awan, F. H., Dunnan, L., Jamil, K., Mustafa, S., Atif, M., Gul, R. F., et al. (2021). Mediating Role of Green Supply Chain Management between Lean Manufacturing Practices and Sustainable Performance. *Front. Psychol.* 12, 810504. doi:10.3389/fpsyg.2021.810504

Aye, G. C., and Edoja, P. E. (2017). Effect of Economic Growth on CO2 Emission in Developing Countries: Evidence from a Dynamic Panel Threshold Model. *Cogent Econ. Finance* 5 (1), 1379239. doi:10.1080/23322039.2017.1379239

Bon, A., Akkermans, H., and Gordijn, J. (2016). Developing ICT Services in a Low-Resource Development Context. *Csimq* 9, 84–109. doi:10.7250/csimq.2016-9.05

Chang, S. J., Van Witteloostuijn, A., and Eden, L. (2010). From the Editors: Common Method Variance in International Business Research. *J. Int. Bus. Stud.* 41 (2), 178–184.

Engle, R. F., and Granger, C. W. J. (1987). Co-integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* 55, 251–276. doi:10.2307/1913236

Fodha, M., and Zaghdoud, O. (2010). Economic Growth and Pollutant Emissions in Tunisia: an Empirical Analysis of the Environmental Kuznets Curve. *Energy policy* 38 (2), 1150–1156. doi:10.1016/j.enpol.2009.11.002

Gul, R. F., Dunnan, L., Jamil, K., Awan, F. H., Ali, B., Qaiser, A., et al. (2021). Abusive Supervision and its Impact on Knowledge Hiding Behavior Among Sales Force. *Front. Psychol.* 12, 800778. doi:10.3389/fpsyg.2021.800778

Helmut, L. (2005). *New Introduction to Multiple Time Series Analysis (With 49 Figures and 36 Tables)*. Spinger.

Huesemann, M. H., and Huesemann, J. A. (2008). Will Progress in Science and Technology Avert or Accelerate Global Collapse? A Critical Analysis and Policy Recommendations. *Environ. Dev. Sustain.* 10 (6), 787–825.

Iqbal, W., Tang, Y. M., Chau, K. Y., Irfan, M., and Mohsin, M. (2021). Nexus between Air Pollution and NCOV-2019 in China: Application of Negative Binomial Regression Analysis. *Process Saf. Environ. Prot.* 150, 557–565. doi:10.1016/j.psep.2021.04.039

Irfan, M., Elavarasan, R. M., Ahmad, M., Mohsin, M., Dagar, V., and Hao, Y. (2022). Prioritizing and Overcoming Biomass Energy Barriers: Application of AHP and G-TOPSIS Approaches. *Technol. Forecast. Soc. Change* 177, 121524. doi:10.1016/j.techfore.2022.121524

Ivascu, L., Sarfraz, M., Mohsin, M., Naseem, S., and Ozturk, I. (2021). The Causes of Occupational Accidents and Injuries in Romanian Firms: an Application of the Johansen Cointegration and Granger Causality Test. *Ijerph* 18 (14), 7634. doi:10.3390/ijerph18147634

Jamil, K., Liu, D., Gul, R. F., Hussain, Z., Mohsin, M., Qin, G., et al. (2021). Do remittance and Renewable Energy Affect CO2 Emissions? an Empirical Evidence from Selected G-20 Countries. *Energy & Environ.* doi:10.1177/0958305X211029636

Kao, C. (1999). Spurious Regression and Residual-Based Tests for Cointegration in Panel Data. *J. Econom.* 90 (1), 1–44.

Kasayanond, A. (2019). Environmental Sustainability and its Growth in Malaysia by Elaborating the Green Economy and Environmental Efficiency. *Int. J. Energy Econ. Policy*. 9, 465–547. doi:10.32479/ijeep.8310

Kasperowicz, R. (2015). Economic Growth and CO2 Emissions: The ECM Analysis. *J. Int. Stud.* 8 (3), 91–98. doi:10.14254/2071-8330.2015/8-3/7

Kauffman, R. J., and Riggins, F. J. (2012). Information and Communication Technology and the Sustainability of Microfinance. *Electron. Commer. Res. Appl.* 11 (5), 450–468. doi:10.1016/j.elerap.2012.03.001

Khan, F. N., Sana, A., and Arif, U. (2020). Information and Communication Technology (ICT) and Environmental Sustainability: a Panel Data Analysis. *Environ. Sci. Pollut. Res.* 27 (29), 36718–36731. doi:10.1007/s11356-020-09704-1

Khan, M. W. A., Panigrahi, S. K., Almuniri, K. S. N., Soomro, M. I., Mirjat, N. H., and Alqaydi, E. S. (2019). Investigating the Dynamic Impact of CO2 Emissions and Economic Growth on Renewable Energy Production: Evidence from FMOLS and DOLS Tests. *Processes* 7 (8), 496. doi:10.3390/pr7080496

Kunkel, S., and Matthess, M. (2020). Digital Transformation and Environmental Sustainability in Industry: Putting Expectations in Asian and African Policies into Perspective. *Environ. Sci. Policy* 112, 318–329. doi:10.1016/j.envsci.2020.06.022

Latif, Z., mengke, Y., Danish, L., Latif, S., Ximei, L., Pathan, Z. H., et al. (2018). The Dynamics of ICT, Foreign Direct Investment, Globalization and Economic Growth: Panel Estimation Robust to Heterogeneity and Cross-Sectional Dependence. *Telematics Inf.* 35 (2), 318–328. doi:10.1016/j.tele.2017.12.006

Lee, J. W., and Brahmasrene, T. (2014). ICT, CO2Emissions and Economic Growth: Evidence from a Panel of ASEAN. *Glob. Econ. Rev.* 43 (2), 93–109. doi:10.1080/1226508x.2014.917803

McCoskey, S., and Kao, C. (1998). A Residual-Based Test of the Null of Cointegration in Panel Data. *Econom. Rev.* 17 (1), 57–84.

Mirza, U. K., Ahmad, N., Harijan, K., and Majeed, T. (2009). Identifying and Addressing Barriers to Renewable Energy Development in Pakistan. *Renew. Sustain. Energy Rev.* 13 (4), 927–931. doi:10.1016/j.rser.2007.11.006

Mohsin, M., Jamil, K., Naseem, S., Sarfraz, M., and Ivascu, L. (2022). Elongating Nexus between Workplace Factors and Knowledge Hiding Behavior: Mediating Role of Job Anxiety. *Prbm* Vol. 15, 441–457. doi:10.2147/prbm.s348467

Mohsin, M., Naseem, S., Sarfraz, M., Ivascu, L., and Albasher, G. (2021b). COVID-19 and Greenhouse Gas Emission Mitigation: Modeling the Impact on Environmental Sustainability and Policies. *Front. Environ. Sci.* doi:10.3389/fenvs.2021.764294

Mohsin, M., Naseem, S., Zia-ur-Rehman, M., Baig, S. A., and Salamat, S. (2020). The Crypto-trade Volume, GDP, Energy Use, and Environmental Degradation Sustainability: An Analysis of the Top 20 Crypto-trader Countries. *Int. J. Finance Econ.* doi:10.1002/ijfe.2442

Mohsin, M., Zhu, Q., Naseem, S., Sarfraz, M., and Ivascu, L. (2021a). Mining Industry Impact on Environmental Sustainability, Economic Growth, Social Interaction, and Public Health: An Application of Semi-quantitative Mathematical Approach. *Processes* 9 (6), 972. doi:10.3390/pr9060972

Murshed, M. (2020). An Empirical Analysis of the Non-linear Impacts of ICT-Trade Openness on Renewable Energy Transition, Energy Efficiency, Clean Cooking Fuel Access and Environmental Sustainability in South Asia. *Environ. Sci. Pollut. Res.* 27 (29), 36254–36281. doi:10.1007/s11356-020-09497-3

Murshed, M., Chadni, M. H., and Ferdaus, J. (2020). Does ICT Trade Facilitate Renewable Energy Transition and Environmental Sustainability? Evidence from Bangladesh, India, Pakistan, Sri Lanka, Nepal and Maldives. *Energy Ecol. Environ.* 5 (6), 470–495. doi:10.1007/s40974-020-00190-2

Naseem, S., Fu, G. L., Mohsin, M., Rehman, M. Z.-U., and Baig, S. A. (2020). Semi-Quantitative Environmental Impact Assessment of Khewra Salt Mine of Pakistan: an Application of Mathematical Approach of Environmental Sustainability. *Min. Metallurgy Explor.* 37, 1185–1196. doi:10.1007/s42461-020-00214-9

Naseem, S., Fu, G. L., ThaiLan, V., Mohsin, M., and Zia-Ur-Rehman, M. (2019). Macroeconomic Variables and the Pakistan Stock Market: Exploring Long and Short Run Relationship. *Pac. Bus. Rev. Int.* 11 (7), 621–672.

Naseem, S., Hui, W., Sarfraz, M., and Mohsin, M. (2021a). Repercussions of Sustainable Agricultural Productivity, Foreign Direct Investment, Renewable Energy, and Environmental Decay: Recent Evidence from Latin America and the Caribbean. *Front. Environ. Sci.* 563, 784570. doi:10.3389/fenvs.2021.784570

Naseem, S., Mohsin, M., Zia-Ur-Rehman, M., Baig, S. A., and Sarfraz, M. (2021b). The Influence of Energy Consumption and Economic Growth on Environmental Degradation in BRICS Countries: an Application of the ARDL Model and Decoupling Index. *Environ. Sci. Pollut. Res.* 29, 1–14. doi:10.1007/s11356-021-16533-3

Nasir, S., and Kalirajan, K. (2016). Information and Communication Technology-Enabled Modern Services Export Performances of Asian Economies. *Asian Dev. Rev.* 33 (1), 1–27. doi:10.1162/adev_a_00059

Niu, S., Ding, Y., Niu, Y., Li, Y., and Luo, G. (2011). Economic Growth, Energy Conservation and Emissions Reduction: A Comparative Analysis Based on Panel Data for 8 Asian-Pacific Countries. *Energy Policy* 39 (4), 2121–2131.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., et al. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Ipcc, 151.

Pedroni, P. (1999). Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. *Oxf. Bull. Econ. statistics* 61 (S1), 653–670. doi:10.1111/1468-0084.61.s1.14

Phillips, P. C., and Moon, H. R. (1999). Linear Regression Limit Theory for Nonstationary Panel Data. *Econometrica* 67 (5), 1057–1111.

Phillips, P. C., and Hansen, B. E. (1990). Statistical Inference in Instrumental Variables Regression With I (1) Processes. *The Review of Economic Studies* 57 (1), 99–125.

Sarfraz, M., Mohsin, M., and Naseem, S. (2022). A Blessing in Disguise: New Insights on the Effect of COVID-19 on the Carbon Emission, Climate Change, and Sustainable Environment. *Environ. Sci. Pollut. Res.* 29, 1–12. doi:10.1007/s11356-021-17507-1

Streimikiene, D., and Kasperowicz, R. (2016). Review of Economic Growth and Energy Consumption: A Panel Cointegration Analysis for EU Countries. *Renew. Sustain. Energy Rev.* 59, 1545–1549. doi:10.1016/j.rser.2016.01.041

Sun, H., Pofoura, A. K., Adjei Mensah, I., Li, L., and Mohsin, M. (2020). The Role of Environmental Entrepreneurship for Sustainable Development: Evidence from 35 Countries in Sub-saharan Africa. *Sci. Total Environ.* 741, 140132. doi:10.1016/j.scitotenv.2020.140132

Tucker, R. C. (1995). *Politics as Leadership: Revised Edition*. University of Missouri Press. Vol. 1.

Urmee, T., Harries, D., and Schlapfer, A. (2009). Issues Related to Rural Electrification Using Renewable Energy in Developing Countries of Asia and Pacific. *Renew. Energy* 34 (2), 354–357. doi:10.1016/j.renene.2008.05.004

Warrick, R. A. (1988). Carbon Dioxide, Climatic Change and Agriculture. *Geogr. J.*, 221–233.

Yang, Z., Abbas, Q., Hanif, I., Alharthi, M., Taghizadeh-Hesary, F., Aziz, B., et al. (2021). Short- and Long-Run Influence of Energy Utilization and Economic Growth on Carbon Discharge in Emerging SREB Economies. *Renew. Energy* 165, 43–51. doi:10.1016/j.renene.2020.10.141

Zhang, D., Mohsin, M., Rasheed, A. K., Chang, Y., and Taghizadeh-Hesary, F. (2021). Public Spending and Green Economic Growth in BRI Region: Mediating Role of Green Finance. *Energy Policy* 153, 112256. doi:10.1016/j.enpol.2021.112256

Zhao, J., Patwary, A. K., Qayyum, A., Alharthi, M., Bashir, F., Mohsin, M., et al. (2022). The Determinants of Renewable Energy Sources for the Fueling of Green and Sustainable Economy. *Energy* 238, 122029. doi:10.1016/j.energy.2021.122029

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.