



Human Development Index, ICT, and Renewable Energy-Growth Nexus for Sustainable Development: A Novel PVAR Analysis

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The relevance of information and communication technology to long-lasting human improvement cannot be disregarded in this modern world. From this perspective, this study analyzed the association between information and communication technologies, renewable energy, economic growth, and human development indices considering CO₂ emissions and remittances from 1990 to 2017 in 30 developing countries by using the panel vector autoregressive (PVAR) model. The findings of the empirical investigation point to the considerable favorable relationship between information and communication technology, renewable energy, and economic growth with the human development index. The causality results suggest that there is bidirectional causality between renewable energy and the human development index. In addition, there is unidirectional causality from human development to information and communication technology. However, the study recommends implementing information and communication technology-related policies to trigger renewable energy for sustainable growth and the human development index.

Keywords: ICT, CO₂ emissions, GDP, technological innovations, poverty

INTRODUCTION

Technological development is commonly known as the main driver in the socioeconomic development of the economies. Recently, enhanced technological advancement for information and communication technologies (ICTs) has been the primary transformer for development procedures (World Bank 2017). ICT has modernized societies worldwide and contributes almost in all undertakings of human life, such as energy, promoting economic growth, and improved development processes (Toader et al., 2018; Khan and Ju, 2019). Significant development of ICT has encouraged many researchers to investigate its importance, improvement of organizational effectiveness, and human development practices (Tyworth 2014). ICT plays a vital role in plummeting poverty not only by crafting new income sources and new employment opportunities but also by dropping the expense of needy individuals' admittance to well-being and instruction services (OECD 2010).

Abbreviations: CO₂, carbon dioxide emissions; EU, European Union; GDP, gross domestic product; HDI, human development index; ICTs, information and communication technologies; MTOE, million tons of oil equivalent; KT, kilo tons; 2SLS, two-stage least squares; OECD, Organization for Economic Co-Operation and Development; PVAR, panel vector autoregressive model; RE, renewable energy; R&D, Research and Development; SGD, sustainable development goals.

The major function of ICT for sustainable development cannot be ignored in the economics literature. The ICT industry is an imperative aspect of enduring development from an integrated perspective, as reported by international organizations like the United Nations, the International Telecommunications Union, the Organization for Economic Co-Operation and Development (OECD), and the World Bank (Toader et al., 2018). Moreover, the sustainable development notion covers the complex development of civilization from numerous perspectives such as economic, social, ecological, political, cultural, and spiritual, and all these constituents are crucial aspects that aim to accomplish elegant, sustainable, and inclusive growth (Azam et al., 2021). However, concerning the effect of ICT on energy consumption and the environment is an extensive argument. The energy is being produced and consumed by all sectors of technology including aerospace, the construction industry, the transportation industry, farming, mining, and the ICT sector. Recently, there has been a greater emphasis on universal environmental apprehensions about the looming threat of environmental change and an 'Earth temperature boost' (Zhang et al., 2021) (Kirikkaleli D. and Adebayo T. S., 2021, Kirikkaleli Dervis and Adebayo Tomiwa Sunday, 2021). The broad measure of carbon dioxide (CO₂) outflows is quickly growing, provoking CO₂ discharges because of the gigantic utilization of non-renewable energy sources around the world.

Under such circumstances, ICT can play a fundamental role in uplifting technological constraints and facilitating the renewable energy phenomenon in tandem (Azam et al., 2021). Sustainable power assets have recently gained a great deal of significance because of the threat of depleting power resources that harm the climate. ICT evolution extensively persuades economic amplification and augments fuel efficiency and development potency by bolstering technology dispersion and modernism, boosting demand, and reducing invention charges (Solarin et al., 2019).

The United Nations sustainable development goals (SDG) proclamation highlights the importance of lowering ambient air pollution globally, restricting traditional energy's share of the energy mix and supplementing sustainable power sources. As a result, multiple nations are attempting to devise renewable energy solutions to regulate environmental deprivation to meet SDG's goals. As a result, it is projected that state power schemes will be aligned with the aims of upgrading environmental prominence and assuring long-term evolution. To achieve these goals, however, it is critical to support technological breakthroughs and technology transfer through global trade (Liddle 2018; Shahbaz and Sinha 2019), particularly from the standpoint of poor regions. Under these circumstances, ICT is vital in delivering technical services for sustainable economic development in both developed and developing countries.

Why did we select developing countries as the focus of our research? Developing countries are open nations that have swiftly incorporated poor economic growth, a low standard of living, and the lack of investment and technology. Recently, more than 170 developing nations are bestowed with natural resources, but low levels of growth and foundations of innovation inaugurate ineffective utilization of energy (X. Zhang et al., 2019). Over the past few decades, a large amount of energy has been splurged on economic development in developing countries, engrossing

almost 74% in the period between 2005 and 2030. Furthermore, the situation of the human development index is precarious in these countries. Educational disparity and rising global income are the key reasons to delay human development growth. Furthermore, these countries have huge and growing populations which cause heavy pressure on the atmosphere.

With this backdrop, given the potential of ICT in terms of availability of energy supply and economic development stability, establishing empirical analysis on the links between ICT, renewable energy growth, and human development index is critical for incorporating CO₂ emissions and remittances in the context of developing countries. However, the goal of this study is to address this issue, which is still understudied. More precisely, with three contributions, we particularly fill a gap in the literature.

The fundamental contributions of this study are threefold: first, this is the first study of its kind in the context of developing countries, with the latest data from 1990 to 2017. Second, this study employs additional variables, including remittances and CO₂ emissions, to elude omitted variable bias. Third, different from the available literature, our study employs a recent panel model, developed by Love and Zicchino, called the panel vector autoregressive model (PVAR); this model allows shock analysis and is beneficial for classifying possible policy effects (Canova and Ciccarelli 2013). Furthermore, causality correlation among indicators is another element determined in the selection of techniques.

The following is a summary of the remainder of this research: Section-II investigated past literature reviews, Section-III discusses data and the methodological framework, Section-IV discusses practical outcomes and debate, and Section-V concludes with policy implications.

2 LITERATURE REVIEW

The correlation between the use of renewable power, economic growth, ICT, and human development index (HDI) has been the subject of intense research. Although numerous empirical studies are analyzing "renewable energy growth", "HDI growth," and "ICT growth" relationship separately, no studies are exploring these links together.

This section will examine these relations separately. Prior research has mostly focused on the liaison between renewable energy usage and economic growth. For example, Azam et al. (2021) observed that renewable energy usage augments economic enlargement in newly industrialized nations. Similarly, other studies of (Azam et al., 2021; Rahman and Velayutham, 2020; Vural, 2020) found that renewable energy significantly influences economic growth (Inglesi-Lotz 2016) and explores the influence of clean energy usage on the economy for OECD by using the panel data method. The empirical findings reveal that renewable energy consumption's impact on economic growth is constructive and analytically important. Similarly, Bhattacharya et al. (2016) confirmed that renewable energy consumption improved economic growth from 1991 to 2012 for 38 high energy-consuming regions.

TABLE 1 | Summary of the literature renewable energy consumption–economic growth and human development index nexus.

Author(s)	Study area	Period	Methodology	Results
Shahbaz, Lean, and Shabbir (2012)	Pakistan	1972:1–2011:4	ARDL Model, Johansen co-integration, and VECM Granger causality	Feedback hypothesis
Apergis and Payne (2010)	Eurasia	1992–2007	Pedroni co-integration, FMOLS, and VECM Granger causality	Feedback hypothesis
Lee and Jung (2018)	South Korea	1990–2012	ARDL Model and VECM Granger causality	Conservation hypothesis
Ohler and Fetters (2014)	20 OECD states	1990–2008	Pedroni co-integration, FMOLS, DOLS, and VECM Granger causality	Feedback hypothesis
Azam et al. (2021)	CO ₂ emitter countries	2000–2016	Regression analysis	REN contributes to economic growth
Azam et al. (2020)	Developing countries	1990–2017	ARDL and causality test	Feedback hypothesis
Niu et al. (2013)	50 income countries	1990–2009	Panel co-integration and causality test	Feedback hypothesis
Ouedraogo (2013)	15 developing countries	1988–2008	Panel co-integration and error correction term	Conservation hypothesis
Sasmaz et al. (2020)	28 OECD	1990–2017	Edgerton panel co-integration and causality test	Feedback hypothesis
Yumashev et al. (2020)	OECD	2006–2017	3SLS	REN contributes to HDI
Abid et al. (2020)	Pakistan	1990–2017	Regression and causality analysis	Neutrality hypothesis

Note: OECD, Organization for Economic Co-Operation and Development, 3SLS, three-stage least squares; FMOLS: fully modified ordinary least squares; DOLS: dynamic ordinary least squares; VECM: vector error correction model; ARDL: auto-regressive distributed lag model.

Alper and Oguz (2016); Sebri and Ben-Salha (2014) premeditated the link between sustainable power usage and economic expansion in the EU countries and confirmed the neutrality hypothesis. In most countries along the BRI, the rise in the renewable energy scale is the main driving force responsible for encouraging CO₂ emissions, while the carbon intensity of renewable energy is the main factor restraining CO₂ emissions. (Wang et al., 2021; Chang et al., 2015; Lin and Moubarak, 2014) found bidirectional causality amid renewable energy use and economic escalation. Unidirectional correlation occurs between renewable energy use to GDP in developing nations (Saidi and Mbarek 2016).

Another study by Dong et al. (2020) found that renewable energy consumption reduces CO₂ emissions, but the effect is minor; the mitigating benefit may be masked by increased non-renewable energy consumption and higher economic growth. The link between renewable energy consumption and growth has been extensively studied (Dogan, 2016; Inglesi-Lotz, 2016; Kahia and Charfeddine, 2016; Koçak and Şarkgüneşi 2017; Rafindadi and Ozturk, 2017), but in addition to the impact of energy on economic growth, it also has an impact on the human development index. The influence of human development on economic growth has been analyzed by many authors in the past decades. Most of the evidence in this area confirms a positive effect on economic growth. Some empirical inquiries on the causal correlation between renewable energy growth and renewable energy HDI are summarized in **Table 1**.

For instance, Ranis (2004) examined the linkage between HDI and economic expansion. According to the findings of the inquiry, human development has a significant impact on economic growth; as a result, it improves human development. Similarly, gross domestic product (GDP) and other HDI, longevity, and instructional accomplishment elements improve a country's financial development at various stages (Hou et al., 2015; Shah, 2016). From 1975 to 2008, an error correction model is used to examine the relationship between economic growth and the human development index in Nigeria (Abraham and Ahmed,

2011). The findings suggest that economic augmentation has a negative correlation with the human development index in the short run, but it is significant for the long-run relationship. Similarly, other studies (Khodabakhshi, 2011; Costantini and Monni, 2005) found that the evolution of human development performs an imperative function to form a sustainable progress path for the case of India and 179 countries.

The world has been remade thanks to ICT in terms of scrimping and enhancing access to information and human capital, which authorize individuals *via* influencing their mental capacity, thinking power, and capacity to liaise with others (Summak et al., 2010; Coelho et al., 2015). However, in particular, people who live in rural regions that have low income frequently face hindrance in accessing educational prospects, where ICT endorses practical and useful ways to alleviate the trouble of accessing education by home-based education and e-learning. Therefore, ICT has the potential effect on development to eradicate impediments in people's lives and to improve their living standards through access to education and health-related information (Palvia et al., 2015; Migliaccio 2016). Previous studies have widely reviewed the association between ICT and economic growth and conclude with positive or negative linkage. For example, ICT's contribution to GDP was compared from 1980 to 2000 in nine OECD countries. According to the findings, ICT assets contributed significantly to GDP in industrial nations (Colecchia and Schreyer, 2002). The carbon emission intensity of ICT investments adds to a large increase in carbon emissions, whereas the structure and efficiency of ICT investments always limit carbon emission growth (Wang et al., 2021). Similarly, other studies (Papaioannou and Dimelis, 2007; Katz, 2012; Zafar n.d.) revealed an affirmative and momentous influence on economic enlargement (Toader et al., 2018). By employing panel data estimation practices, researchers looked at the influence of ICT infrastructure on economic development in European Union (EU) nations from 2000 to 2017.

The ICT industry might be used to certify the environmental quality in industrial operations, electrical grids, and transportation networks (Añón et al., 2017).

The empirical findings imply an affirmative and vigorous effect of using ICT infrastructure on economic augmentation, although the amount of the benefit varies depending on the type of technology studied. Similarly (Chimbo, 2020), ICT increased economic growth through its energy efficiency effect in Africa by using the GMM model from 2001 to 2015. Since ICT and human development have remained important topics in recent years, Gupta et al. (2019) evaluated how evolution in ICT could stimulate human capital advancement for the South Asian region over the period of 2000 to 2016 by using the panel fixed effects model. The results revealed a strong positive connection of internet access, technological readiness, and mobile use with the human development index. Khan et al. (2019) analyzed the association between ICT, economic growth, and the HDI for the period from 1990 to 2014 by using ARDL and VECM approaches in Pakistan. The findings suggest that ICT boosts the human development index and economic growth and has a constructive and significant influence on human development.

Little research has been carried out on linkage among links between the use of renewable energy and the human development index. For instance, using the 2SLS technique, Wang et al. (2018) scrutinized the association between renewable energy usage, economic growth, and human development index in Pakistan from 1990 to 2014. The empirical findings suggest that renewable energy does not contribute to the human development process in Pakistan. Energy use and HDI are strongly interrelated, and enough energy resources ensure mounting economic and human development in South Asia economies (Salam et al., 2020). Renewable energy has a negligible impact on HDI in high-income group countries (Amer, 2020).

In conclusion, ICT, renewable energy consumption, economic growth, and human development index have not been analyzed yet. The correlation between renewable energy, non-renewable energy, and economic growth is mostly disregarded but not lectured effectively. Human activities are responsible for a substantial amount of energy usage around the planet. According to the research, renewable energy is a vital component to augment economic growth that can help to reduce poverty and improve the human development index. Furthermore, scarce inquiries scrutinize the affiliation between renewable energy consumption and human development. Moreover, ICT has an enormous prospective for boosting GDP and enhancing HDI. Nevertheless, the present inquiry aims to close this gap on the potential of energy economy and environment liaison in the setting of selected developing states.

3 EMPIRICAL METHODOLOGY AND THEORETICAL FRAMEWORK

3.1 Theoretical Framework

Before going to the panel data econometric analysis, we need to construct the theoretical framework of our study that will assist us

in deciding upon the model indicators. The developing countries referred to in this study are characterized by high economic growth, and this upward trend in economic growth is strongly related to the burning of fossil fuels, which results in an increase in CO₂ emissions in these selected economies (Zafar et al., 2019). However, this type of traditional energy is not only harmful to the environment but also to the nation's long-lasting growth.

To tackle this kind of issue, a clean generation system comes to mind, which largely focuses on the use of renewable energy. This type of clean energy can be produced from a variety of sources, for example, tidal, wind, solar, and geothermal, and these are indispensable for the sustainable environment and economic growth. Now, putting the renewable energy-producing process in place necessitates a significant investment, which may impede economic development.

Saying this, remittances provide a potential impetus for national investment while also ensuring reliable and clean energy. For developing countries, remittance inflows have proven to be an economically indispensable source of cash. Moreover, the role of ICT is imperative in providing technological facilities for sustainable development. In a nutshell, ICT development not only improves economic growth but also has a substantial impact on human well-being, increases energy efficiency, and promotes environmental quality. In addition, there is a direct linkage between clean energy service, modern health and education facilities, sustainable growth, and environment as well as ICT. The lack of any indicator services leads to poor health facilities and fewer opportunities for education and development.

3.2 Data Descriptions

Annual data were collected from 1990 to 2017 in this current study by incorporating variables such as information and communication technologies (medium and high-tech exports), renewable energy (MTOE), economic growth (constant US\$), human development index (HDI), CO₂ emissions (kt), and remittances (current US\$). The data for HDI and RE were extracted from the study by Cammack (2017) and the British Petroleum (BP) statistical Review of World Energy (Petroleum, 2019). The data for ICT, CO₂ emissions, economic growth, and remittances were mined from the World Development Indicators (Bank, 2018). To lessen non-normality and heteroscedasticity, all these variables were transferred into a natural logarithm.

Regarding the list of developing countries in this study, it includes Azerbaijan, Belarus, Bangladesh, China, India, Indonesia, Iran, Iraq, Kazakhstan, Malaysia, Pakistan, Philippines, Russia, Sri Lanka, Ukraine, Vietnam, Algeria, Egypt, Morocco, South Africa, Argentina, Brazil, Chile, Colombia, Ecuador, Peru, Greece, Poland, Romania, and Turkey.

3.3 Estimation Strategy

The panel vector autoregressive (PVAR) model proposed by Love and Zicchino is employed in this study, which permitted us to account for overlooked entity heterogeneity for inclusive series

and the presence of stationary endogenous variables. There are several econometric benefits within the PVAR model that make it a more appropriate method to examine macroeconomic dynamics. First, PVAR is useful in analyzing the transmission of shocks that can happen within a unit and time. Second, PVAR is based on existing series motion rather than a scrupulous notion of macroeconomy, which, if not approved, can be warping (Kireyev, 2000). Third, this model does not make dissimilarity among dependent and independent variables, and whole factors are treated as endogenous to one another. In addition, it provides a procedure of dependent and independent variables' jolts that are emphatically the most imperative sources of macroeconomic dynamics for small open states. Finally, the PVAR technique may also be employed to examine the significance of interdependencies and test whether the feedback is generalized (Canova and Ciccarelli, 2013). The specification of the PVAR model used in the empirical analysis is given in Eq. 1:

$$Y_{it} = \mu_{it} + \Gamma(L)Y_{it} + \varepsilon_{it}, \quad (1)$$

where Y_{it} symbolizes the vector of stationary series in this study, μ_{it} is the vector of deterministic fixed effects, $\Gamma(L)$ denotes a matrix polynomial in lag order with $\Gamma(L) = \Gamma_1 L^1 + \Gamma_2 L^2 + \dots + \Gamma_p L^p$, and ε_{it} represent the random error term. The above matrix form of the PVAR model with the algorithm may also be revised in six equations, Eqs 2–7, as follows:

$$\begin{aligned} \Delta LHDI_{it} = & \varphi_{1j} + \sum_{k=1}^m a_{1k} \Delta LHDI_{it-k} + \sum_{k=1}^m b_{1k} \Delta LRE_{it-k} \\ & + \sum_{k=1}^m c_{1k} \Delta LGDP_{it-k} + \sum_{k=1}^m d_{1k} \Delta LICT_{it-k} \\ & + \sum_{k=1}^m e_{1k} \Delta LREM_{it-k} + \sum_{k=1}^m f_{1k} \Delta LCO_{2it-k} + \varepsilon_{1it}, \end{aligned} \quad (2)$$

$$\begin{aligned} \Delta LRE_{it} = & \varphi_{2j} + \sum_{k=1}^m a_{2k} \Delta LHDI_{it-k} + \sum_{k=1}^m b_{2k} \Delta LRE_{it-k} \\ & + \sum_{k=1}^m c_{2k} \Delta LGDP_{it-k} + \sum_{k=1}^m d_{2k} \Delta LICT_{it-k} \\ & + \sum_{k=1}^m e_{2k} \Delta LREM_{it-k} + \sum_{k=1}^m f_{2k} \Delta LCO_{2it-k} + \varepsilon_{2it}, \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta LGDP_{it} = & \varphi_{3j} + \sum_{k=1}^m a_{3k} \Delta LHDI_{it-k} + \sum_{k=1}^m b_{3k} \Delta LRE_{it-k} \\ & + \sum_{k=1}^m c_{3k} \Delta LGDP_{it-k} + \sum_{k=1}^m d_{3k} \Delta LICT_{it-k} \\ & + \sum_{k=1}^m e_{3k} \Delta LRAM_{it-k} + \sum_{k=1}^m f_{3k} \Delta LCO_{2it-k} + \varepsilon_{3it}, \end{aligned} \quad (4)$$

$$\begin{aligned} \Delta LICT_{it} = & \varphi_{4j} + \sum_{k=1}^m a_{4k} \Delta LHDI_{it-k} + \sum_{k=1}^m b_{4k} \Delta LRE_{it-k} \\ & + \sum_{k=1}^m c_{4k} \Delta LGDP_{it-k} + \sum_{k=1}^m d_{4k} \Delta LICT_{it-k} \\ & + \sum_{k=1}^m e_{4k} \Delta LREM_{it-k} + \sum_{k=1}^m f_{4k} \Delta LCO_{2it-k} + \varepsilon_{4it}, \end{aligned} \quad (5)$$

$$\begin{aligned} \Delta LRAM_{it} = & \varphi_{5j} + \sum_{k=1}^m a_{5k} \Delta LHDI_{it-k} + \sum_{k=1}^m b_{5k} \Delta LRE_{it-k} \\ & + \sum_{k=1}^m c_{5k} \Delta LGDP_{it-k} + \sum_{k=1}^m d_{5k} \Delta LICT_{it-k} \\ & + \sum_{k=1}^m e_{5k} \Delta LREM_{it-k} + \sum_{k=1}^m f_{5k} \Delta LCO_{2it-k} + \varepsilon_{5it}, \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta LCO_{2it} = & \varphi_{6j} + \sum_{k=1}^m a_{6k} \Delta LHDI_{it-k} + \sum_{k=1}^m b_{6k} \Delta LRE_{it-k} \\ & + \sum_{k=1}^m c_{6k} \Delta LGDP_{it-k} + \sum_{k=1}^m d_{6k} \Delta LICT_{it-k} \\ & + \sum_{k=1}^m e_{6k} \Delta LREM_{it-k} + \sum_{k=1}^m f_{6k} \Delta LCO_{2it-k} + \varepsilon_{6it}. \end{aligned} \quad (7)$$

ICT represents information and communication technology; REM indicates the remittances, and CO₂ is the carbon dioxide emission. The study used the Schwarz information (SIC) criterion to ascertain the best autoregressive lag length in the estimation process, $K \in (1 \dots p)$. The PVAR approach agrees to an enclosure of fixed effects in regions, which is nominated by 8) *Pited capital formattion act* φ_j , and accounts for all constant time factors that are not seen at the state level. Subscripts i and t represent the country and time, respectively. The theoretical framework of the VAR model is shown in Figure 1.

4 EMPIRICAL RESULTS AND DISCUSSION

The VAR model includes several steps. Before analysis, the first step is to analyze the detailed descriptive statistics. However, a comprehensive summary of the variables is provided in Appendix Table 2 with mean, variation (standard deviation), and bounds (minimum and maximum). Next, it is necessary to check the integration order of the studied variables. Thus, the primary goal of using a unit root test is to determine whether data contain a unit root. This study used three-unit root tests (Maddala and Wu, 1999; Im et al., 2003; Levin et al., 2002) to analyze the stationarity of the variables.

The results of the unit root tests are illustrated in Table 3, including (Maddala and Wu, 1999; Im et al., 2003; Levin et al., 2002) variables that display that variables comprise a unit root at their levels, denoting that the variables are not stationary. All the coefficients of the variables' first difference are significant at the 1% level, indicating that all variables are stationary at their first difference. Choosing the lag order is the next stage. This stage aims to find the VAR model's optimal lag order, which is based on the following selection criteria: LR-sequential modified LR test statistics, Hannan–Quinn information criterion, and SIC—Schwarz information criterion. This process is required because if the lag length is chosen incorrectly, the results will be skewed (Hdom and Fuinhas, 2020). Table 4 shows that the result of the appropriate lag length is 2.

Next, the outcomes of the panel vector autoregressive model using lag 2 with the GMM-style option are reported in Table 5. First, the HDI equation indicates that only three coefficients are statistically significant at the conventional level of significance. More particularly, findings indicate that the first lag length of HDI is positively interrelated with its recent stage. The predictable coefficient of HDI is equal to 0.139%, and it is significant at the 1% level. Furthermore, the coefficient of usage of renewable energy positively resolves the current level of HDI at a 1% significance level, which specifies that rising renewable energy use will augment the level of HDI. The results

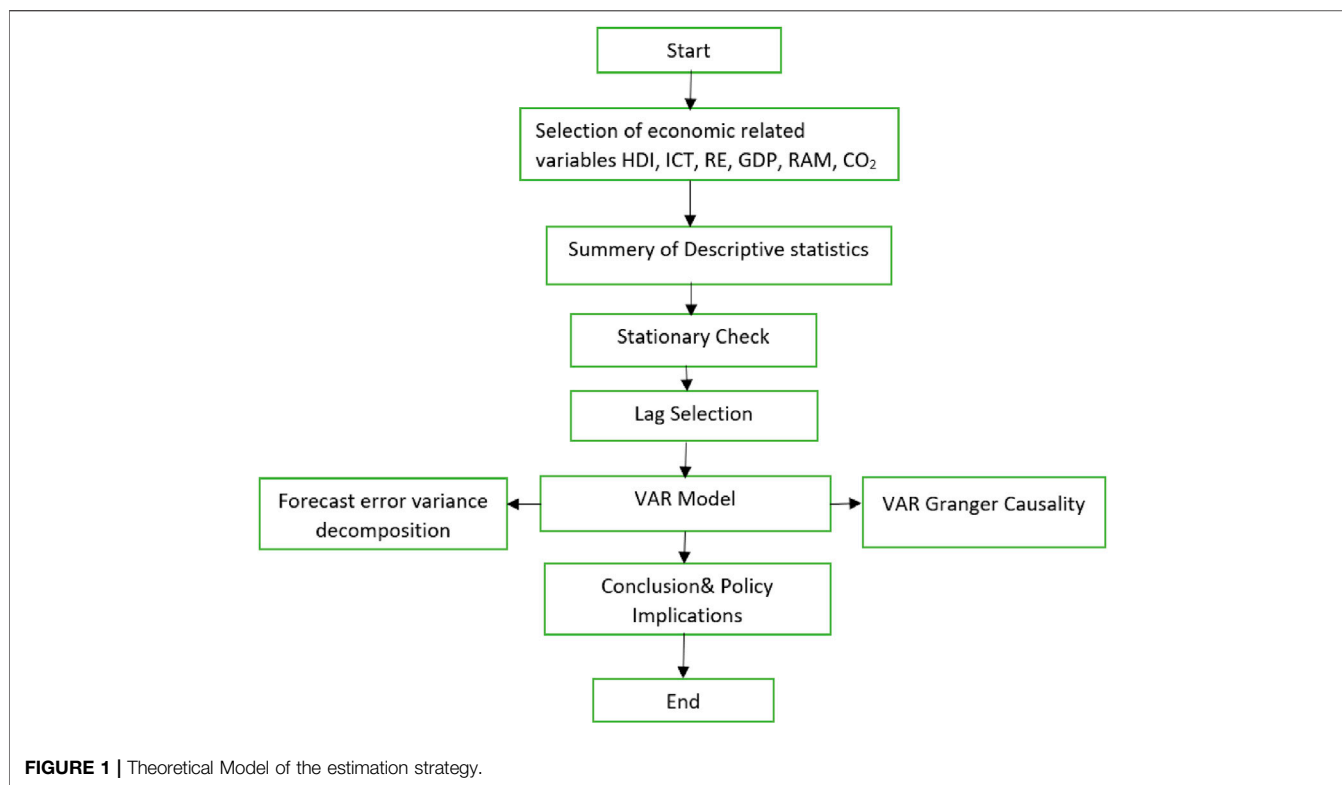


TABLE 2 | Descriptive Statistics of the variables.

Variable	HDI	RE	GDP	ICT	REM	CO ₂
Mean	-0.389207	1.824232	8.111383	3.076216	20.59040	3.215571
Median	-0.384193	1.995378	8.321284	3.348022	21.12906	11.59213
Max	4.317488	9.851510	10.31078	4.420023	24.97730	16.14687
Mini	-0.931404	-5.521461	2.825596	-3.283799	0.296394	3.077312
Std.Dev	0.316075	2.286571	1.141358	0.982249	3.215571	1.882120

are similar to the findings of Abid et al. (2020); Sasmaz et al. (2020) but dissimilar to the study of Wang et al. (2018), who argued that renewable energy does not contribute to the situation of the human development index. As expected, the coefficient value of GDP is an optimistic and momentous effect on the human development index at a 1% level of significance, which shows that these countries need to provide more goods and services to improve the living standards of each country. Additionally, a surge in GDP lessens the unemployment rate and raises income, which will endorse human development. People favor devoting after-tax capital to education, food, and the health sector; these factors directly donate to human development (Engo, 2018). For any economy, human development is a critical predictor of economic progress. Greater levels of education, better health, and more income, all of which translate into a higher standard of living and more possibilities, boost the working force’s intellectual aptitude and productivity. The coefficient of ICT is positively determined by the HDI at the 1% significance level, which

specifies rising in technological innovation, and will help to augment the level of HDI because ICT plays an important part in the development course. This conclusion conforms to the studies by Khan et al. (2019); Gupta et al. (2019).

Second, the renewable energy equation findings specify that just two indicators have a vital influence on RE. HDI and RE coefficients are positive and significant at a 1% level, respectively. The results are in line with the study of Yahya and Rafiq (2020). This means that renewable energy improves the HDI in developing economies by economic development and leads toward higher human development levels. Without accessing and ensuring a clean, reliable, and efficient energy, it would not be possible to attain the social and economic development in developing nations. Third, in terms of the economic growth equation, GDP values positively and significantly impact the current value of GDP at 1% as expected; the outcomes display that these three coefficients are significant at the 1% significance level, which is reflected. Furthermore, as projected by the coefficient of remittances, we discovered that the value has a

TABLE 3 | Panel unit root test results.

Method	Variables	Level	First difference
ADF	LHDI	74.279	240.639 ^a
	LRE	54.345	345.829 ^a
	LGDP	34.634	269.378 ^a
	LICT	60.925	184.121 ^a
	LREM	72.104	268.453 ^a
	LCO ₂	63.061	365.799 ^a
IPS	LHDI	0.1670	-10.300 ^a
	LRE	2.263	-15.771 ^a
	LGDP	5.295	-12.719 ^a
	LICT	-0.890	-13.452 ^a
	LREM	-0.417	-20.628 ^a
	LCO ₂	1.722	
LLC	LHDI	-0.268	-7.832 ^a
	LRE	2.843	-12.805 ^a
	LGDP	-0.302	-0.302 ^a
	LICT	-1.155	-11.836 ^a
	LREM	-0.805	-22.083 ^a
	LCO ₂	42.247	-2.435 ^a

Note:^a implies significance level at 1%. HDI, GDP, RE, ICT, REM, and CO₂ represent the human development index, gross domestic product, renewable energy, information and communication technology, remittances, and carbon dioxide emission.

significant positive effect on remittances. The positive influence of GDP on remittances indicates that for every 1 unit increase in GDP, the remittances will increase by a 5% level. This means that developing countries need to improve their development levels by investing in physical and human capital and also contributing in remittances to ensure the efficient and reliable transfers and reducing the cost of transfers by increasing their political stability. Conclusively, environmental deprivation, which is signified by CO₂ emanations, has a positive and significant influence at a 1% level of significance on the current GDP

level. These findings conform with those of Xie et al. (2018); Charfeddine and Kahia (2019).

Fourth, only CO₂ emissions have an adverse influence at a 1% level of significance on ICT in the equation related to the ICT variable. This finding shows that ICT significantly decreases CO₂ emissions, and it may be regarded as one of the spillover impacts of spending on renewable energy sources. Thus, there is a need to explore and induce the use of cleaner energy sources. Another contribution to mitigate the environment is to encourage the latest ICT technologies that are less polluting and investing in research and development (R&D) to provide opportunities to import new innovations. Fifth, two coefficients in the remittance equation are positive and significant at 5 and 1% levels. The finding indicates that coefficients of HDI and remittance variables are strongly related at 10 and 1% levels of significance, respectively. The significant and positive coefficient means that the increase in remittances will augment the human development index, such as education, the health sector, and the living standard in developing countries. Finally, in the CO₂ emission equation, the outcomes embody that only ICT improves environmental quality through the latest technology and innovations.

Next, to conclude the alteration of sources in the variance decomposition of variables in the PVAR model, variance decomposition exploration is applied in **Table 6**. This method acquired from the moving averages section of the PVAR model articulates the source of the shocks that happen in the variables themselves and other variables as a percentage. The findings of the variance decomposition show that HDI explains approximately 0.371, 0.184, 1.224, 0.221, and 4.25% of the variations in GDP, renewable energy consumption, ICT, REM, and CO₂ emission, respectively. In addition, usage of renewable energy explicates around 0.101% of variations in HDI, 2.698% of the vicissitudes in CO₂ discharge, and 0.258% of disparity in economic enlargement; economic growth explains approximately

TABLE 4 | VAR lag order selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-6,688.408	NA	9.630915	19.29224	19.33151	1930743
1	-2026.492	9,229.788	1.56e-05	5.961071	6.235975	6.067380
2	-1840.200	365.6038	1.01e-05 ^{sc}	5.527954 ^{sc}	6.038491 ^{sc}	5.725385 ^{sc}
3	-1806.359	65.82852 ^{sc}	1.02e-05	5.534177	6.280346	5.822730

TABLE 5 | Panel VAR results.

Response to	Response of					
	LHDI	LRE	LGDP	LICT	LREM	LCO ₂
LHDI	0.139672 ^a	0.925762 ^a	0.006677	0.024755	0.183593 ^c	-0.015255
LRE	0.034802 ^a	0.962296 ^a	0.000812	0.001495	0.0006300	-0.009355
LGDP	0.059813 ^a	0.004706	0.986979 ^a	0.010608	-0.036821	0.071178
LICT	0.034802 ^a	0.001434	0.002642	0.919910	0.006583	-0.012288 ^b
LRAM	-0.003227	0.000278	0.001580 ^b	0.001068	0.901669 ^a	-0.032196
LCO ₂	-0.015525	-0.069573	0.004317 ^b	-0.084549 ^a	0.033206	0.913093

Note: ^{a, b, c} denote significance level at 1, 5, and 10%, respectively.

TABLE 6 | Variance decomposition of the PVAR (%).

Variables	LHDI	LRE	LGDP	LICT	LREM	LCO ₂
LHDI	93.746	0.371	0.184	1.224	0.221	4.252
LRE	0.101	84.49	0.258	0.054	0.093	2.698
LGDP	0.480	0.216	67.733	1.153	0.287	30.128
LICT	0.064	0.180	0.236	93.190	0.020	6.307
LRAM	0.137	0.163	0.034	0.179	90.442	9.089
LCO ₂	0.098	0.087	0.351	0.914	1.441	97.193

Note: % of the variation in the column variable (10 periods ahead) explicate by the row variable.

0.480% of the changes in HDI and 0.216% of oscillation in clean energy. ICT explains approximately 0.064% of amending in HDI and 6.307% of fluctuations in CO₂ emission.

After PVAR estimation and variance decomposition analysis, we performed the Granger causality test (Granger, 1969) based on the Wald check. The null hypothesis is the absence of Granger causality. **Table 7** represents the Granger causality test. The outcomes show that bidirectional causation is occurring between the use of renewable energy and HDI. In addition, there is unidirectional causality from economic expansion to human development index, from ICT to human development index, and from remittances to human development index and CO₂ emission to HDI. However, there is a one-way antecedent from renewable energy usage to CO₂ release and from economic enlargement to remittances and CO₂ emissions. The causality associations between variables are represented in **Figure 2**.

These findings indicate that an increase in renewable energy may lead to an increase HDI in developing countries. However, improvement in the level of clean energy (health and education sectors) will add to the nations' economic augmentation. However, more investment in the clean energy sector is needed; developing countries must join forces to achieve levels of investment capable of meeting expectations. Furthermore, an increase in economic growth would lead to augment the level of HDI in developing regions. Economic growth makes this likely to accomplish a high level of human development, and in contrast, a rise in the level of human development results in increased prospects for economic growth. Moreover, ICT performs a significant part in the development process through ICT-enabled technologies that will bring innovative changes in education, health services, and industrial purposes; in this way, the government may develop labor skill development and

technical training organizations to more productivity for high-income gains, which will further lead to increased economic growth and human development index. When migrant workers send money home to their families in poor nations, it improves HDI. As a result, remittances have an important role in boosting economic activity by increasing aggregate spending and expanding access to critical social infrastructure such as health and education, all of which contribute to improved social well-being. Furthermore, to contest any environmental threat from excessive energy consumption, more renewable energy should be adopted to the energy mix. CO₂ emissions influence the human development process in developing economies, and a low level of the human development index leads to environmental degradation. Therefore, clean energy is critical for improving environmental quality, which aids in the advancement of the human development index.

5 CONCLUSION AND POLICY IMPLICATIONS

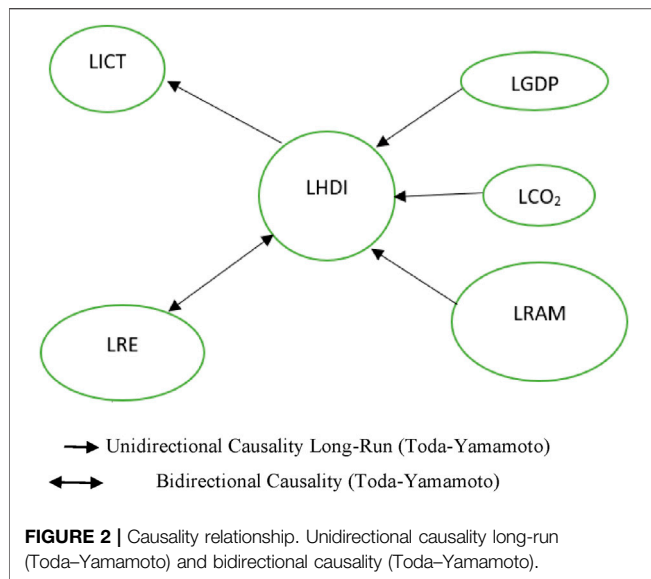
This analysis examined correlation among ICT, human development index, renewable power usage, and economic development, incorporating remittances and CO₂ emission in the context of developing nations by utilizing the PVAR practice that Love and Zicchino lately established for 1990–2017. We applied the Toda–Yamamoto–Granger casualty methodology to analyze the study's underlying variables.

The empirical results can be outlined in four essential points. First, we investigated that economic expansion has a large positive impact on the human development index, and an increase in GDP will accelerate human development. For sustainable economic growth, developing countries can direct more plans for better education facilities, health, and other social and economic sectors. Second, ICT and remittances stimulate the human development process. The significant results show that both ICT and the remittance sector play a decisive role in the development process. Third, the use of renewable energy has a positive and significant effect on HDI. Additionally, we found that ICT helps improve CO₂ emissions. Finally, CO₂ emissions and remittances have a noteworthy effect on economic expansion. Based on causality findings, we discovered that economic growth, remittances, and CO₂ emission Granger cause to human development index. Thus, there is

TABLE 7 | Granger causality Wald test.

Independent variable	Dependent variable					
	LHDI	LRE	LGDP	LICT	LREM	LCO ₂
LHDI	—	4.733 ^b	1.076	7.735 ^a	0.776	2.609
LRE	4.733 ^b	—	0.061	0.0005	0.007	4.284 ^b
LGDP	32.732 ^a	0.566	—	1.505	6.627 ^b	6.403 ^b
LICT	0.238	0.036	0.529	—	0.037	1.464
LREM	2.587 ^c	0.001	1.363	0.030	—	1.286
LCO ₂	0.720 ^c	0.124	1.355	1.347	3.871 ^b	—

Note: ^a, ^b, ^c denote significance levels at 1, 5, and 10%, respectively.



unidirectional causality from HDI to renewable energy and ICT, while renewable energy Granger causes CO₂ emission.

However, the empirical findings suggest that policymakers and government officials should make ICT-related policies more effective in terms of economic growth to stimulate human development. Furthermore, it reinforces the ICT and R&D-related projects that support a better human development index and enhances the usage of renewable energy that is helpful to the construction of a clean environment. The efficient use of renewable energy is helpful to improve the quality of life of poor masses, economic empowerment, and consequently improve human development. However, renewable energy resources are imperative in achieving an efficient and reliable human development index for developing countries.

Furthermore, policymakers should empower people with ICT expertise to offer trained labor force to marketplace and prospects through education, health services that broaden people's horizons, and competencies to contribute to institutions responsible for providing social facilities and economic inducements for the development. Moreover, economic growth makes this likely to realize a high degree of human development, an enhancement in the level of human development results in rising prospects for economic growth.

The positive coefficient of GDP on CO₂ emission suggests that with an increase in income, pollution levels start to increase due to inefficient energy use and consumption of more goods. Nevertheless, countries must enhance understanding by promotions and basic amendments at the state and global levels, which assist in raising the growth without accelerating the environmental contamination that would deliver environment-friendliness. Similarly, numerous nations adopted the latest environmental strategies and policies to slash environmental outward. Economic affluence results in larger energy consumption. Therefore, modification of green power revolutions and energy efficiency policies *via* ICT would be

beneficial for economic and ecological sustainability. Furthermore, CO₂ mitigation measures based on the “Paris agreement” are inadequate as continual decarbonization operations are not fully acknowledged in numerous countries (Sun et al., 2020).

The outbreak of COVID-19 has severely affected episodic national and global economic growth and the energy industry at an unprecedented pace; the expected losses of GDP due to outbreak of the novel coronavirus was roughly 0.42% in the first quarter of the year (Azam et al., 2021), and still, this disease is underway in worldwide. The emergence of this pandemic is causing a huge impact on global socioeconomic factors such as higher unemployment, poverty rates, health insecurity, and loss of education, energy, and environmental pollution. However, due to the shutting down of the industries, e-commerce is highlighted, and businesses with more developed e-commerce infrastructures have shown more resilience to the economic shock caused by the epidemic situation. Furthermore, it is necessary to develop defensive epidemiological models to discover the occurrence of viruses, for example, COVID-19.

In addition, governments and policymakers need to take essential steps like healthcare services for better prevention of viruses for all citizens and suggested that more investment is needed in research and development programs to control this pandemic or other related similar crises for the sustainable energy sector and economic development in the future.

Since this study enables us to draw some preliminary conclusions on the human development index, ICT, and renewable energy-growth nexus, certain investigations still need to be looked further. First, this study is limited to emerging or developing economies; this leaves room for the future to research advanced countries. Second, the panel data research should be supplemented with individual economy time-series estimations. This gives us a better understanding of the idiosyncratic and draws a clear policy implication. Last, future studies can enhance the number of variables and different methodologies to explore the relationship further.

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

AA: conceptualization, methodology, software, data curation, writing—original draft, visualization, validation, and writing—reviewing and editing; MR: conceptualization, methodology, software, and writing—original draft, reviewing, and editing; MS: conceptualization, methodology, and writing—reviewing and editing; SS: conceptualization and funding acquisition; JY: conceptualization, methodology, and supervision.

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