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Effect of Economic Indicators, Renewable Energy Consumption and Human Development on Climate Change: An Empirical Analysis Based on Panel Data of Selected Countries

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Global warming is mainly influenced by factors such as energy consumption, human development, and economic activities, but there is no consensus among researchers and there is relatively little research literature on less developed countries. Therefore, this study attempts to explore the impact of renewable energy consumption, human development and economic growth on climate change from a macroeconomic perspective for 105 countries worldwide over the period 1990–2019 by constructing a panel vector autoregressive (PVAR) model and using generalized method of moments (GMM) and panel impulse response analysis. The analysis includes four panels of high-income, upper-middle-income, lower-middle-income, and low-income countries. The results of the study find that economic growth, FDI, trade openness, industrialization, renewable energy consumption and HDI have different impacts on climate change (CO_2 emissions) in different regions during the sample period. Specifically, in the four panels, economic growth, industrialization, FDI, and trade openness all play a varied role in aggravating environmental pollution (CO_2 emissions). In high-income and upper-middle-income countries, industrialization has a positive effect on CO_2 emissions, while FDI has a negative impact, which supports the pollution halo hypothesis. However, both have a positive impact on CO_2 emissions in lower-middle-income and low-income countries. The results also found that except for upper-middle-income countries, trade openness and renewable energy consumption help reduce CO_2 emissions, while renewable energy consumption has little effect on suppressing CO_2 emissions in low-income countries. In addition, HDI has promoted CO_2 emissions in upper-middle-income and lower-middle-income countries, but has curbed CO_2 emissions in high-income countries. Therefore, under the premise of not affecting economic growth and HDI, those empirical results will not only help decision-makers formulate appropriate renewable energy policies, but also are of great significance to the realization of a healthy and sustainable global environment.

Keywords: renewable energy consumption, economic growth, human development, CO2 emissions, PVAR model, panel impulse response, GMM estimation

1 INTRODUCTION

In recent years, on the issue of global warming, energy, environmental and social science researchers have increasingly discussed the challenging significance of economic globalization and climate change for the realization of human development, economic growth and environmental sustainability (Kirikkaleli and Adebayo, 2021). Meanwhile, economic growth and the improvement of environmental quality are also of great significance to sustainable human development. Under current economic conditions, energy activities are the main source of climate warming (Mongo et al., 2021). From a product perspective, there are many factors that affect the sustainable development of the environment, such as economic growth, energy consumption, industrial production, foreign direct investment, trade openness, and financial development (Hung, 2021). However, CO_2 emissions are one of the biggest factors causing environmental pollution and global warming and have become a serious problem for the world and the future of the Earth (Farhani and Shahbaz, 2014; Bilgili et al., 2016). Therefore, according to the 2020 Emission Gap Report issued by the United Nations Environment Programme, although COVID-19 has reduced CO_2 emissions in 2020, the concentration of main greenhouse gases (CO_2, methane) and nitrous oxide produced in the atmosphere in 2019 and 2020 has continued to rise, causing the global temperature to increase by more than 3°C degrees. For the continuous rise of global temperature, it is likely to lead to catastrophic weather events, ozone depletion and ecosystem degradation, etc., which will pose a serious threat to human production and life (HasnisahAzlina et al., 2019; Kumari et al., 2021). Inger Andersen, Executive Director of the United Nations Environment Programme, has said: it is an indisputable fact that climate change is all around us. Even if we have fulfilled the goal of the Paris Agreement, which is to control the rise of global temperature below 2°C in 21st century and strive to achieve the target of 1.5°C in temperature control, the impact of climate change will still intensify and cause the most severe damage to the most vulnerable countries and communities (Rogelj et al., 2016). In response, it also said that the COVID-19 crisis can only reduce global CO_2 emissions in the short term in 2019, and its contribution to emissions reduction in 2030 will be negligible, unless countries pursue economic recovery while vigorously achieving decarbonization. However, compared with 2019, the global CO_2 emission gap has not narrowed, and it has not been affected by the COVID-19 crisis. To achieve the temperature control target of 2°C the annual CO_2 emissions by 2030 must be 15 billion tons of carbon dioxide, less than the current unconditional nationally determined contribution; to achieve the temperature control target of 1.5°C the annual CO_2 emissions must be 32 billion tons of carbon dioxide, less than the current unconditional nationally determined contribution. For developing and underdeveloped countries, even if the temperature rises by only 2°C the climate in some areas will undergo drastic changes, which is inevitable (Brini, 2021). Therefore, in order to achieve the Paris Agreement target and the long-term energy and environmentally sustainable development goals, clean and sustainable green renewable energy must be used in life, production and consumption as part of the global response to climate change.

Currently, renewable energy has important political, economic and environmental advantages, and it is also the first choice for replacing fossil energy (Bilgili et al., 2016). Therefore, with the increasing threat of global warming and climate change, the relationship between energy consumption and environmental pollutants has become the focus of global attention, prompting renewable energy to become an important challenge. Especially in developing and underdeveloped countries, environmental sustainability, energy security and economic growth are particularly important. Increasing energy demand and supply losses have led to a dual problem of adequate energy fuel supply and electricity consumption (Doganalp, 2018). In order to reduce the dependence on fossil energy for living, production and consumption, some countries have tried to develop nuclear power generation in recent years, thus achieving the dual effect of protecting the ecological environment and reducing costs (Ben Mbarek et al., 2018). However, since nuclear disasters and nuclear threats have occurred in many parts of the world, many countries have gradually realized the potential hazards of nuclear energy and have begun to turn their attention to safer, cleaner, and more reliable renewable energy fields, prompting the source of the renewable energy industry to usher in a broader space for development.

Existing literature extensively discusses the relationship between renewable energy consumption, economic growth and climate change in various countries. The results of these studies can be summarized as follows: Mazur (2011) (Mazur, 2011), Bélaïd et al. (2017) (Bélaïd and Youssef, 2017), Shahbaz et al. (2017) (Shahbaz et al., 2017), Aydin (2019) (Aydin, 2019), Charfeddine et al. (2019) (Charfeddine and Kahia, 2019), and Adekoya et al. (2021) (Adekoya et al., 2021) obtain results supporting the relationship between renewable energy consumption and economic growth. In contrast, Banday et al. (2020) (Banday and Aneja, 2020) and Destek et al. (2017) (Destek and Aslan, 2017) obtain results supporting neutrality between variables. On the other hand, Ben Mbarek et al. (2018) (Ben Mbarek et al., 2018), Bilgili et al. (2016) (Bilgili et al., 2016), and Kumari et al. (2021) (Kumari et al., 2021) obtain the causal relationship between renewable energy consumption and climate change. Despite that the significant role played by renewable energy consumption and economic growth in Energy saving and emission reduction has been approved by a lot of case studies and events, the academic researches on this topic is still missing, in particular those regarding the empirical researches on the effect of human development on climate change (CO_2 emissions). In the context of the imbalance of contemporary economic development, the heterogeneous effects of human development on CO_2 emissions reduction have received little attention, especially in less developed countries. Therefore, to fill this gap, this study uses panel data from 105 countries around the world from 1990 to 2019, and uses a panel vector autoregressive model (PVAR) model to analyze the impact of economic indicators, renewable energy, and human development on climate change. Although the existing literature has carried out similar relevant analyses, economic growth and human development in Pakistan and five countries in the South Asian Association for Regional Cooperation (SAARC) region, as well as the OECD countries, the research from the perspective of climate change has not yet been carried out. To this end, this study has conducted an in-depth study and discussion of the links between economic indicators, renewable energy, human development, as well as climate change, and explored other possibilities in conjunction with other control variables in different countries, we explore the following aspects in order to provide future researchers with more knowledge and understanding of this issue.

First, the relationship between consumption of human development and CO_2 emissions of the four panels and which panel benefits the most from consuming renewable energy with regard to its development level. Second, the relationship between renewable energy consumption and human development for each panel in addition to how these variables are related to the different panels with their different stage of development. Third, the relationship between renewable energy consumption, human development and CO_2 emissions, and which panel is benefited more with respect to the environmental degradation. Fourth, comparing the effects of economic growth, trade opening, FDI, industrialization on the different levels of human development of the four-panels and at which stage of development do their role increase and/or decrease while at the same time comparing their influence on the renewable energy consumption and CO_2 emissions. In conclusion, this paper analysis is new in examining this kind of relationships among the whole globes. To fill this gap, we use a system of simultaneous equations to analyze the important feedback relationships between Human Development, renewable energy consumption, economic growth, trade openness, FDI, industrialization and climate chang is being employed through a global panel that represents the four income levels all around the world.

The remaining sections of the paper are organized as follows. **Section 2** presents a review of the literature related to the impact of renewable energy, human development and economic indicators on climate change. **Section 3** presents the methodology and data used in this research study. **Section 4** presents and discusses the empirical findings, and **Section 5** concludes the paper with a summary of the main findings and provides some policy recommendations based on the empirical results.

2 LITERATURE REVIEW

In the energy economics literature, the causal relationship between macroeconomic indicators, renewable energy, human development and climate change has been well studied, but the academic community has not yet reached a consensus (Farhani and Shahbaz, 2014; Destek and Aslan, 2017; Brini, 2021). Although some studies have established the relationship between human development and renewable energy, other studies have shown that this relationship is only applicable to upper-middle-income and high-income countries or regions (Chen et al., 2019; Danish, 2021). However, some researchers have also concluded that there is no causal relationship between renewable energy and human development (Mazur, 2011). In contrast, Adekoya et al. (2021) (Adekoya et al., 2021) found that renewable energy and CO_2 emissions contribute to human development in all regions, so every country or region is trying to improve the human development index, especially in less developed regions. It is worth mentioning that the effective use of renewable energy is the only way to solve high energy demand, energy supply shortage, energy security, human development and environmental issues. Hence, many studies have studied the combined effects of various economic variables, renewable energy and human development on climate change based on different methods. Those studies have proved the impact of economic growth, industrialization, foreign direct investment, trade openness, renewable energy consumption, and human development on climate change.

2.1 Renewable Energy Consumption, Human Development and Economic Growth

Energy consumption is an important indicator reflecting the level of social development. Therefore, in the research on renewable energy, human development and economic growth, some researchers believe that renewable energy is not only the main cause of economic growth, but also one of the determinants of human development (Niu et al., 2013; Ouedraogo, 2013; Wang et al., 2018; Amer, 2020; Mongo et al., 2021). Ouedraogo (2013) examines the long-term relationship between human development, energy consumption, and socioeconomic development through a panel of 15 developing countries from 1988 to 2008. The study finds that there is a long-term relationship between the human development index (HDI), economic development and power consumption, but in the short term, the impact of power consumption on human development is neutral. However, Niu et al. (2013) have studied the relationship between power consumption and human development based on panel data from 50 countries from 1990 to 2009. They conclude that there is a long-term two-way causal relationship between electricity consumption and GDP per capita and HDI, which supports the feedback hypothesis. If the income of a country is higher, electricity consumption will be greater and the level of human development will be higher (Aydin, 2019). Wang et al. (2018) (Wang et al., 2018) have used the two-stage least squares (2SLS) method to explore the relationship between Pakistan's renewable energy consumption, economic growth and HDI from 1990 to 2014. The study indicates that renewable energy consumption has not improved the status of Pakistan's human development process. More interestingly, the higher the national income, the lower the HDI level. Based on the above view, Hung (2021)

(Hung, 2021) has adopted a multi-wavelet framework approach to examine the causal relationship between China's economic growth, renewable energy and HDI from 1990 to 2019. The study finds that there is a two-way relationship between economic growth and HDI in different time and frequency domains. However, as for renewable energy and HDI, they only have a positive impact on HDI in low and medium frequencies. This is in line with Shahbaz et al. (2017) (Shahbaz et al., 2017), Kaya et al. (2017) (Kaya et al., 2017) and Khan et al. (2021) (Khan et al., 2021) studies and argues that economic growth positively affects human development, but FDI and trade openness hinders human development in the country. On the basis of this research, Sasmaz et al. (2020) (Sasmaz et al., 2020) have examined the relationship between renewable energy and human development in 28 OECD countries from 1990 to 2017. They have summarized that there is a two-way causal relationship between renewable energy and HDI, but the impact of renewable energy on human development is greater than that of HDI on renewable energy. However, this relationship will promote economic development, such as education and income. This is contrary to the study of Adekoya et al. (2021) (Adekoya et al., 2021) who argued that renewable energy consumption only has a positive impact on human development in developed countries, while the negative impact on less developed countries is either negative or neutral.

2.2 Renewable Energy Consumption, Human Development and CO_2 Emission

In the past, people believed that energy consumption was the main reason that directly affected economic growth. However, when environmental problems related to energy consumption become more serious, this view is no longer applicable (Wang et al., 2020). Bekun et al. (2020) (Bekun et al., 2020) found that the wave of high globalization has led to environmental degradation in China by investigating the impact of globalization and energy consumption on environmental sustainability and argued that increased energy consumption should be adequately increased without compromising environmental quality, and that efficient, clean and safe alternatives to fossil fuels should be sought, and seek efficient, clean and safe energy alternatives to fossil fuels. Pîrlogea (2012) (Pîrlogea, 2012) has used regression analysis to investigate the role of renewable energy in human development in EU countries from 1997 to 2008. The study has found that the consumption of renewable energy not only reduces the intensity of CO_2 emissions, which has a positive impact on human development. Especially in Romania, Bulgaria, Poland and other countries, it has showed strong influence. However, for countries such as Portugal, Ireland, and the Netherlands, the intensity of CO_2 emissions has a relatively small impact on human development. However, Wang et al. (2018) (Wang et al., 2018) believe that CO_2 emissions can help improve the human development index. Amer (2020) (Amer, 2020) has investigated the panel data of 101 countries around the world from 1990 to 2015, and performed PVAR analysis on each panel by using the systematic GMM approach. The study indicates that in the selected countries of all panels, the impact of renewable energy consumption on reducing per capita carbon emissions is insignificant, and except for lower-middle-income countries, the impact of renewable energy consumption on the human development index is also negligible. However, Farhani et al. (2014) (Farhani and Shahbaz, 2014) has investigated the causal relationship between the renewable energy and CO_2 emissions of 10 Middle East and North Africa (MENA) countries from 1980 to 2009, and concluded that renewable consumption has promoted CO_2 emissions, while there is an inverted U-shaped relationship between economic growth and CO_2 emissions, which affects the decline of human health and productivity (Bekun et al., 2021). This is supported by the studies of Chen et al. (2019) (Chen et al., 2019), Danish (2021) (Danish, 2021) and Apergis et al. (2010) (Apergis et al., 2010), and the results support the environmental Kuznets curve (EKC) hypothesis. However, Menyah et al. (2010) (Menyah and Wolde-Rufael, 2010) concluded that there is no significant effect of renewable energy consumption on CO_2 emissions. Nevertheless, Sinha et al. (2016) (Sinha and Sen, 2016) and Wang et al. (2020) (Wang et al., 2020) consider the panel data of Brazil, Russia, India, and China (BRIC countries), and conclude that CO_2 emissions promote the economic growth of BRIC countries, and that the relationship between economic growth and human development supports the feedback hypothesis. Adekoya et al. (2021) (Adekoya et al., 2021) use fixed individual effect and fixed time effect models to examine the relationship between renewable energy, carbon emissions, and human development in 126 countries around the world from 2000 to 2014. The study has found that renewable energy consumption has a significant positive impact on human development, but the impact on the Middle East, North Africa, Central America, and the Caribbean regions is completely negative, while the impact on Sub-Saharan Africa region is negligible. However, human development responds positively to carbon emissions in all the regions. Brini (2021) (Brini, 2021) finds that renewable energy consumption can help alleviate climate change in African countries by analyzing sample data from 16 selected African countries from 1980 to 2014, and this result was confirmed by the study of Adedoyin and Nwulu et al. (2021) (Adedoyin et al., 2021), and Gyamfi et al. (2021) (Gyamfi et al., 2021).

It is also argued that the use of renewable energy alone will not achieve the desired goal when it comes to combating climate change. Therefore, in the area of carbon emissions, buildings have the potential to be the last mile in the transition of carbon neutrality (Zhang et al., 2022). Likewise, Chen et al. (2022) (Chen et al., 2022) and Li et al. (2022) (Li et al., 2022) examined the relationship between CO_2 emissions and buildings through an econometric approach and showed a long-term causal relationship between the two, supporting the carbon Kuznets curve (CKC) hypothesis.

In summary, the existing empirical research on the relationship between economic growth, renewable energy, human development and climate change mainly reveals how to use different groups and different methods from the perspective of advanced and rapidly developing emerging countries to lead to uncertain results, especially focusing on the OECD, BRICS and European countries, and thus lacking relevant discussions on underdeveloped regions. Specifically, this may be because the above countries are more prominent in the deployment and use of renewable energy, and they tend to be more industrialized and therefore carbon intensive. However, with the rapid economic growth of various countries in the world, the impact of renewable energy and human development in countries with different income levels on climate change needs to be further explored, especially in lower-middle-income and low-income countries. Therefore, this study fills the gap in the existing literature, and this will further probe, significantly, the inter-links between these variables in lower-middle-income and low-income countries. In other words, this study analyzes the impact of economic growth, renewable energy, and HDI on climate change from a macroeconomic perspective in countries with different income levels, and is the extension of studies of Adekoya et al. (2021) (Adekoya et al., 2021), Wang et al. (2018) (Wang et al., 2018), Sasmaz et al. (2020) (Sasmaz et al., 2020), Pîrlogea (2012) (Pîrlogea, 2012) and Sinha et al. (2016) (Sinha and Sen, 2016).

3 METHODOLOGY AND DATA

3.1 PVAR Model Specification

Panel autoregression model (panel VAR) was first proposed by Holtz-Eakin et al. (1988) (Holtz-Eakin et al., 1988), and then Love et al. (2006) (Love and Zicchino, 2006) further improved it. Compared with the ordinary VAR model, this model is an organic synthesis of the panel data model and the vector autoregressive model, and has the dual advantages of time series and panel data. It is not only suitable for analyzing the relationship between complex variables, but also suitable for analyzing the influence of one variable on other variables (Shen, 2020). In addition, the model treats all variables as endogenous variables, which circumvents the relationship assumptions of the fixed structure model, and to a certain extent reduces some restrictive conditions of the vector autoregressive model, which is used to examine the interaction between the variables and their leads and lags (Aydin, 2019). Given that there are individual differences in the impact of different types of variable indicators on climate change, and individual variable data will also change over time. Therefore, this study adds individual fixed effects and time fixed effects to the model, and the general manifestation of PVAR model is as follows:

$$y_{i,t} = \alpha_i + \sum_{j=1}^{p} \beta_j y_{i,t-j} + x_i + \varphi_i + \varepsilon_{i,t} \tag{1}$$

where i refers to each sample; t refers to the year; $y_{i,t}$ is a vector of dependent variable; γ_i is the individual effect of the sample; β_j is the parameter matrix; p is the lag order; x_i is individual effect; φ_i is the time effect; $\varepsilon_{i,t}$ is random interference terms that obey the normal distribution.

The matrix form of the PVAR model reported in **Eq. 1** can also be rewritten in six equations, **Eqs 2–8**, as follows:

$$\begin{aligned}\Delta \ln(CE_{it}) = \alpha_{1i} &+ \sum_{j=1}^{p}\beta_1\Delta\ln(CE_{i,t-j}) + \sum_{j=1}^{p}\gamma_1\Delta\ln(RE_{i,t-j}) \\ &+ \sum_{j=1}^{p}\delta_1\Delta\ln(HDI_{i,t-j}) + \sum_{j=1}^{p}\theta_1\Delta\ln(IND_{i,t-j}) \\ &+ \sum_{j=1}^{p}\rho_1\Delta\ln(FDI_{i,t-j}) + \sum_{j=1}^{p}\tau_1\Delta\ln(TRO_{i,t-j}) \\ &+ \sum_{j=1}^{p}\omega_1\Delta\ln(GDP_{i,t-j}) + x_{1i} + \varphi_{1i} + \varepsilon_{1i,t}\end{aligned} \tag{2}$$

$$\begin{aligned}\Delta \ln(RE_{it}) = \alpha_{2i} &+ \sum_{j=1}^{p}\beta_2\Delta\ln(RE_{i,t-j}) + \sum_{j=1}^{p}\gamma_2\Delta\ln(CE_{i,t-j}) \\ &+ \sum_{j=1}^{p}\delta_2\Delta\ln(HDI_{i,t-j}) + \sum_{j=1}^{p}\theta_2\Delta\ln(IND_{i,t-j}) \\ &+ \sum_{j=1}^{p}\rho_2\Delta\ln(FDI_{i,t-j}) + \sum_{j=1}^{p}\tau_2\Delta\ln(TRO_{i,t-j}) \\ &+ \sum_{j=1}^{p}\omega_2\Delta\ln(GDP_{i,t-j}) + x_{2i} + \varphi_{2i} + \varepsilon_{2i,t}\end{aligned} \tag{3}$$

$$\begin{aligned}\Delta \ln(HDI_{it}) = \alpha_{3i} &+ \sum_{j=1}^{p}\beta_3\Delta\ln(HDI_{i,t-j}) \\ &+ \sum_{j=1}^{p}\gamma_3\Delta\ln(CE_{i,t-j}) + \sum_{j=1}^{p}\delta_3\Delta\ln(RE_{i,t-j}) \\ &+ \sum_{j=1}^{p}\theta_3\Delta\ln(IND_{i,t-j}) + \sum_{j=1}^{p}\rho_3\Delta\ln(FDI_{i,t-j}) \\ &+ \sum_{j=1}^{p}\tau_3\Delta\ln(TRO_{i,t-j}) \\ &+ \sum_{j=1}^{p}\omega_3\Delta\ln(GDP_{i,t-j}) + x_{3i} + \varphi_{3i} + \varepsilon_{3i,t}\end{aligned} \tag{4}$$

$$\begin{aligned}\Delta \ln(IND_{it}) = \alpha_{4i} &+ \sum_{j=1}^{p}\beta_4\Delta\ln(IND_{i,t-j}) \\ &+ \sum_{j=1}^{p}\gamma_4\Delta\ln(CE_{i,t-j}) + \sum_{j=1}^{p}\delta_4\Delta\ln(RE_{i,t-j}) \\ &+ \sum_{j=1}^{p}\theta_4\Delta\ln(HDI_{i,t-j}) + \sum_{j=1}^{p}\rho_4\Delta\ln(FDI_{i,t-j}) \\ &+ \sum_{j=1}^{p}\tau_4\Delta\ln(TRO_{i,t-j}) \\ &+ \sum_{j=1}^{p}\omega_4\Delta\ln(GDP_{i,t-j}) + x_{4i} + \varphi_{4i} + \varepsilon_{4i,t}\end{aligned} \tag{5}$$

$$\begin{aligned}\Delta \ln(FDI_{it}) = \alpha_{5i} &+ \sum_{j=1}^{p}\beta_5\Delta\ln(FDI_{i,t-j}) + \sum_{j=1}^{p}\gamma_5\Delta\ln(CE_{i,t-j}) \\ &+ \sum_{j=1}^{p}\delta_5\Delta\ln(RE_{i,t-j}) + \sum_{j=1}^{p}\theta_5\Delta\ln(HDI_{i,t-j}) \\ &+ \sum_{j=1}^{p}\rho_5\Delta\ln(IND_{i,t-j}) + \sum_{j=1}^{p}\tau_5\Delta\ln(TRO_{i,t-j}) \\ &+ \sum_{j=1}^{p}\omega_5\Delta\ln(GDP_{i,t-j}) + x_{5i} + \varphi_{5i} + \varepsilon_{5i,t}\end{aligned} \tag{6}$$

$$\begin{aligned}\Delta \ln(TRO_{it}) = \alpha_{6i} &+ \sum_{j=1}^{p}\beta_6\Delta\ln(TRO_{i,t-j}) + \sum_{j=1}^{p}\gamma_6\Delta\ln(CE_{i,t-j}) \\ &+ \sum_{j=1}^{p}\delta_6\Delta\ln(RE_{i,t-j}) + \sum_{j=1}^{p}\theta_6\Delta\ln(HDI_{i,t-j}) \\ &+ \sum_{j=1}^{p}\rho_6\Delta\ln(IND_{i,t-j}) + \sum_{j=1}^{p}\tau_6\Delta\ln(FDI_{i,t-j}) \\ &+ \sum_{j=1}^{p}\omega_6\Delta\ln(GDP_{i,t-j}) + x_{2i} + \varphi_{6i} + \varepsilon_{6i,t}\end{aligned} \tag{7}$$

$$\Delta \ln(GDP_{it}) = \alpha_{7i} + \sum_{j=1}^{p}\beta_7\Delta\ln\left(GDP_{i,t-j}\right) + \sum_{j=1}^{p}\gamma_7\Delta\ln\left(CE_{i,t-j}\right) + \sum_{j=1}^{p}\delta_7\Delta\ln\left(RE_{i,t-j}\right) + \sum_{j=1}^{p}\theta_7\Delta\ln\left(HDI_{i,t-j}\right) + \sum_{j=1}^{p}\rho_7\Delta\ln\left(IND_{i,t-j}\right) + \sum_{j=1}^{p}\tau_7\Delta\ln\left(FDI_{i,t-j}\right) + \sum_{j=1}^{p}\omega_7\Delta\ln\left(TRO_{i,t-j}\right) + x_{7i} + \varphi_{7i} + \varepsilon_{7i,t} \quad (8)$$

where CE represents the growth rate of carbon emissions per capita, HDI refers to Human Development Index growth rate, RE denotes renewable energy consumption, GDP represents economic growth. Macroeconomic variables comprise the foreign direct investment, trade openness and industrialization, denoted as FDI, TRO and IND, respectively.

In addition, after the vector autoregressive model (VAR) is widely used in the time series model, and through the continuous improvement and development of scholars, the GMM estimation method of the parallel panel model is obtained in the PVAR method. The GMM removes deterministic effects by performing some transformation other than differencing, which is called "forward mean differencing or orthogonal deviation" (Helmert process). To eliminate the fixed effects, all variables in the equation are transformed in deviations from forward means in this procedure (Amer, 2020). Therefore, before the GMM estimation, the forward mean difference method will be used to eliminate the time effects and individual fixed effects in the panel data to ensure that the lagged variables and the transformed variables are orthogonal to form effective instrumental variables, and use AIC, BIC, and HQIC information criterion to calculate, screen the lag order of the model, and select the optimal lag order. The general equation is as follows:

Akaike information criterion:

$$AIC = \left[M.\ln(2\pi) + M + ln\left|\hat{V}\right|\right] + \frac{2k}{N^*}$$

Bayesian information criterion:

$$BIC = \left[M.\ln(2\pi) + M + ln\left|\hat{V}\right|\right] + \frac{ln(N^*)k}{N^*}$$

Hannan-Quinn information criterion:

$$HQIC = \left[M.\ln(2\pi) + M + ln\left|\hat{V}\right|\right] + \frac{2ln[ln(N^*)]k}{N^*}$$

where $N^* = N(T-P)$ is the number of valid samples in the model, and k is the number of parameters in the model.

3.2 Data

The purpose of this study is to understand whether economic indicators, renewable energy and human development will have an impact on climate change. Therefore, we obtained secondary data from four sources, including the World Bank, the International Energy Agency (IEA) and the United Nations Development Programme (UNDP) is obtained (**Table 1**), and transformed all variables in the specified model into double logarithmic form considering the principles of data comprehensiveness and availability. Such conversion helps to obtain the relative normal distribution of the data and solve the problem of heteroscedasticity, making the estimation results meaningful and easy to interpret. Due to the lack of data for some countries in Central Europe, Southern Europe, Africa, South America, and the Middle East regions, this study selects four panel groups (high-income countries, upper-middle-income countries, lower-middle-income countries, and low-income countries) composed of 105 countries in the world from 1990 to 2019. The panel data of those countries are used as samples. Then, the impact on climate change is explored from the perspective of seven variables, including carbon dioxide emissions per capita (CE), human development index (HDI), renewable energy consumption (RE), industrialization (IND), foreign direct investment (FDI), trade openness (TRO), and GDP growth rate (GDP). According to the latest income grouping standard of the World Bank (2020), the selected countries are divided into four groups, as shown in **Table 2**.

4 RESULTS AND DISCUSSION

4.1 Stationarity Test of Panel Data

Since the panel data used has the nature of time series, in order to avoid the problem of spurious regression caused by non-stationary, before using the Panel VAR model to measure the dynamic interaction effects between economic indicators, renewable energy, human development and climate change, the unit root test is an inevitable preliminary verification method. According to the two common panel unit root tests (LLC and IPS criteria) proposed by Levin et al. (2002) (Levin et al., 2002) and Im et al. (2003) (Im et al., 2003), this study first takes the natural logarithm of the data and then performs the unit root test. As a result, the variable indicators of the four panel groups are not completely stable at the test levels of 10, 5, and 1%, so no results are given (**Tables 3–6**). Secondly, after the first-order difference transformation, the non-stationary variable index becomes a stationary sequence at the 1% significance level, which indicates that the variable sequence is a first-order integral sequence I (1). Therefore, it is believed that the variable indicators in the four panel groups of the selected countries are I (0) integrals or a first-order integral sequence I (1). Finally, this study screens the lag order of the model according to the AIC, BIC and HQIC information criteria, and determines the maximum lag order of the four panel groups as $p = 1$ (**Tables 4**, **7**).

4.2 Generalized Methods of Moments Estimation of Panel VAR Model

Before the generalized method of moments (GMM) estimation, in order to avoid errors in the estimation results, it is necessary to perform Helmert process conversion on the data first to eliminate the time point effect in the model. Secondly, on this basis, the forward mean difference method is used to remove individual

TABLE 1 | Variable description.

Variables	Description	Data source	Measure
CE	Carbon emissions	World bank	Tons per capita
RE	Renewable energy consumption	IEA	% of primary energy
HDI	Human development index	UNDP	Index
IND	Industrialization	World bank	% of GDP
FDI	Foreign direct investment	World bank	% of GDP
TRO	Trade openness	World bank	% of GDP
GDP	Economic growth	World bank	GDP growth (annual %)

TABLE 2 | Description of regions.

Panel	List of selected countries	No. of countries
Low income countries	Congo, Ethiopia, Eritrea, Gambia, Guinea, Haiti, Malawi, Mozambique, Niger, Rwanda, Sierra Leone, Syrian Arab Republic, Tanzania, Togo, Uganda	15
Lower middle income countries	Algeria, Bangladesh, Benin, Bolivia, Cote d'Ivoire, Arab Republic of Egypt, El Salvador, Ghana, Honduras, India, Indonesia, Kenya, The Lao People's Democratic Republic, Mauritania, Mongolia, Morocco, Nepal, Nicaragua, Papua New Guinea, Philippines, Senegal, Sudan, Tunisia, Ukraine, Vietnam, Zimbabwe	26
Upper middle income countries	Argentina, Armenia, Azerbaijan, Belarus, Botswana, Bulgaria, Brazil, China, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Gabon, Guatemala, Jamaica, Kazakhstan, Malaysia, Mauritius, Mexico, Moldova, North Macedonia, Panama, Paraguay, Peru, Romania, Russian Federation, Serbia, South Africa, Thailand, Turkey	31
High income countries	Australia, Austria, Belgium, Canada, Chile, Cyprus, Czechia, Denmark, Finland, France, Germany, Greece, Hong Kong (China), Hungary, Ireland, Israel, Italy, Japan, Korea, Lithuania, Luxembourg, New Zealand, Norway, Poland, Portugal, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States	33

Notes: The source from World Bank database.

TABLE 3 | Test result of panel unit root-High income countries.

Variables	LLC test		IPS test		Int. order
	t value	*p* value	W-t-bar value	*p* value	
CE	−7.521	0.000[a]	−13.713	0.000[a]	I(1)
RE	−10.748	0.000[a]	−16.621	0.000[a]	I(1)
HDI	−9.856	0.000[a]	−2.685	0.004[a]	I(0)
IND	−13.678	0.000[a]	−14.819	0.000[a]	I(1)
FDI	−6.318	0.000[a]	−6.504	0.000[a]	I(0)
TRO	−17.637	0.000[a]	−16.385	0.000[a]	I(1)
GDP	−10.240	0.000[a]	−11.738	0.000[a]	I(0)

[a]*Note: means passing the significance test at 1% level.*

TABLE 4 | Test result of panel unit root-Upper middle-income countries.

Variables	LLC test		IPS test		Int. order
	t value	*p* value	W-t-bar value	*p* value	
CE	−4.076	0.000[a]	−2.981	0.001[a]	I(0)
RE	−3.715	0.000[a]	−2.338	0.010[a]	I(0)
HDI	−33.813	0.000[a]	−18.125	0.000[a]	I(1)
IND	−2.973	0.002[a]	−3.008	0.001[a]	I(0)
FDI	−5.962	0.000[a]	−7.474	0.000[a]	I(0)
TRO	−4.388	0.000[a]	−3.403	0.000[a]	I(0)
GDP	−6.011	0.000[a]	−9.420	0.000[a]	I(0)

[a]*Note: means passing the significance test at 1% level.*

fixed effects to achieve orthogonality between lagged variables and transposed variables. This study uses the GMM estimation method to estimate the interaction between economic indicators, renewable energy, human development, and climate change. The estimated results of the PVAR model of the four panel groups are shown in **Tables 8–11**.

TABLE 5 | Test result of panel unit root-Lower middle-income countries.

Variables	LLC test		IPS test		Int. order
	t value	*p* value	W-t-bar value	*p* value	
CE	−10.366	0.000[a]	−14.049	0.000[a]	I(1)
RE	−12.390	0.000[a]	−14.055	0.000[a]	I(1)
HDI	−17.511	0.000[a]	−9.986	0.000[a]	I(1)
IND	−9.952	0.000[a]	−12.010	0.000[a]	I(1)
FDI	−7.117	0.000[a]	−6.990	0.000[a]	I(0)
TRO	−2.840	0.002[a]	−1.534	0.063[b]	I(0)
GDP	−6.595	0.000[a]	−8.742	0.000[a]	I(0)

[a]*Notes: means passing the significance test at 1% levels.*
[b]*means passing the significance test at 10% levels.*

TABLE 6 | Test result of panel unit root-Low-income countries.

Variables	LLC test		IPS test		Int. order
	t value	*p* value	W-t-bar value	*p* value	
CE	−10.353	0.000[a]	−10.712	0.000[a]	I(1)
RE	−9.597	0.000[a]	−9.168	0.000[a]	I(1)
HDI	−3.660	0.001[a]	−7.887	0.000[a]	I(1)
IND	−10.318	0.000[a]	−7.401	0.000[a]	I(0)
FDI	−18.039	0.000[a]	−10.084	0.000[a]	I(0)
TRO	−3.661	0.001[a]	−4.925	0.000[a]	I(0)
GDP	−5.774	0.000[a]	−6.527	0.000[a]	I(0)

[a]*Note: means passing the significance test at 1% level.*

TABLE 7 | Selection order criterion.

Panel	Lag	AIC	BIC	HQIC
High income countries	1	−9.594[a]	−9.284[a]	−9.475[a]
Upper middle-income countries	1	−7.207[a]	−6.889[a]	−7.085[a]
Lower middle-income countries	1	−3.627[a]	−3.274[a]	−3.491[a]
Low-income countries	1	3.243[a]	3.782[a]	3.456[a]

[a]*Notes: indicates lag order selected by the criterion*
AIC: akaike information criterion; BIC: bayesian information criterion; HQIC: Hannan-Quinn information criterion.

4.2.1 High Income Countries

The estimated results of the PVAR model for high-income countries are shown in **Table 8**. Firstly, in the lagging period, economic indicators (FDI, trade openness, and economic growth), renewable energy consumption, human development, and CO_2 emissions are vulnerable to its own impact at the 10% and 1% significance levels, but industrialization does not have obvious effect on itself **Table 5**.

Secondly, from the impact of economic indicators on CO_2 emissions, it can be seen that economic growth and industrialization have positive effects on CO_2 emissions at the 1% and 10% significance levels, and vice versa, supporting the feedback hypothesis (Banday and Aneja, 2020). However, CO_2 emissions have a significant negative impact on FDI at the 10% significance level, and the positive impact of CO_2 emissions is much greater than the negative impact of economic indicators, which shows that some high-emission industries in high-income countries are being replaced by low-carbon industries under the dual effect of energy saving and emission reduction. In addition, economic growth has a positive impact on industrialization, FDI, and trade openness at the 1% significance level. This indicates that economic growth not only attracts large inflows of FDI and the improvement of industrialization level for those countries, but also has a positive impact on technological innovation, employment and income. Moreover, it plays an important role in improving productivity. However, industrialization has a negative impact on FDI and trade openness at the 5 and 10% significance levels, and vice versa. This result implies that those high-income countries have increased awareness of environmental pollution and quality issues in life. This result is supported by the studies of Mongo et al. (2021) (Mongo et al., 2021), Eller et al. (2005) (Eller et al., 2005) and Rahman (2015) (Rahman, 2015). Conversely, when CO_2 emissions increase by 1%, industrialization and FDI will also increase, but the increase relative to economic growth is almost insignificant, especially at the 10% significance level, which is statistically weak. This is consistent with the results of Koengkan (2019) (Koengkan, 2019) and Soukiazis et al. (2019) (Soukiazis et al., 2019). They believe that the increase in CO_2 emissions is positively correlated with fossil energy consumption. As expected, the economic growth of high-income countries promotes the increase of CO_2 emissions.

Thirdly, from the impact of renewable energy consumption on CO_2 emissions and economic indicators, it can be seen that renewable energy consumption has no significant impact on CO2 emissions, industrialization, trade openness, and FDI in high-income countries. This supports the neutral hypothesis. This means that any renewable energy consumption policy

TABLE 8 | Panel VAR model estimation results for high-income countries.

Dependent variables	Independent variables (GMM estimates)						
	D.CE(−1)	**D.RE(−1)**	**HDI(−1)**	**D.IND(−1)**	**FDI(−1)**	**D.TRO(−1)**	**GDP(−1)**
D.CE	−0.126[c] (−16.24)	0.010 (0.732)	−0.162[a] (−1.867)	−0.050[a] (−1.857)	−0.002 (−0.578)	−0.020 (−1.199)	0.010[c] (12.582)
D.RE	−0.138 (−1.518)	−0.059[a] (−1.718)	0.336 (0.537)	−0.296 (−1.269)	−0.022 (−1.428)	0.040 (0.671)	−0.039[c] (−4.519)
HDI	0.002[c] (4.569)	−0.001 (−1.216)	0.964[c] (23.44)	0.005[b] (2.189)	0.0003 (1.679)	−0.004[c] (−3.454)	−2.06E-05 (−0.325)
D.IND	−0.018[c] (−3.083)	−0.004 (−0.934)	−0.120[a] (−1.816)	0.014 (0.977)	−0.003[a] (−1.956)	−0.024[b] (−2.031)	0.004[c] (4.363)
FDI	−0.314[a] (−1.745)	0.096 (0.837)	0.319 (0.146)	−0.857[b] (−2.273)	0.221[c] (7.940)	0.338 (0.763)	0.235[c] (7.126)
D.TRO	0.001 (0.096)	−0.003 (−0.225)	−0.191 (−1.450)	−0.026[a] (−1.811)	−0.0001 (−0.034)	−0.079[c] (−3.365)	0.011[c] (6.188)
GDP	0.800[c] (2.926)	0.0004 (0.005)	−2.367 (−1.288)	−0.667 (−1.222)	0.028 (1.012)	−0.413 (−0.558)	0.277[c] (7.382)

Notes: 1) The panel VAR model is estimated by system GMM. 2) Stability condition is satisfied where all of the Eigen values lie inside the unit circle and brackets indicate t-statistics.
[a]indicates significance at the 10% levels of significance.
[b]indicates significance at the 5% levels of significance.
[c]indicates significance at the 1% levels of significance, and D. denotes the first differences.

TABLE 9 | Panel VAR model estimation results for upper middle–income countries.

Dependent variables	Independent variables (GMM estimates)						
	CE(−1)	**RE(−1)**	**D.HDI(−1)**	**IND(−1)**	**FDI(−1)**	**TRO(−1)**	**GDP(−1)**
CE	0.839[b] (17.18)	0.002 (0.086)	1.375[b] (4.847)	−0.023 (−0.741)	0.001 (0.231)	−0.032 (−1.134)	0.006 (1.152)
RE	−0.017 (−0.156)	0.727[b] (6.059)	−2.502[a] (−2.048]	−0.109 (−0.469]	0.009 (0.735)	−0.098 (−0.903)	0.009 (0.491)
HDI	0.005[a] (−2.501)	−0.001 (−0.806)	0.010 (0.974)	0.006 (1.112)	−0.002[b] (−5.633)	−0.001 (−1.004)	0.002[b] (5.787)
IND	−0.033[b] (−2.873)	−0.003 (−0.280)	0.073 (0.431)	0.815[b] (47.12)	−0.004[a] (−2.289)	−0.005 (−0.329)	−0.004 (−1.323)
FDI	−0.017 (−0.100)	0.053 (0.455)	9.633[b] (6.938)	−0.060 (−0.151)	0.427[b] (15.90)	0.300 (1.221)	0.054 (1.200)
TRO	−0.106[b] (−3.631)	−0.008 (−0.441)	−0.424 (−1.592)	−0.173[b] (−7.193)	0.005[b] (2.843)	0.779[b] (48.53)	0.007[a] (2.462)
GDP	−0.687 (−1.131)	−0.347 (−1.185)	4.145 (0.840)	−0.840 (−1.018)	0.014 (0.263)	0.060 (0.152)	0.301[b] (3.227)

Notes: 1) The panel VAR model is estimated by system GMM. 2) Stability condition is satisfied where all of the Eigen values lie inside the unit circle and brackets indicate t–statistics.
[a]indicates significance at the 10% levels of significance, and D. denotes the first differences.
[b]indicates significance at the 5% levels of significance, and D. denotes the first differences.

TABLE 10 | Panel VAR model estimation results for lower middle–income countries.

Dependent variables	Independent variables (GMM estimates)						
	D.CE(−1)	**D.RE(−1)**	**D.HDI(−1)**	**D.IND(−1)**	**FDI(−1)**	**TRO(−1)**	**GDP(−1)**
D.CE	−0.045[a] (−2.015)	−0.030 (−0.477)	0.811[a] (1.887)	0.055 (1.114)	0.014[c] (3.282)	−0.022 (−0.799)	0.010[a] (1.655)
D.RE	−0.142[c] (−2.723)	−0.154[b] (−2.723)	0.186 (0.202)	−0.030[a] (−1.717)	0.019[b] (2.736)	−0.119[c] (−3.576)	0.010[a] (1.846)
D.HDI	0.001 (0.902)	0.002 (0.940)	0.318[c] (9.036)	0.004[a] (1.831)	−0.001[c] (−3.578)	0.003 (0.877)	0.002[c] (3.389)
D.IND	−0.039[c] (−6.567)	−0.025 (−1.509)	0.510[c] (3.601)	−0.349[c] (−25.94)	−0.003 (−1.327)	0.080[c] (5.772)	0.032[c] (12.90)
FDI	0.340 (1.510)	−0.004 (−0.009)	3.849 (0.665)	0.336[b] (2.233)	0.350[c] (15.71)	0.846[b] (2.354)	0.16[c] (2.980)
TRO	0.018 (0.799)	−0.003 (−0.038)	0.970 (1.646)	0.048[b] (2.235)	0.010[c] (3.420)	0.775[c] (25.33)	−0.004 (−0.660)
GDP	0.601[a] (2.039)	0.485 (0.957)	2.369 (0.227)	0.128 (0.303)	−0.048 (−0.704)	0.216 (0.777)	0.144 (1.340)

Notes: 1) The panel VAR model is estimated by system GMM. 2) Stability condition is satisfied where all of the Eigen values lie inside the unit circle and brackets indicate t–statistics.
[a]indicates significance at the 10% levels of significance.
[b]indicates significance at the 5% levels of significance.
[c]indicates significance at the 1% levels of significance, and D. denotes the first differences

can be adopted independently of economic growth. Chiu et al. (2009) (Chiu and Chang, 2009) suggest that this result may be due to the fact that those countries have not yet reached the threshold point where renewable energy consumption starts to significantly reduce CO_2 emissions. It is in line with the conclusion of a study by Amer (2020) (Amer, 2020), which believes that only when renewable energy supply accounts for about 8.3889% of the total energy supply can it have an impact on reducing CO_2 emissions. Thus, according to the BP Statistical Review of World Energy (2020), the renewable energy consumption as a percentage of total energy consumption in some selected countries are: Saudi Arabia 0.144%, Singapore 0.239%, United Arab Emirates 0.771%, Hungary 4.017%, Luxembourg 4.061%, Belgium 6.937%, United States 8.912%, Japan 9.313%, France 11.733%, United Kingdom 14.45%, Germany 17.485%, Canada 27.638%, etc. However, according to Menyah et al. (2010) (Menyah and Wolde-Rufael, 2010) and Bilan et al. (2019) (Bilan et al., 2019), we argue that in the case of global warming, these countries must

TABLE 11 | Panel VAR model estimation results for low–income countries.

Dependent variables	Independent variables (GMM estimates)						
	D.CE(–1)	D.RE(–1)	D.HDI(–1)	IND(–1)	FDI(–1)	TRO(–1)	GDP(–1)
D.CE	–0.245[c] (–8.775)	–0.197[a] (–1.790)	0.049 (0.075)	0.057 (0.731)	–0.005 (–0.304)	–0.103 (–0.478)	–0.022 (–0.592)
D.RE	0.149[c] (4.272)	0.048 (0.191)	2.258 (1.058)	–0.188 (–1.395)	0.043 (1.420)	–0.031 (–0.072)	0.043 (0.743)
D.HDI	–0.004 (–0.542)	–0.019 (–0.376)	–0.072 (–0.815)	0.006 (0.388)	0.003 (0.820)	–0.021 (–0.784)	0.011[a] (1.784)
IND	–0.048 (–1.248)	0.024 (0.251)	0.558 (0.635)	0.795[c] (8.811)	–0.008 (–0.810)	–0.105 (–0.707)	–0.008 (–0.253)
FDI	0.296 (0.726)	1.979 (1.145)	–1.329 (–0.391)	–0.808[b] (–2.219)	0.385[c] (5.663)	0.326 (0.533)	0.042 (0.217)
TRO	–0.094 (–1.086)	–0.180 (–0.434)	0.572 (0.348)	0.032 (0.171)	0.014 (0.484)	0.603[a] (2.024)	0.069 (1.333)
GDP	0.169 (0.316)	–1.223 (–0.372)	–3.318 (–0.235)	–0.153 (–0.085)	0.038 (0.299)	–0.688 (–0.235)	–0.461 (–0.516)

Notes: 1) The panel VAR model is estimated by system GMM. 2) Stability condition is satisfied where all of the Eigen values lie inside the unit circle and brackets indicate t–statistics
[a]indicates significance at the 10% levels of significance.
[b]indicates significance at the 5% levels of significance.
[c]indicates significance at the 1% levels of significance, and D. denotes the first differences

reduce the share of fossil fuel consumption in their productive lives, while strengthening their support policies to promote a faster development of the renewable energy sector. In addition, economic growth has a negative impact on renewable energy consumption at the 1% significance level, supporting the protection hypothesis, which means that conservative policies on renewable energy consumption will not have a negative impact on economic activities. This finding is similar to existing energy literature such as Destek et al. (2017) (Destek and Aslan, 2017) for the case of Emerging economies and Marques et al. (2012) (Marques and Fuinhas, 2012) for the case of Europe countries.

Fourth, from the impact of HDI on economic indicators, it can be seen that HDI has a negative impact on industrialization at the 10% significance level, while industrialization has a positive impact on HDI at the 5% significance level, but HDI has a negative impact. The positive impact is greater than the positive impact of industrialization, which shows that to some extent HDI has suppressed the decline in the unemployment rate in high-income countries. In addition, trade openness has a significant negative impact on HDI at the 1% significance level. This result is supported by the research of Wang et al. (2018) (Wang et al., 2018) and Khan et al. (2019) (Khan et al., 2019) argue that trade openness will lead to a decline in HDI. Conversely, the increase in HDI will inhibit more external economic activities. However, Amer (2020) (Amer, 2020) argues that higher levels of HDI helps stimulate economic activity in the outside world, and that as standards of living increase, high-income countries can have the opportunity to consume different kinds of goods and services that are not available domestically or are produced relatively cheaply.

Finally, there are not many studies on the impact of HDI on CO_2 emissions in previous literature, and there are relatively few empirical studies on this relationship. In summary, HDI has a significant negative impact on CO_2 emissions at the 10% significance level, but this negative impact is far greater than the positive impact of CO_2 emissions at the 1% significance level (Amer, 2020). Therefore, the positive impact of CO_2 emissions on HDI is negligible. With the high-quality economic development of high-income countries, to a certain extent HDI has led to a reduction in CO_2 emissions, which also reflects those high-income countries are increasingly aware of the important role of high-quality human development in order to achieve the expectations of reducing CO_2 emissions. However, this is contrary to the findings of Soukiazis et al. (2019) (Soukiazis et al., 2019) for OECD countries, who concluded that CO_2 emissions have a negative impact on HDI and do not have any statistical correlation.

4.2.2 Upper Middle-Income Countries

Table 9 shows the estimation results of the PVAR model for upper-middle-income countries. Firstly, in the lagging period, economic indicators (industrialization, FDI, trade openness, and economic growth), renewable energy consumption, and CO_2 emissions are vulnerable to its own influence at the 1% significance level, but HDI is not significant to itself.

Secondly, by analyzing the impact of renewable energy consumption and economic indicators on CO_2 emissions, it can be seen that CO_2 emissions have a negative impact on industrialization and trade openness at the 1% significance level (one-way causality), and the impact coefficients are all over 0.03. This shows that there is an inverted U-shaped relationship between industrialization, trade openness, and CO_2 emissions in upper-middle-income countries, and supports the EKC hypothesis that CO_2 emissions initially increase with the economic development of upper-middle-income countries until they reach a stable point and then decline. In the case of China, studies such as Jalil et al. (2011) (Jalil and Feridun, 2011), Riti et al. (2017) (Riti et al., 2017) and Hao et al. (2021) (Hao and Cho, 2021) also confirm the inverted U-shaped relationship between income and environment performance for other pollutants. Surprisingly, FDI has a negative impact on industrialization at the 5% significance level, which shows that FDI has not only failed to promote the growth of the industrial sector in upper-middle income countries, but has hindered the economic growth of the industrial sector. At the same time, FDI has a positive impact on trade openness at the 1% significance level, which shows that the large inflow of FDI has greatly promoted the trade exports of those countries, and the trade exports of those countries have also indirectly hindered the development of industrialization and vice versa. This may be due to the extensive economic development of upper-middle-income countries in recent years, which has prompted a large inflow of

FDI, which will lead to the continuous deterioration of the environment in those countries. Therefore, investors from these countries pay more attention to environmental regulations and clean technologies in terms of FDI inflows, thereby improving energy efficiency and reducing CO_2 emissions (Zhang and Zhou, 2016). In addition, there is no statistical impact between economic growth, FDI, renewable energy consumption, and CO_2 emissions in upper-middle-income countries, and vice versa. Therefore, one may conclude that the EKC hypothesis and the PHH are invalid for these countries.

Thirdly, from the impact of HDI on economic indicators, it can be seen that there is a significant impact relationship (two-way causality) between HDI and FDI. From the perspective of the impact coefficient, the positive impact of HDI on FDI (9.633) is far greater than the negative impact of FDI on it (−0.002), which indicates that upper-middle-income countries have begun to pay attention to environmental pollution and quality issues in life, and are raising their requirements when attracting foreign direct investment projects, especially in environmental regulations. These results were supported by studies undertaken in relation to China by Hung (2021) (Hung, 2021) and in BRICS countries by Wang et al. (2020) (Wang et al., 2020). However, this result was contrary to those of Reiter et al. (2010) (Reiter and Steensma, 2010), who pointed out the positive relationship between foreign direct investment and HDI for upper middle-income countries, which supports the feedback hypothesis. In addition, economic growth has a positive impact on HDI at the 1% significance level, and its impact coefficient is positive, which means that economic growth promotes HDI in the long run. The similar findings are found in the studies of Niu et al. (2013) (Niu et al., 2013), and Sasmaz et al. (2020) (Sasmaz et al., 2020). However, this finding differs with the conclusions of Adekoya et al. (2021) (Adekoya et al., 2021), Wang et al. (2018) (Wang et al., 2018) and Mustafa et al. (2017) (Mustafa et al., 2017). With the improvement of the level of economic development, upper-middle-income countries pay more attention to environmental pollution and quality issues in life, so that they can better obtain social services such as medical treatment and education and improve the quality of life of national. Meanwhile, upper middle-income countries are the middle force of global economic development, and FDI inflows play an important role in economic development, increasing productivity, creating jobs and income, so FDI inflows contribute to the human development of these countries.

Finally, from the impact of HDI on CO_2 emissions and renewable energy consumption, it can be seen that HDI and CO_2 emissions are positively correlated at the 1% and 5% significance levels, which supports the feedback hypothesis. This shows that CO_2 emissions are a strong and positive determinant of human development indicators, and on the contrary, CO_2 emissions can help increase HDI. This result was supported by studies undertaken in relation to 126 countries by Adekoya et al. (2021) (Adekoya et al., 2021). However, studies like Farhani et al. (2014) (Farhani and Shahbaz, 2014) and Chen et al. (2019) (Chen et al., 2019) have also disproved the claim of positive relationship between human development and CO_2 emissions. In addition, HDI has a negative impact on renewable energy consumption at the 5% significance level, and renewable energy consumption also has a negative impact on HDI, but it is not statistically significant. As expected, the increase in HDI levels has hindered the development of renewable energy in those countries. Our findings do not support the papers of Amer (2020) (Amer, 2020), Pîrlogea (2012) (Pîrlogea, 2012), and Ergun et al. (2019) (Ergun et al., 2019), who put forwarded the positive association between HDI and renewable energy consumption but agree with Ouedraogo (2013) (Ouedraogo, 2013). For example, in the newly industrialized countries (NIC's), energy consumption sources are being considered as inputs in the production process given that these countries are considering them as part of the industrialization process. Based on this, we take the example of China, which has become the world's largest energy consumer in the last decade or so, but the share of renewable energy is still relatively low, and it is not enough to support sustainable economic and environmental development. Therefore, in order to improve living standards and protect the global environment, energy needs to be used more efficiently and clean and reliable energy supplies need to be sought, and green growth must play a key role.

4.2.3 Lower Middle-Income Countries

The estimated results of the PVAR model for lower-middle-income countries are shown in **Table 10**. First, in the lagging period, economic indicators (industrialization, FDI and trade openness), renewable energy consumption and CO_2 emissions are easily affected by themselves at the 10, 5, and 1% significance levels, but economic growth does not have an obvious effect on itself.

Secondly, from the impact of economic indicators on CO_2 emissions, it can be seen that economic growth has a positive impact on CO_2 emissions at the 1% significance level, which supports the feedback hypothesis. This shows that economic growth is the main reason for the increase in CO_2 emissions in lower-middle-income countries. At the same time, FDI promotes CO_2 emissions at the 1% significance level and supports the protection hypothesis. However, compared with economic growth, the correlation between FDI and CO_2 emissions is stronger. In addition, it is also found that industrialization has a positive impact on FDI, and there is a two-way causal relationship between trade openness, FDI and industrialization. This shows that FDI provides necessary resources for the industrialization and economic growth of lower-middle-income countries. However, in order to promote economic growth in lower-middle-income countries, it is necessary to reduce environmental standards to attract FDI, which will attract high-polluting industries and backward technologies in developed countries. As a result, CO_2 emissions in those countries have risen and environmental pollution has increased. That is, these countries need to improve their environmental standards in order to effectively attract FDI without negatively impacting on trade activities and industrialization development, thus increasing their technological requirements, for example, in highly polluting industries. Therefore, one may conclude that there is some evidence for the PHH in lower middle-income countries. These results were supported by studies undertaken in BRICS countries by He et al. (2020) (He et al., 2020) and in relation to 54 countries by Omri et al. (2014) (Omri et al., 2014).

Thirdly, from the impact of CO_2 emissions and economic indicators on renewable energy consumption, it can be seen that economic growth and FDI have a positive impact at the 10% and 5% significance levels, which supports the growth hypothesis. However, at the 1% significance level, CO_2 emissions have a negative impact on renewable energy consumption. This means that lower-middle-income countries have gradually realized that it is not advisable to attract FDI to promote their own economic growth by lowering environmental regulations. Therefore, the rational and effective use of renewable energy is the most effective way to reduce CO_2 emissions without affecting their own economic growth. More interestingly, it is also found that although renewable energy consumption has a negative impact on CO_2 emissions, it is not significant. This shows that despite the continuous growth of lower-middle-income economies in recent years, although the average consumption of renewable energy in their energy supply structure accounts for 5.6% of the total primary energy consumption, those countries have failed to have a favorable impact on environmental quality. Thus, lower middle-income countries need to advance their technology requirements in order to use energy efficiently without negatively affecting economic development (Amer, 2020). These results were similar to Charfeddine et al. (2019) (Charfeddine and Kahia, 2019) who found, for lower middle-income countries, that renewable energy consumption does not contribute to reductions in CO_2 emissions in the short run.

Fourthly, from the impact of economic indicators on HDI, it can be seen that economic growth and industrialization have a positive impact on HDI at the 1% and 10% significance levels, and positive growth has a positive impact on industrialization at the 1% significance level, which supports the growth hypothesis. This result is not surprising. For lower-middle-income countries, industrialization plays an important role in economic growth, job creation, productivity increase, and income generation. Therefore, the process of industrialization helps promote human development in lower middle-income countries. This result was supported by studies undertaken in relation to BRICS countries by Wang et al. (2020) (Wang et al., 2020) and in 90 countries over the period 1990–2014 by Tran et al. (2019) (Tran et al., 2019). However, FDI has a negative impact on HDI at the 1% significance level, which means that foreign direct investment reduces the level of human development in lower-middle-income countries. The most direct reason is that lower-middle-income countries have reduced environmental standards to attract FDI and provide key resources for their economic growth and industrialization, thereby ignoring environmental pollution. Therefore, FDI leads to environmental degradation, which seriously affects the health and well-being and life quality of people in those countries. Our findings do not support the papers of Wang et al. (2020) (Wang et al., 2020) and Tran et al. (2019) (Tran et al., 2019), who put forward the positive association between human development and foreign direct investment but agree with Khan et al. (2019) (Khan et al., 2019), Mustafa et al. (2017) (Mustafa et al., 2017), and Gorus et al. (2019) (Gorus and Aslan, 2019).

Finally, from the impact of HDI on CO_2 emissions, it can be seen that HDI has a positive impact on CO_2 emissions at a significance level of 10%, which supports the growth hypothesis. Although CO_2 emissions also have a positive impact on HDI, it is not significant. Obviously, this situation is not necessarily wrong, because this study only focuses on the meaning of the indicators. By analyzing this situation, it follows the point of view put forward by Pîrlogea (2012) (Pîrlogea, 2012), which believes that according to HDI, global CO_2 emissions are generally divided into CO_2 emissions generated by the economic development of developed countries with HDI higher than 0.8 and the CO_2 emissions developing countries with HDI lower than 0.8 need to develop. Obviously, in the process of rapid economic development, the CO_2 emission index of lower-middle-income countries has reached a relatively high level. But once it enters the category of developed countries, according to the strategy aimed at reducing emissions, the CO_2 emission level will begin to decline. Therefore, for lower-middle-income countries, the speed of economic development and human activities are the main reasons for the current increase in CO_2 emissions (Adekoya et al., 2021).

4.2.4 Low-Income Countries

The estimated results of the PVAR model for low-income countries are shown in **Table 11**. First, in the lagging period, industrialization, FDI, and trade openness are susceptible to their own influence at the 1% and 10% significance levels, and the sign of the influence coefficient is positive. This means that more development in low-income countries is through FDI, industrialization and trade to bring more progress and success, thereby enhancing the overall economic strength and HDI of low-income countries. However, CO_2 emissions have a negative impact on themselves at the 1% significance level, with an impact coefficient of −0.245. This indicates that the consumption of renewable energy has little impact on the reduction of CO_2 emissions in low-income countries. This may be because most of the renewable energy consumed by economic development and human activities in low-income countries comes from traditional biomass, rather than clean modern renewable energy. Therefore, with the high demand for energy in low-income countries, since most of the energy supply comes from non-renewable resources, pollution levels are also increasing. These results were similar to Hasnisah, et al. (2019) (HasnisahAzlina et al., 2019) and Amer (2020) (Amer, 2020), who found that renewable energy consumption effect is insignificant in contributing to less pollution regarding the CO_2 emissions in selected 13 Asian countries.

Secondly, from the impact of renewable energy consumption on CO_2 emissions, it can be seen that renewable energy consumption has a negative impact on CO_2 emissions at the 10% significance level, with an impact coefficient of −0.197. However, CO_2 emissions have a positive impact on renewable energy consumption at the 1% significance level, with an impact coefficient of 0.149. This may be because that compared with relatively high-income countries, low-income countries have relatively low CO_2 emission coefficients, which makes renewable energy consumption more significant in reducing CO_2 emissions, but this situation will not last long. This result was similar to Bildirici et al. (2017) (Bildirici and Gökmenoğlu, 2017) and Ummalla et al. (2019) (Ummalla et al., 2019) who found that the marginal impact of CO2 emissions on economic growth is higher at the higher quantiles of income. Thus, in order to achieve the goal of high economic growth, those countries will rely more on fossil fuels, resulting in high carbon dioxide emissions that seriously affect climate change (Belaïd and Zrelli, 2019).

Thirdly, economic growth has a positive impact on HDI, but the impact is weak at the 10% significance level. This result shows that low-income countries are in the initial stage of economic development and economic transformation has not yet been completed. As the economy becomes more developed, the HDI of those countries will become higher, which also means that the economic growth of low-income countries will help improve the living standards of people, who can obtain better medical and educational services (Wang et al., 2020). However, this will inevitably lead to the unequal distribution of social income, social welfare and living resources in low-income countries, and will have a serious negative impact on the lives of the poor living in rural areas.

Finally, for low-income countries, HDI and industrialization are obviously the main determinants of CO_2 emission levels, but they are not statistically significant. Therefore, one may conclude that the EKC hypothesis and the PHH are invalid for low-income countries. This result was supported by studies undertaken in relation to MENA countries by Gorus et al. (2019) (Gorus and Aslan, 2019).

4.3 Variable Impulse-Responses of Panel VAR Model

Because the PVAR model is a dynamic model, only regression estimation cannot fully reflect the interactive relationship between the variables. In order to be able to intuitively and comprehensively understand the impact of economic indicators, renewable energy consumption and human development on the current and future values of CO_2 emissions, this study adopts the impulse response function (IRF) and performs 500 Monte-Carlo simulations on the CO_2 emissions of the four panel groups under the condition of 95% confidence interval. The impulse response results are shown in Figures 1–4. In the figures, the abscissa represents the number of response periods, the ordinate represents the response value, and the middle solid line represents the impact effect of the impulse response function. **Figures 1–4** report the impulse response function of CO_2 emissions with 5% errors bands, and it can be seen from the figures that the shock effect of each variable shows a gradual convergence trend in the later period, which shows that the PVAR model constructed in this study is robust.

4.3.1 High Income Countries

Figure 1 shows how CO2 emissions in high-income countries respond to standard deviation shock. For CO_2 emissions in high-income countries, the impact of renewable energy consumption, FDI, and trade openness on CO_2 emissions is not statistically significant in the previous PVAR estimates, then the interpretation of the impulse response function to one standard deviation shock on FDI should be considered carefully. The impulse response function shows that a standard deviation impact of economic growth and industrialization has a positive impact on CO_2 emissions, which will first rise and then fall, and reach the maximum value in the second year, with the impacts being 0.007 and 0.003, respectively. However, as time increases, the positive impact gradually decreases and approaches or equals zero after 5 years. However, one standard deviation impact of renewable energy consumption, FDI and trade openness has always had a negative impact on CO_2 emissions, and will be close to or equal to zero after 4 years. In addition, the standard deviation impact of HDI has a positive impact on CO_2 emissions from the first year to the second year, and then gradually decreases until the third year is negative and stabilizes, and its impact has always been maintained at −0.0007. Overall, the impulse response results are basically consistent with the PVAR model estimation results, but the opposite results have appeared in industrialization. The reason for this result may be that these countries have not fully completed the transition from high-energy-consumption and high-emission industries to low-carbon green industries. This result is supported by the studies of Mahmood et al. (2020) (Mahmood et al., 2020) in Saudi Arabia, which believes that there is an asymmetric linear relationship between industrialization and CO_2 emissions. As a country's degree of industrialization increases, the possibility of using fossil fuel resources will increase, leading to many types of environmental degradation (Koengkan, 2019; Mongo et al., 2021). Thus, the increasing industrialization has larger environmental effect than decreasing industrialization.

4.3.2 Upper Middle-Income Countries

Figure 2 shows the response of CO_2 emissions in upper-middle-income countries to standard deviation shock. Under a standard deviation shock, the impulse response of CO_2 emissions to HDI in upper-middle-income countries is basically consistent with the estimated results of the PVAR model. From the perspective of the response path of CO_2 emissions impulse emission, a standard deviation shock of economic growth, renewable energy consumption, HDI, industrialization and trade openness have a positive impact on CO_2 emissions, of which industrialization has a continuously increasing positive impact. This shows that economic growth, renewable energy consumption, HDI, industrialization, and trade openness have all contributed to the increase of CO_2 emissions in upper-middle-income countries. In the long run, the environment is deteriorating as the economy continues to develop, but CO_2 emissions will decrease after reaching a certain level (Kumari

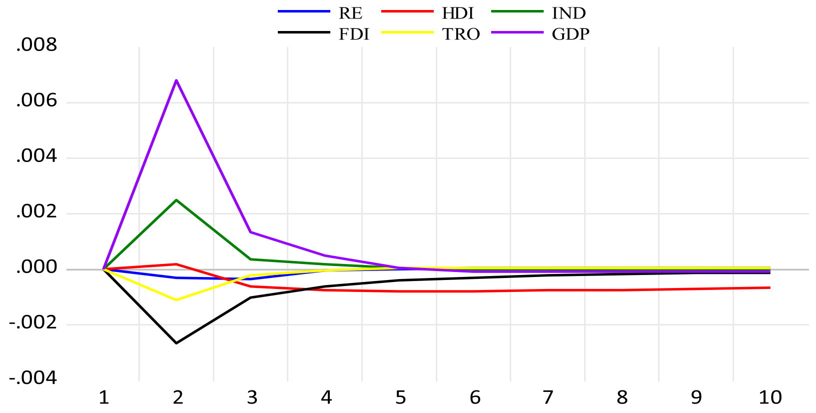

FIGURE 1 | Panel VAR impulse response functions for high income countries: Reaction of CO_2 emissions (CE) to renewable energy consumption (RE), human development index (HDI), industrialization (IND), foreign direct investment (FDI), trade openness (TRO) and economic growth (GDP) one standard deviation shock.

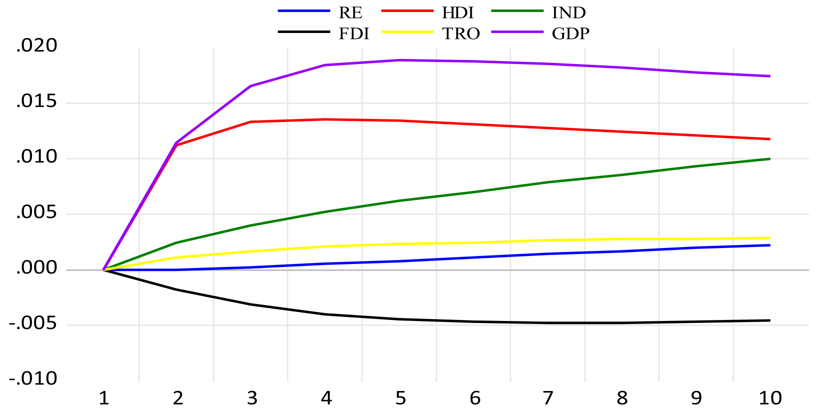

FIGURE 2 | Panel VAR impulse response functions for upper middle-income countries: Reaction of CO_2 emissions (CE) to renewable energy consumption (RE), human development index (HDI), industrialization (IND), foreign direct investment (FDI), trade openness (TRO) and economic growth (GDP) one standard deviation shock.

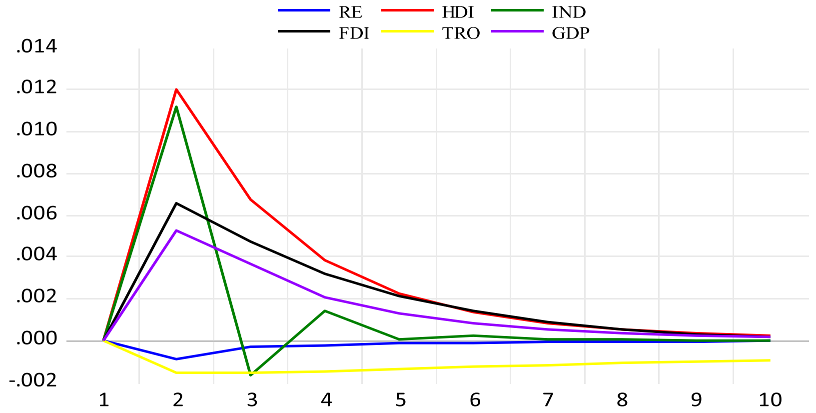

FIGURE 3 | Panel VAR impulse response functions for lower middle-income countries: Reaction of CO_2 emissions (CE) to renewable energy consumption (RE), human development index (HDI), industrialization (IND), foreign direct investment (FDI), trade openness (TRO) and economic growth (GDP) one standard deviation shock.

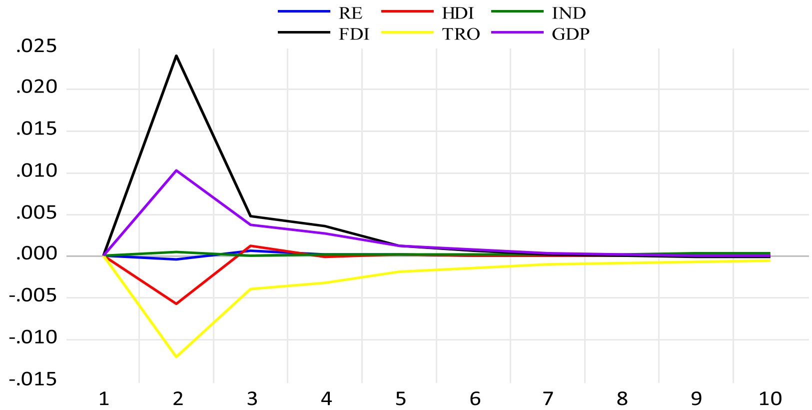

FIGURE 4 | Panel VAR impulse response functions for low-income countries: Reaction of CO_2 emissions (CE) to renewable energy consumption (RE), human development index (HDI), industrialization (IND), foreign direct investment (FDI), trade openness (TRO) and economic growth (GDP) one standard deviation shock.

et al., 2021). However, this impact will not last long. With the continuous improvement of the industrialization level of these countries, CO_2 emissions begin to rise, making the environment deteriorate again. This finding is similar to existing energy literature such as Mahmood et al. (2020) (Mahmood et al., 2020) for the case of Saudi Arabia, and Li et al. (2019) (Li et al., 2019) for the case of China. In addition, the standard deviation impact of FDI has a negative impact on CO_2 emissions, and it stabilizes after 10 years, with an impact of −0.005. This shows that investors tend to abide by environmental regulations and international standards when entering these countries, so FDI inflows help the transfer of clean technology, thereby improving energy efficiency and reducing greenhouse gas emissions. This result is consistent with research of Zhang et al. (2016) (Zhang and Zhou, 2016) and Ghazouani (2021) (Ghazouani, 2021), which believes that these countries are technically more likely to obtain more environmentally friendly technologies from developed countries and conduct business in an environmentally friendly manner, supporting the pollution halo hypothesis.

4.3.3 Lower Middle-Income Countries

Figure 3 shows the response of CO_2 emissions in lower-middle-income countries to standard deviation shock. It can be seen from **Figure 3** that the impact path of economic indicators, renewable energy consumption and human development in lower-middle-income countries on CO_2 emissions is basically consistent with the previous PVAR model estimation results. As previously expected, HDI, FDI, industrialization and economic growth are the main reasons for the increase in CO_2 emissions in these countries. Compared with other influential factors, HDI has the greatest impact on CO_2 emissions, while the impact of industrialization fluctuates greatly. For example, for underdeveloped countries, FDI inflows promote the improvement of industrialization, provide necessary resources and advanced technology for the economic development of these countries, and play an important role in economic growth, job creation, income creation and productivity improvement. Therefore, we identify the positive effects of HDI, FDI, industrialization and economic growth on CO_2 emissions, which was consistent with the findings of Sinha et al. (2016) (Sinha and Sen, 2016) and Khan et al. (2019) (Khan et al., 2019). However, studies like Zaman et al. (2016) (Zaman et al., 2016) have also disproved the claim of positive relationship between human development and CO2 emissions in lower middle-income countries. In addition, it has also noticed that renewable energy consumption and trade openness have a continuous negative impact on CO_2 emissions, but the reduction of CO_2 emissions by renewable energy consumption is minimal, which is also in line with the current basic status quo of economic development in lower-middle-income countries. For example, most of Pakistan's population mainly relies on agriculture, but the government's excessive reliance on industrial development has led to a sharp deterioration in the environment, prompting trade openness to curb the increase in CO_2 emissions and also hindering human development, is in line with Wang et al. (2018) (Wang et al., 2018), Khan et al. (2021) (Khan et al., 2021) and Belaïd et al. (2019) (Belaïd and Zrelli, 2019). However, this study also confirms the inverted-U shaped relationship between trade openness and CO_2 emissions for the lower middle-income countries is in line with Shahbaz et al. (2017) (Shahbaz et al., 2017), this also shows that trade increase environmental degradation at initial stage but then it starts to improve environmental quality after a certain threshold level of trade openness, just as is also established by our study.

4.3.4 Low-Income Countries

Figure 4 shows the response of CO_2 emissions in low-income countries to standard deviation shock. Firstly, it can be seen from **Figure 4** that the standard deviation impact of economic growth and FDI has a positive impact on CO_2 emissions, and it reaches its maximum value in 2 years. The impacts are 0.010 and 0.024, respectively, but as time increases, the positive impact gradually decreases, and approaches or equals zero after 7 years. This shows that FDI and economic growth are the most direct factors affecting CO_2 emissions (Tran et al., 2019). Secondly, the standard deviation shock of HDI and trade openness has a negative impact on CO_2 emissions, and it reaches the maximum value in the second year, and its impact is –0.006 and –0.012. However, as time increases, the negative impact gradually decreases, and approaches or equals zero after 10 years. This is because the national income of most low-income countries mainly depends on agricultural production, which promotes trade openness to curb the increase in CO_2 emissions in the short term. But in the long run, with the inflow of FDI, low-income countries will be more likely to obtain the necessary resources and advanced technologies for life and production from developed countries, which will also promote trade openness and HDI to have a positive impact on CO_2 emissions (Bélaïd and Youssef, 2017; Sasmaz et al., 2020). Finally, under standard deviation shock, industrialization has a positive impact on CO_2 emissions, while renewable energy consumption has a negative impact, but the impact is minimal (Belaïd and Zrelli, 2019). As previously analyzed, CO_2 emissions have a positive effect on the development of renewable energy in low-income countries. This is because most low-income countries are in the primary stage of economic development and have not yet completed economic transformation, leading to a low level of industrialization and low efficiency of energy use in these countries (Tiba and Belaid, 2021). In general, there is an inverted U-shaped relationship between economic growth (or FDI) and CO_2 emissions in low-income countries (Ozcan, 2013), and a U-shaped relationship between trade openness (or HDI) and CO2 emissions.

5 CONCLUSION AND POLICY RECOMMENDATION

Based on the annual panel data of 105 countries around the world from 1990 to 2019, this study has investigated four different income levels by constructing a panel vector autoregressive (PVAR) model, using the generalized method of moments (GMM) and panel impulse response analysis method to analyze the macroeconomic impact of economic indicators, renewable energy consumption and human development on climate change in four panel groups (high-income, upper-middle-income, lower-middle-income, and low-income countries), while incorporating economic growth, industrialization, foreign direct investment, and trade openness into a multiple framework.

In the four panel groups, economic indicators, renewable energy consumption and human development all have varying degrees of impact on climate change. Therefore, the most important results of this study can be summarized in the following four conclusions.

1) The preliminary test results have proven that the four panel models all have multicollinearity, cross-sectional dependence between variables, unit roots, fixed effects in the model, etc., and the need to use lag length in PVAR regression ($p = 1$).
2) From the perspective of economic indicators, in many cases, rapid economic development (economic growth, industrialization, FDI, and trade openness) has a certain promotion effect on environmental pollution (CO_2 emissions), despite the results of different countries or regions, and that it depends on the control differences of fixed effects. Therefore, in these four panel groups (high-income, upper-middle-income, lower-middle-income, and low-income countries), the results are the same, regardless of the countries. Specifically, high-income and lower-middle-income countries support the feedback hypothesis between economic growth and CO_2 emissions, while upper-middle-income and low-income countries support the growth hypothesis (Banday and Aneja, 2020). However, except for upper-middle-income countries, trade openness in selected countries has a negative impact on CO_2 emissions. This supports the protection hypothesis and rejects the pollution haven hypothesis (PHH). This may be because trade and the environment have been influenced by certain policies, such as pollution taxes or import tariffs. Our findings do not support the papers of Shahbaz et al. (2017) (Shahbaz et al., 2017), who put forwarded an inverted U-shaped relationship between trade openness and CO_2 emissions but agree with Mehra (2010) (Keswani Mehra, 2010). In addition, as expected, industrialization and FDI have a positive impact on CO_2 emissions in lower-middle-income and low-income countries, but in high-income and upper-middle-income countries, they have diametrically opposed results. In these two panel groups, industrialization has a positive impact on CO_2 emissions, while FDI has a negative impact. This may be because in countries with higher levels of economic development and industrialization, the government pays more attention to environmental pollution and quality issues in life, prompting FDI inflows to be more inclined to comply with environmental regulations and clean technologies (Kaya et al., 2017).
3) From the perspective of renewable energy, except for upper-middle-income countries, renewable energy consumption has a negative impact on CO2 emissions, while low-income countries have minimal impact. This shows that it is feasible to improve the environmental quality of these countries by promoting and encouraging the development of clean and sustainable green energy in the renewable energy sector. For example, the economic development level and renewable energy sector of low-income countries in the Middle East and Africa regions are still too weak to promote the improvement of environmental quality (Charfeddine and Kahia, 2019). In fact, governments of all countries should formulate corresponding renewable energy policies to promote the investment and development of green and clean technologies, as well as the consumption of alternative fossil fuel energy, especially in countries that are highly dependent on fossil fuels, such as Latin American countries (Koengkan, 2019).
4) From the perspective of HDI level, HDI in upper-middle-income and lower-middle-income countries have a positive impact on CO_2 emissions, while HDI in high-income and low-income countries has a negative impact on CO_2 emissions, and the impact in low-income countries is minimal. In the long run, the more developed the country, the higher the HDI

level, and the lower the CO_2 emissions (Chen et al., 2019; Bekun et al., 2020). From this point of view, upper-middle-income countries and lower-middle-income countries still need to make more efforts on the road to energy conservation and emission reduction in order to catch up with high-income countries and to achieve an environmentally sustainable and healthy development.

Based on these results, it is necessary to formulate more energy saving and emission reduction policies to lessen the impact of economic development, energy consumption (renewable and non-renewable energy consumption) and human development on climate change, and make sure that these policies will not hinder economic growth and human development. Relevant suggestions provided by this study for environmental issues are as follows. First, countries around the world should improve relevant environmental legal systems to tackle environmental pollution problems from the source, especially for high-income and upper-middle-income countries. Secondly, in the context of today's globalization, all countries should pay attention to the development and utilization of renewable energy and change the traditional energy consumption structure in order to reduce the emission of greenhouse gases, especially in developing countries. Thirdly, the renewable energy sector is relatively slow to develop in lower middle income and low-income countries compared to high-income and upper-middle-income countries. To better address the climate issue, lower middle income and low-income countries should reduce the bureaucracy of institutions and lobbying groups that discourage foreign investment in renewable energy. Fourth, for developing countries, especially low- and middle-income countries, most of which do not have enough funds to develop renewable energy industries, more green investments (FDI) and innovative green manufacturing technologies should be attracted from developed countries. At the same time, in terms of industrial structure upgrading, corresponding environmental investment preferential policies and environmental regulations need to be formulated in order to promote sustainable economic and environmental development of these countries. Finally, it should enhance the deep understanding of the environmental pollution of the citizens in various countries, and make contributions to the realization of sustainable economic, social and environmental development.

In addition, in this study, it focuses on the impact of economic indicators, human development, and renewable energy consumption on climate change. Although this study provides a lot of empirical evidence that affects global climate change, there are still some limitations that are worth exploring in future research. Therefore, this study can be used in other case studies, and several factors should be considered, such as urbanization, buildings, population, ecological environment (soil and vegetation), and other factors affecting environmental quality, etc. This study can also be used as recommendations for future research, to provide comprehensive policy guidelines for decision makers.

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

All authors have made substantial contributions to the conception, design of the work; analysis; and drafting of the paper. All authors read and approved the final manuscript.

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