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ORIGINAL RESEARCH

The Impact of Socio-economic and Environmental Sustainability on CO_2 Emissions: A Novel Framework for Thirty IEA Countries

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Abstract

The extent to which socio-economic factors other than income and household size are associated with household CO_2 emissions and whether associations vary across emission domains remains contested in the literature. We explore the impact of socio-economic and environmental sustainability indicators on CO_2 emissions in the presence of combustible renewables, and the economic growth of thirty International Energy Agency (IEA) member countries. We develop a comprehensive empirical analysis using panel data and apply advanced econometric techniques for the period from 1995 to 2018. The panel co-integration analysis indicates long-run relationships among the variables. In addition, augmented mean group analysis and common correlated effects mean group analyses explain that environmental sustainability reduces CO_2 emissions in the short run. Findings of fully modified least square estimates and long-run dynamic least squares estimates confirm that socio-economic sustainability increases CO_2 emissions and environmental sustainability decreases them. The results of Dumitrescu and Hurlin Granger causality analysis reveal that combustible renewables, environmental sustainability, and economic growth bidirectionally Granger cause CO_2 emissions, but socio-economic sustainability unidirectional Granger causes environmental quality. Policymakers in the IEA economies are encouraged to establish policies that promote a sustained lifestyle, ecological awareness, clean technological innovations, limit CO_2 emissions, ecological trade-offs, and CO_2 emissions ceilings to avoid rebound effects and limit environmental degradation. The study's limitations are discussed, and useful directions for future research in the area are proposed.

Keywords Environmental sustainability · Socio-economic sustainability · CO_2 emissions · Economic growth · IEA countries

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1 Introduction

Humanity faces unprecedented environmental and socio-economic sustainability challenges (Ameyaw and Yao 2018; Aye and Edoja 2017; Bhattacharya 2020). Climate change is considered the greatest influencing factor on both the social and ecological business settings. Scientists and environmentalists agree to a great extent that the continuous increase in carbon (CO_2) emissions is one of the biggest environmental threats, as it is raising the temperature and increasing weather anomalies and will ultimately influence the world's long-term climate fluctuations. CO_2 emissions are at the center of concern because of its grave implications for the health of the environment and all life on earth. Growing CO_2 emissions is a problem for the entire world, rather than the issue of any individual nation, since no country can confront such global challenges alone. Therefore, a cumulative effort at the global level is obligatory in addressing environmental problems (Ikram et al. 2020; Jebli et al. 2016; Mendonça et al. 2020).

CO_2 emissions present a significant threat to a sustainable environment. An increase in the frequency and intensity of extreme meteorological conditions, rising sea levels, and biodiversity rearrangements contribute to human-induced climate change that is due to CO_2 emissions (Bhattacharya 2020). In return, these environmental complications generate a flood of problems, damage the infrastructure, risk health and well-being, impact livelihoods and nutrition, and increase migration and violent encounters, among other crucial social issues (Bhattacharya 2020; Pecl et al. 2017; Watts et al. 2018). Countries that have set on the path of social and economic development have faced the challenge of environmental emissions from increased energy use. To address such socio-economic and environmental threats, the United Nations Sustainable Development Goals (SDGs) deliver a plan for global collaborations as a blueprint for a sustainable future for all.

Energy sustainability is the dynamic consideration of the SDGs framework, which plays a significant role in improving socio-economic development. From the background of environmental sustainability, The seventh SDG (SDG 7) comprises three goals related to sustainable energy: universal availability of reliable and affordable energy facilities, increased use of renewable energy, and improvement of energy efficiency (Gielen et al. 2019). Non-renewable and renewable energies are the primary energy sources. The former includes crude oil, natural gas, coal, and nuclear power, and the latter geothermal, biomass, wind, hydroelectric, and wave energy (Zafar et al. 2019). The non-renewable sources can have negative consequences for the environment because they produce pollution and CO_2 emissions, thus contributing to global warming. Renewable energy sources, on the other hand, are environmentally sustainable and a source toward which the modern world should move in pursuit of efficient energy production (Adams et al. 2018; Akif and Sinha 2020; Aydin 2019; Belaïd and Zrelli 2019; Luqman et al. 2019; Mohamed et al. 2019; Tugcu and Topcu 2018; Yao et al. 2019).

Technological transformations and the efficient energy policies that support them can help to reduce CO_2 emissions and energy consumption, and gains from increased efficiency of energy consumption may considerably reduce the per-unit price of energy, causing energy consumption to increase again. The literature names this effect the "rebound" or "take-back" effect (Gottron 2001; Greening et al. 2000; Herring and Roy 2007; Small and Dender 2005; Sorrell 2007). The rebound (or "take-back") effect refers to an increase in energy consumption that is due to a decrease in energy prices after the implementation of technological transformations and energy efficiency (Greening et al. 2000; Wilby andWigley 1997). As Gottron (2001) explains, the rebound consists of three kinds of effects: direct effects, indirect effects, and market or dynamic effects.

The primary purpose of this study is to determine the impact of crucial socio-economic and environmental sustainability indicators on CO_2 emissions in the presence of economic growth in thirty International Energy Agency (IEA) member countries. IEA countries were selected because of their high rate of economic growth, resulting in high energy consumption. The IEA countries, which are at the heart of worldwide engagement in environmental sustainability, provide authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all. Empirical investigation of IEA countries is appropriate because they work with other countries to shape energy and environmental policies in pursuit of a secure and sustainable global future. IEA countries' research and development in oil and gas extraction, innovations in hydraulic fracturing, policies, and enhancement of the reliability, affordability, and sustainability of energy efficiency vastly increased these countries' importance in terms of energy research (IEA 2019).

This study addresses the SDG agenda of 2030 by considering the social, economic, and ecological dimensions of sustainable development. The dynamic links between CO_2 emissions and socio-economic and environmental sustainability are only marginally discussed in the literature. As far as we know, this study is the first to link socio-economic and environmental sustainability with the sustainability concepts of the rebound effect and the cap-and-trade system. The literature is deficient in clustering the crucial aspects of socio-economic and environmental sustainability to determine the aggregated antecedents of environmental quality. Therefore, this study constructs two indices using principal component analysis (PCA), one for socio-economic sustainability, which undertakes seven critical indicators of socio-economic sustainability (Table 1), and one for environmental sustainability, which incorporates significant indicators of environmental sustainability. Using these indices as independent variables, this study draws the dynamics between CO_2 emissions and socio-economic and environmental sustainability in a multivariate production function.

The remainder of this paper is structured as follows. Section 2 briefly discusses the related literature and theoretical context. Section 3 reports on the study's modeling and data. Section 4 contains the methodological framework, and Sect. 5 provides results and a discussion. Section 6 contains the concluding remarks and limitations, while Sect. 7 provides policy implications.

2 The Literature and Theoretic Contextual

The theoretical idea of environmental quality in academics originates with the seminal paper of Grossman and Krueger (1991), who discuss the environmental dynamics of greenhouse gas emissions (GHGE) and economic growth. Since then, remarkable academic progress and work have been conducted that uses various socio-economic and environmental sustainability indicators of the aspects of environmental quality and distress. Appropriate assessment and follow-up for sustainability measurements are necessary but may be difficult because of the large number of indicators in the sustainability framework. Various organizations group the sustainability matrices by categorizing indicators (Goals n.d.; Labuschagne et al. 2005). The source of the indicators of both socio-economic and

Table 1 Detail of variables

Variables	Symbols	Unit	Definition	Source
Carbon emissions	CO_2	Total CO_2 emissions KTOE	Total CO_2 emissions fuel combustion Mt-CO_2 represents total CO_2 emissions from fuel combustion	IEA
Renewables and waste (total primary energy supply)	REW	(Total primary energy supply) KTOE	Renewables and waste contain hydro, geothermal, solar, wind, and tide/wave/ocean energy and usage of these energy procedures for energy and heat generation	IEA
Gross domestic product	GDP	Current US$	GDP is the summation of the gross value added by all domestic producers within the economy, including the product taxes and minus subsidies not included in the cost of the production process	WDI
Renewable energy consumption	Environmental sustainability	Electricity output (GWh)	Renewable energy is energy production from hydro, geothermal, solar, wind, tide/wave/ocean energy, biofuels, and renewable waste sources	IEA
Non-renewable energy consumption		Electricity output (GWh)	Non-renewable energy is energy production from coal, peat, oil shale, oil, and natural gas sources	IEA
Natural resource depletion		% of GNI	*Natural resource-depletion measures* the resource consumptions quicker than it can be regeneration	HDI
Mortality rate		Per 1000 live births	Less than five mortality-rate is the possibility per 1000 that a newborn infant will die before the age of 5 years	WDI
Adolescent-fertility rate		Births per 1000 Women ages 15–19	The adolescent-fertility rate is the sum of births per 1000 women ages 15–19	WDI
Forest area		Sq. km	Forest-area reflects the standing trees irrespective of the condition of productive or not	WDI

Table 1 (continued)

Variables	Symbols	Unit	Definition	Source
Surface area		Sq. km	The surface area is the total area of the country, comprising areas under inland bodies of water and coastal waterways	WDI
Research and development expenditures	Socio-economic sustainability	% of GDP	Expenditure towards research and development activities for the provision of goods and services to society	WDI
Gross fixed capital formation		Constant 2010 US$)	Gross fixed capital formation comprises land improvements, machinery, plant, purchase of equipment, road construction, institutions, industrial and commercial buildings, etc.	WDI
Labor force		Total labor force	The labor force includes the worker presently employed and the workers who are currently unemployed, but they are seeking employment opportunities having the age of 15 years and above	WDI
Final consumption-expenditure		% of GDP	Final consumption-expenditure is the total of private, governmental, and household final consumption	WDI
Inflation, consumer prices		Annual %	Inflation measured from the consumer price index imitates the annual percentage change in the cost to the average purchaser of buying a basket of goods and services	WDI
Population growth		Annual %	The population is de-facto based, derived from the total population	WDI
Imports of goods and services		% of GDP	Imports of goods and services are the market value of all products and services	WDI

environmental sustainability selected for this study's indices is the list provided by the human development reports (HDR) (Kapur and Kazi 2015; Martin and Martin 2019).

The seven indicators of environmental sustainability are renewable energy consumption, non-renewable energy consumption, natural resources, mortality rate, adolescent fertility, forest area, and surface area. The socio-economic index's seven indicators are labor force, population growth, research and development expenditure, gross fixed capital formation, consumer prices, and consumption expenditure. The HDR also lists CO_2 emissions among the environmental sustainability indicators, but we did not include it in the index; instead, we included CO_2 emissions as a dependent variable for environmental quality, as in Aye and Edoja (2017), Khan et al. (2020a), and Shafik (1994). The current literature reflects a little picture of two research aspects of the associations between CO_2 emissions and environmental and socio-economic sustainability factors.

2.1 Environmental Sustainability Factors and CO_2 Emissions

The effect of energy consumption on the environmental quality is widely discussed in several seminal works (Nasreen et al. 2017, 2020; Zafar et al. 2020), and authors find that energy consumption stimulates CO_2 emissions (Khan et al. 2019; Naseem et al. 2020). Cai et al. (2018) study the relationship between energy consumption and CO_2 emissions for G-7 countries and explain that CO_2 emissions lead to clean energy consumption. Adedoyin and Zakari (2020) examine the impact of energy consumption and economic expansion on CO_2 emissions for the United Kingdom (UK) using the autoregressive distributed lag (ARDL) model and find that energy policy certainty reduced CO_2 emissions in the UK from 1985 to 2017. Using the long-run estimates of the fully modified least squares (FMOLS) approach, Badeeb et al. (2020) assess the natural resource dependence in the orthodox Environmental Kuznets Curve (EKC) hypothesis and conclude that resource dependent economies do not follow the pattern of the EKC hypothesis. Danish et al. (2019) conclude that abundant natural resources contribute to pollution in South Africa, although studies like Balsalobre et al. (2018) and Hussain et al. (2020) confirm that abundant natural resources reduce CO_2 emissions.

Morton et al. (2009) elucidate that deforestation is the second-largest anthropogenic source of CO_2 emissions to the atmosphere, after fossil fuel combustion. Brack (2019) confirms that forests are highly desirable for achieving objectives related to climate mitigation and adaptation. According to the World Health Organization (2012), 12.6 million people—23% of all deaths in that year—died because of poor living situations and working in unhealthful environments. Rasoulinezhad and Taghizadeh-hesary (2020) explain that mortality is profoundly affected by fossil fuels and CO_2 emissions in the Commonwealth of Independent States (CIS) region. Overall, growing CO_2 emissions reduces life expectancy at birth and increases infant mortality (Erdoğan et al. 2019).

2.2 Socio-economic Sustainability Factors and CO_2 Emissions

Abdouli and Hammami (2017), Le and Sarkodie (2020), and Nasreen et al. (2020) find a bidirectional causality relationship and trade-off effects between economic growth and CO_2 emissions. The environmental influences of population growth are highlighted in O'Sullivan (2020) and Rahman (2017). Employing FMOLS and dynamic least squares (DOLS), Rahman (2017) states that population density adversely affects environmental quality. However, O'Sullivan (2020) argues that increasing population stabilizes the steady-state economy and predicts that population dynamics may contribute significantly to the ecological research agenda in the future. Ike et al. (2020) assess the role of imports and exports (trade) influences on environmental quality using a vector error correction model (VECM) and Granger causality analysis, and confirm that trade volume is positively associated with CO_2 emissions (Tawiah et al. 2021).

Ma et al. (2020) and Zhang et al. (2018) discussed the important role of labor supply and labor productivity in managing environmental pollution. Further, Ma et al. (2020) report that labor productivity is negatively associated with environmental management, while quality management moderates this relationship. However, using spatial correlations, Zhang et al. (2018) confirm the significant negative impact of labor supply on air pollution in China's 112 cities, while Ahmad et al. (2019b) and Khan et al. (2020b) show that remittance inflows help combat CO_2 emissions. The role of capital accumulation on environmental uncertainty is incorporated in work conducted by Kwok et al. (2018) and Zhang et al. (2020). Zhang et al.'s (2020) empirical findings show that rational and cognitive capital accumulation is positively associated with environmental performance, while Ahmad et al. (2019a) and Ahmad and Khattak (2020) show that an increase in domestic spending and innovation degrades environmental quality in the long run.

All these studies are conducted by employing several socio-economic and environmental factors with different variables. However, none of the literature labels and clusters these factors to identify the aggregated antecedents of environmental quality. The dynamic links between CO_2 emissions and such clustered indices of socio-economic and environmental sustainability indicators are only marginally discussed in the literature. This study fills the gap by clustering the crucial socio-economic and environmental sustainability indicators using PCA.

The control of the CO_2 emissions that come with economic growth is vital for sustainable economic growth (Ameyaw and Yao 2018). Environmental degradation is the trademark of industrial development and is a significant driver of growth and development. However, economic growth may feed adverse ecological and sustainability outcomes (Lu 2017). Socio-economic sustainability is a prerequisite to improved living standards, social welfare, and a flourishing natural environment. However, socio-economic sustainability has a significant influence on CO_2 emissions (Zhou et al. 2018).

Environmental sustainability reduces CO_2 emissions in the long run (Medina et al. 2016). Analogously, anthropogenic CO_2 emissions are a severe challenge to a sustainable environment (Bhattacharya 2020). The link between energy consumption, CO_2 emissions, and sustainable economic growth is of grave concern, as higher energy consumption is associated with higher economic growth and higher carbon emissions (Waheed et al. 2019). Non-renewable energy relies mostly on fossil fuels, which involves the hydrocarbon construction process that creates air pollution. Combustible renewable energy institutes a substantial energy supply component, which carries the possibility of improving the prevailing energy mix, balancing market inconsistency, and protecting the ecological environment by lowering CO_2 emissions (Zafar et al. 2019).

Hence, given this literature and this theoretical backdrop, economic growth and socio-economic sustainability are significantly positively associated with CO_2 emissions, while environmental sustainability and combustible renewables and waste (as a primary energy supply) are negatively related to CO_2 emissions. Figure 1 explains the underlying theoretical framework of this study.

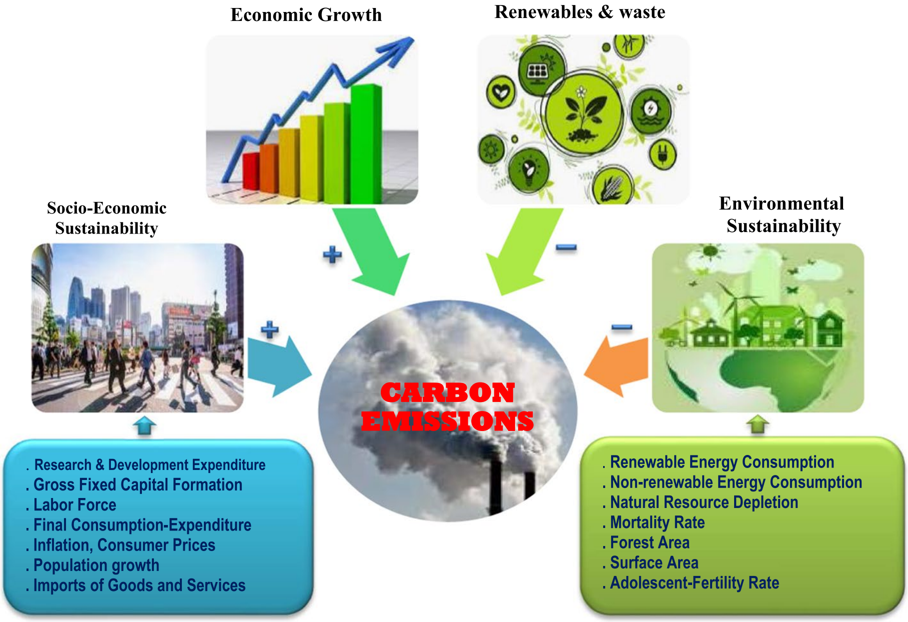

Fig. 1 Theoretical framework

3 Modeling and Data

3.1 Economic Modeling

Instead of individually estimating the parameters presented in Table 1 under the brackets of socio-economic and environmental sustainability, we form indices to determine the aggregated antecedent to environmental quality. We construct two indices using PCA, one for environmental sustainability and one for socio-economic sustainability. (Empirical details of the principal components are presented in “Appendix 2”). Using these indices as independent variables, we investigate the impact of socio-economic and environmental sustainability on CO_2 emissions, taking economic growth and combustible renewables and waste as additional determinants of CO_2 emissions in a multivariate production function, such that:

$$CO_{2_{it}} = f\left(ENS_{it}, SES_{it}, GDP_{it}, REW_{it}\right). \tag{1}$$

We transform the study variables into their log forms to safeguard the elastic interpretations of research coefficients. The log-linear form of Eq. (2) is as below:

$$\ln CO_{2_{it}} = \beta_0 + \beta_1 \ln ENS_{it} + \beta_2 \ln SES_{it} + \beta_3 \ln GDP_{it} + \beta_4 \ln REW_{it} + \mu_{it}, \tag{2}$$

where β_0 is the slope for the coefficient, t is the time (1995–2018), i is the cross-sections (1–30), μ is an error, and $\beta_1, \beta_2, \beta_3$, and β_4 are coefficients of an index for environmental sustainability (ENS), an index for socio-economic sustainability (SES), economic growth (GDP), and combustible renewable and waste (primary energy supply), respectively.

3.2 Data

We seek to determine the links between the CO_2 emissions of thirty IEA member countries with environmental and socio-economic sustainability, and explore the moderating effects of economic growth and renewables and waste on these relationships. We collect panel data on the thirty IEA member countries (details in "Appendix 1") from the IEA, the Human Development Index (HDI), and World Development Indicators (WDI) from 1995 to 2018. Table 1 presents details about the variables we use in this research.

4 Methodological Framework

4.1 Cross-Section Dependence Test

Economic cooperation and the global village have allowed countries worldwide to share several economic, social, and business interests. As a result of such cross-section collaborations, cross-border associations prevail (Aydin 2019). This research uses Pesaran's (2004) cross-section dependence (CD) test to examine the cross-sectional dependence Eq. (3):

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{T_{ij}\hat{\rho}_{ij}}\right)CD \sim N(0,1), \tag{3}$$

where N is the sample, T is time, and ρ_{ij} is the correlation error for individual cross-sections i and j.

4.2 Second-Generation Panel Unit Root Test

We incorporate the second-generation panel unit root test developed by Pesaran (2007) using the augmented cross-section ISP (CIPS), and the cross-section augmented Dickey–Fuller (CADF) approaches:

$$\Delta Y_{i,t} = \alpha_i + b_i Y_{i,t-1} + c_i \overline{Y}_{t-1} + d_i \Delta \overline{Y}_t + \varepsilon_{i,t}, \tag{4}$$

where $\overline{Y}_t = \frac{1}{N}\sum_{i=1}^{N} Y_{i,t}$, $\Delta\overline{Y}_t = \frac{1}{N}\sum_{i=1}^{N} \Delta Y_{i,t}$,, and $\varepsilon_{i,t}$ is the error. Equation (5) presents the equation for CIPS:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i. \tag{5}$$

Both the CIPS and the CADF methodologies argue that each cross-section is non-stationary and a minimum of one cross-section is stationary that at least one cross-section is non-stationary and at least one is stationary.

4.3 Panel Co-integration Test

We use the Pedroni panel co-integration test from Pedroni (1999) and Kao (1999) to access the long-run relationship of the variables. We consider the basic framework to be:

$$y_{i,t} = a_i + b_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \cdots + \beta_{Mi} x_{Mi,t} + e_{i,t}, \tag{6}$$

for $t = 1, \ldots, T$; $i = 1, \ldots, N$; $m = 1, \ldots, M$, while y and x consider the co-integrated of order one, which is I(1). T denotes time, N is each member's numeral in the panel data set, M is the size of the variables, and a_i and b_i are the individual parameters.

4.4 Short-Run Estimations

Given the evidence of panel unit-root and co-integration for the entire panel of variables, we highlight how environmental sustainability and socio-economic sustainability influence CO_2 emissions in the short run, as employed by Li et al. (2020). We use two stages for this purpose: Eberhardt and Teal's (2010) Augmented Mean Group (AMG) approach and Pesaran's (2006) Common Correlated Effects Mean Group (CCE-MG) approach:

$$\text{Stage (i)} \quad \Delta y_{it} = b' \Delta x_{it} + \sum_{t=2}^{T} c_t \Delta D_t + e_{it} \Rightarrow \hat{c}_t \equiv \hat{\mu}_t^{\cdot} \tag{7}$$

$$\text{Stage (ii)} \quad y_{it} = a_i + b_i' x_{it} + c_i t + d_i \hat{\mu}_t^{\cdot} + e_{it} \Rightarrow \hat{b}_{AMG} = N^{-1} \sum_i \hat{b}_i, \tag{8}$$

where stage (i) is the first difference least squares and stage (ii) includes cross-sections $\hat{\mu}_t^{\cdot}$. These regressions use a linear trend term to capture the omitted idiosyncratic process that evolves in a linear approach over time.

4.5 Long-Run Estimations

Countries require time to establish and implement policies that support their economies and environmental treaties. To handle the issues of heterogeneity among the cross-sections and the long-run covariance estimates, we use FMOLS, a robust panel econometric method (Chiang 2000; Pedroni 2001), for long-run coefficient estimates. The regression model proposed by Pedroni (2000) is shown in Eq. (9):

$$y_{it} = \alpha_i + \beta x_{it} + \mu_{it}, \tag{9}$$

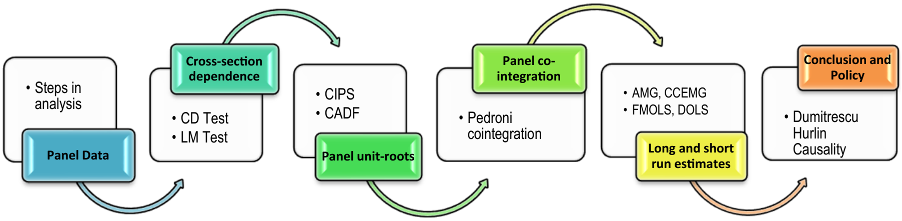

Fig. 2 Estimation steps

where $x_{it} = x_{it-1} + \varepsilon_{it}$, $i = 1, 2 \ldots, N$, $t = 1, 2 \ldots, T$, for which we model the vector error process. Figure 2 explains the steps in modeling estimates.

5 Results and Discussion

Table 2 explains the effect of empirical distribution tests for the CO_2 emissions, renewables and waste, environmental sustainability, socio-economic sustainability, and economic growth of IEA member countries. The results show that all the variables have statistically normal distribution. The cross-sectional dependence using the CD and langrage multiplier (LM) methods are presented in Table 3. Both methods support the rejection of the null hypothesis of no significance, as the corresponding probability values of both the CD and LM approaches are significant at 1%. Therefore, the variables CO_2 emissions, renewables, and waste (primary energy supply), environmental sustainability, socio-economic sustainability, and economic growth have cross-sectional dependence.

Table 4 presents the second-generation unit-root tests of CIPS and CADF, which confirm that the variables CO_2 emissions, renewables and waste, environmental sustainability, socio-economic sustainability, and economic growth have unit-root at the level. All these variables become stationary when transformed into the first difference, so all variables are non-stationary, although they are stationary at the first-difference, which is of degree one I(1). We use the Pedroni co-integration test to examine the long-run associations of the variables, as shown in Table 5. The Pedroni co-integration test involves three sections—the individual intercept, the individual intercept and trend, and no intercept or trend—and each section divides into two sub-sections, within dimensions and between dimensions.

Table 2 Empirical distribution analysis

Methods	ln CO_2	ln REW	ln ENS	ln SES	Ln GDP
Lilliefors (D)	0.077950[a]	0.070619[a]	0.070500[a]	0.075408[a]	0.038667[b]
Cramer-von mises (W2)	0.896188[a]	0.708662[a]	0.694936[a]	0.857145[a]	0.208076[a]
Watson (U2)	0.867515[a]	0.625056[a]	0.688651[a]	0.756127[a]	0.208018[a]
Anderson–Darling (A2)	7.185936[a]	4.471175[a]	5.208068[a]	6.629906[a]	1.257980[a]
MU	10.33060[a]	8.669639[a]	−0.007888[a]	−0.066035[a]	26.78335[a]
SIGMA	1.835677[a]	1.372632[a]	1.662631[a]	1.938841[a]	1.496434[a]

[a] Significant at 1%

[b] Significant at 5%

Table 3 Cross-section dependence test

Variables	ln CO_2	ln REW	ln ENS	ln SES	Ln GDP
CD-test	5.730729[a]	81.61358[a]	9.555505[a]	43.98067[a]	92.99823[a]
p value	0.000	0.000	0.000	0.000	0.000
LM-test	111.1256[a]	245.7341[a]	115.3202[a]	114.2330[a]	283.6840[a]
p value	0.000	0.000	0.000	0.000	0.000

Under the null hypothesis of cross-section independence CD ~ N (0, 1)

[a] Rejected at 1%

Table 4 Second-generation unit root test

Variables	CIPS		CADF	
	Level	First difference	Level	First difference
ln CO_2	1.63662	−15.4594[a]	1.71528	−13.3719[a]
ln REW	5.84382	−23.2831[a]	5.74007	−18.1136[a]
ln ENS	1.80250	−17.1704[a]	1.73074	−14.5597[a]
ln SES	−0.59761	−19.5922[a]	−0.54816	−16.8210[a]
ln GDP	3.08569	−11.5180[a]	3.30503	−11.1270[a]

[a] Significant at 1%

[b] Significant at 5%

[c] Significant at 10%

Table 5 Co-integration analysis

Methods	Within dimension		Between dimension
Individual intercept			
Panel v statistic	2.01966[b]	0.52785	2.863660
Panel rho statistic	0.37498	0.40642	−4.630961[a]
Panel PP statistic	−3.58067[a]	−4.41763[a]	−6.215712[a]
Panel ADF statistic	−4.87918[a]	−5.89012[a]	
Individual intercept and trend			
Panel v statistic	0.58536	−1.33239	4.780787
Panel rho statistic	2.42061	2.37943	−6.246620[a]
Panel PP statistic	−3.34851[a]	−4.57770[a]	−5.179844[a]
Panel ADF statistic	−4.47404[a]	−6.19454[a]	
No intercept or trend			
Panel v statistic	−1.26422	−3.31467	2.737909
Panel rho statistic	1.01884	1.49131	−3.119920[a]
Panel PP statistic	−1.92666[b]	−1.31811[b]	−4.650587[a]
Panel ADF statistic	−3.05288 [a]	−2.07679[b]	

[a] Significant at 1%

[b] Significant at 5%

The results of the three methodologies show the co-integration among the variables, as the CO_2 emissions, renewables and waste, environmental sustainability, socio-economic sustainability, and economic growth of the thirty IEA member countries have a long-run relationship and move together in the long run.

Table 6 reports the outcome of the short-run AMG and CCE-MG. The result shows that environmental sustainability influences CO_2 emissions even in the short run, while socio-economic sustainability has no short-run influence on CO_2 emissions in the thirty IEA member states. The negative coefficient of environmental sustainability reveals that a 1% acceleration in environmental sustainability decreases CO_2 emissions by 58% in the short run, suggesting that, in the short run, environmental sustainability is more sensitive to CO_2 emissions than socio-economic sustainability is in the IEA economies. It also means that countries should see environmental degradation as a short-run consequence

Table 6 Short-run elasticity

Panel AMG				Panel CCE-MG			
Variables	Coefficients	z	$p>\lvert z\rvert$	Variables	Coefficients	z	$p>\lvert z\rvert$
ln REW	0.4495699[a]	6.00	0.000	ln REW	0.4870228[a]	5.99	0.000
ln ENS	−0.5826044[b]	−2.70	0.007	ln ENS	−0.613825[b]	−2.96	0.003
ln SES	0.0530536	0.99	0.324	ln SES	0.0198436	0.68	0.499
Ln GDP	−0.1983345[c]	−1.86	0.063	ln GDP	0.0521868	1.40	0.162
Trend	−0.0040862	−0.35	0.724	c_d_p	0.7680766[b]	2.60	0.009
ln CO_2_avg	0.6817058[b]	2.36	0.018	Trend	−0.0122161[b]	−2.69	0.007
ln REW_avg	−0.4302085	−1.49	0.135	_Cons	5.629914[a]	4.51	0.000
ln ENS_avg	0.129767	0.92	0.358				
ln SES_avg	−0.0572789	−1.37	0.172				
ln GDP_avg	0.2477091[b]	2.10	0.036				

Root mean squared error (sigma): 0.0460 and 0.0360 respectively, c_d_p refers to the standard dynamic process, and the variable trend refers to the group-specific linear trend terms

[a] Significant at 1%

[b] Significant at 5%

[c] Significant at 10%

Table 7 Long-run estimations

Variable	Panel-FMOLS		Panel-DOLS	
	Coefficient	t-Statistic	Coefficient	t-Statistic
ln ENS	−0.264966[a]	−18.31112	−0.347356[a]	−7.161616
ln SES	0.135486[a]	5.698528	0.112227[a]	3.833679
ln GDP	0.216913[a]	20.11569	0.257881[a]	5.383558
ln REW	−0.035069[b]	−4.937745	−0.127115[a]	−2.373084

[a] Significant at 1%

[b] Significant at 5%

of environmental sustainability and economic growth (Basiago 1998; Khan 1995). For the long-run coefficient estimates, we use Panel-FMOLS, and Panel-DOLS approaches (Table 7) for environmental sustainability, socio-economic sustainability, economic growth, and renewables and waste. The link between environmental sustainability and CO_2 emissions is significantly negative at the 1% level of significance, which confirms both the panel-FMOLS and panel-DOLS methodologies. The panel-FMOLS and panel-DOLS show that a 1% acceleration in environmental sustainability results in decreasing the CO_2 emissions of IEA member countries by 26% and 34%, respectively. This result suggests that any measures taken by the IEA economies to address environmental sustainability will contribute significantly to reducing CO_2 emissions. These findings are in line with the findings of Lin and Xu (2020), Mikayilov et al. (2018), and Xie and Liu (2019).

The link between socio-economic sustainability and CO_2 emissions is positive and highly significant, as a 1% increase in socio-economic sustainability increases the CO_2 emissions by 13% (panel-FMOLS) and 11% (panel-DOLS). This result suggests that higher socio-economic sustainability increases CO_2 emissions in the economies of IEA member countries and that, as the center of socio-economic activity develops, urbanization, population aggregation, and cities are more likely to be the primary sources of growing CO_2 emissions. These results are consistent with the findings of Liu et al. (2019), Mi et al. (2017) and Ou et al. (2019).

The link between renewables and waste (primary energy supply) is significant at the 5% level and is adversely associated with CO_2 emissions. A 1% acceleration in the primary energy supply from renewables and wastes reduces CO_2 emissions in IEA economies by 3% (panel-FMOLS) and 12% (panel-DOLS), suggesting that renewable sources are environmentally friendly in reducing CO_2 emissions (Zaidi et al. 2019). Similarly, economic growth and CO_2 emissions are positively linked at a 1% level of significance. Thus, when the economic growth of the thirty IEA member countries accelerates by 1%, it increases CO_2 emissions by 21% (panel-FMOLS) and 25% (panel-DOLS) in the long run.

Further, the positive relationship between economic growth and CO_2 emissions in the IEA economies suggests that, at the initial stage of growth, emerging economies are primarily concerned with economic expansion, infrastructure, and increased consumption, and they overlook the environmental aspects of increased CO_2 emissions. However, with further economic growth, the increasing CO_2 emissions start to decline, which is the EKC framework's situation. This finding demonstrates the sharp distinction of the EKC hypothesis for CO_2 emissions, which reflects the inverse U-shaped relationship between CO_2 emissions and economic growth. These results are consistent with previous studies (Muhammad and Khan 2019; Wasti and Zaidi 2020; Zaidi et al. 2019; Zhou et al. 2018) that show that economic growth is positively associated with CO_2 emissions (Khan and Hou 2020; Khan et al. 2021), but our results are contrary to the findings of Ben Jebli and Belloumi (2017) and Muhammad (2019), which suggest that economic growth is adversely associated with CO_2 emissions. The interaction of all these long-run estimates is summarized in Figs. 3 and 4. The scatter confidence ellipse boxplot matrix in Fig. 3 shows the multiple interactions among the variables in a single graph of the long-run FMOLS and DOLS estimates, while the rotated boxplot multiple plots in Fig. 4 show the shape of the normal distribution, its central value, and its variability.

Supporting the result of long-run elasticity, the results of a pairwise Dumitrescu and Hurlin panel causality analysis shown in Table 8 reveal that renewables and waste, environmental sustainability, and economic growth bidirectional Granger caused CO_2 emissions in IEA countries during the research period. However, socio-economic sustainability unidirectional Granger caused CO_2 emissions in these countries. A bidirectional causality relationship also ran from renewables and waste and GDP to the CO_2 emissions of IEA member countries from 1995 to 2018.

6 Conclusion and Limitations

CO_2 emissions have steadily risen worldwide since the beginning of the 2010s (Dong et al. 2020). This study addresses the 2030 SDG agenda by considering the social, economic, and environmental dimensions of sustainable development. We construct two indices using PCA—one for environmental sustainability and one for socio-economic sustainability—to identify their impact on the CO_2 emissions of thirty IEA member countries and explore the moderating effects of economic growth and renewables and waste. We use panel data from IEA, HDI, and WDI for the period from 1995 to 2018. We apply advanced econometric approaches for empirical analysis, including cross-section dependency, a second-generation

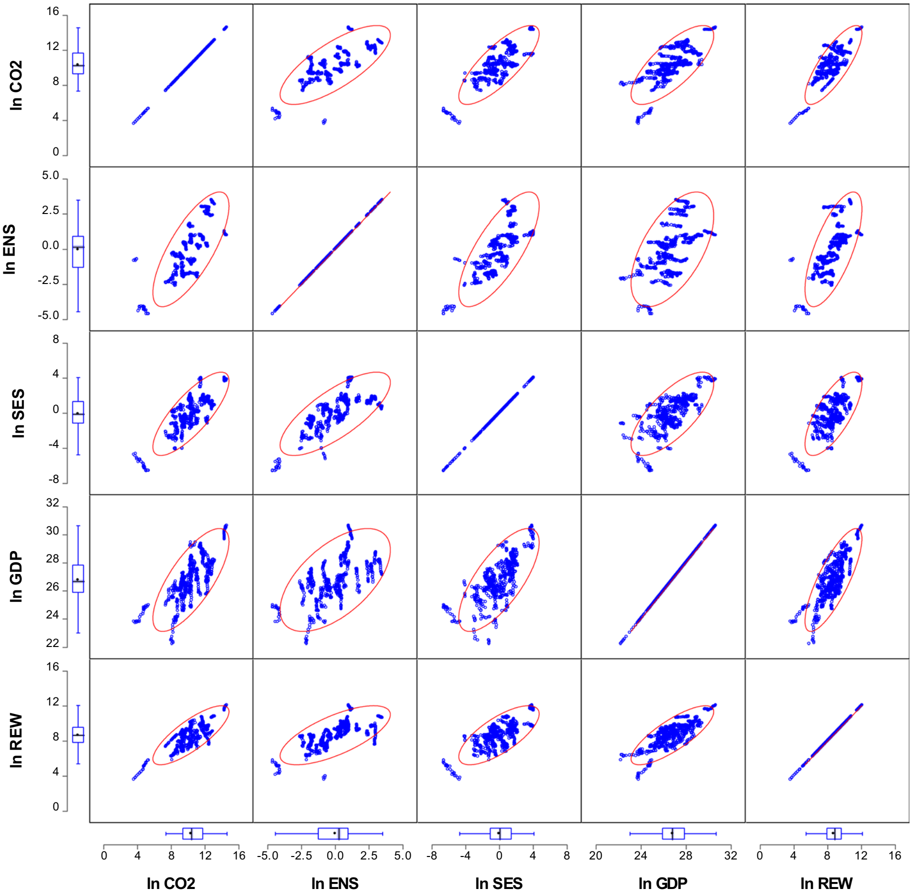

Fig. 3 Scatter confidence ellipse boxplot matrix

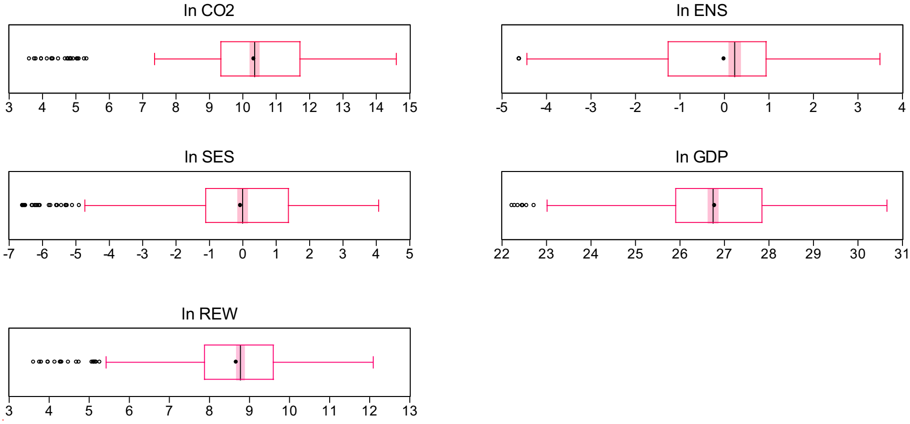

Fig. 4 Rotated boxplot multiple plots

Table 8 Pairwise dumitrescu hurlin panel causality tests

Dependent	Independent				
	ln CO_2	ln REW	ln ENS	ln SES	ln GDP
ln CO_2	–	3.81644[a] (0.0001)	6.14198[a] (0.0000)	1.35159 (0.1765)	2.46434[b] (0.0137)
ln REW	3.89875[a] (0.0001)	–	8.69177[a] (0.0000)	3.76764[a] (0.0002)	1.68064[c] (0.0928)
ln ENS	3.62208[a] (0.0003)	7.24148[a] (0.0000)	–	2.54863[b] (0.0108)	4.14427[a] (0.0000)
ln SES	2.02925[b] (0.0424)	3.53867[a] (0.0004)	3.13700[a] (0.0017)	–	3.97951[a] (0.0000)
ln GDP	5.34291[a] (0.0000)	11.9964[a] (0.0000)	8.92993[a] (0.0000)	3.68205[a] (0.0002)	–

[a] Significant at 1%

[b] Significant at 5%

[c] Significant at 10%

unit root test, and empirical distribution analyses. Short and long-run dynamics are evaluated using AMG and CCE-MG, the Pedroni residual test of co-integration, panel FMOLS, panel DOLS and pairwise Dumitrescu Hurlin Panel causality analysis.

Our findings suggest that environmental sustainability reduces CO_2 emissions in the short and long runs, while socio-economic sustainability raises CO_2 emissions in the long run. Further, renewables and waste are negatively associated with CO_2 emissions, suggesting that renewable sources of energy are environmentally friendly and improve environmental quality. Similarly, economic growth and CO_2 emissions are positively linked with each other, demonstrating the sharp distinction of the EKC framework. Our findings suggest that renewables and waste, environmental sustainability, and economic growth bidirectionally Granger causes CO_2 emissions, while socio-economic sustainability unidirectionally Granger causes CO_2 emissions in IEA member countries.

One of this study's limitations is that it does not divide by their level of income. Future research could incorporate the countries' income levels and technology imports to investigate this crucial relationship in IEA countries. The study also includes only socio-economic and environmental sustainability indicators and incorporates limited factors in the PCA matrices. Future studies could also bring into play the economic and political sustainability indicators and include other factors, such as urbanization, the ecological footprint, the role of education, per capita income, and debt servicing for added value. Moreover, including the quality of life index could make the study exciting by examining its relationship with CO_2 emissions in the IEA member countries.

7 Implications for Theory and Practice

The growth and development in the thirty IEA member countries have resulted in a dilemma related to environmental sustainability, socio-economic sustainability, and CO_2 emissions. Efficient legislation and policy should be implemented to resolve this dilemma. Examining the links among socio-economic sustainability, environmental sustainability, economic growth, and CO_2 emissions provides a strong theoretical background. The long-run estimates of environmental sustainability in Table 7 suggest that existing resources and cost-effective measures can reduce CO_2 emissions, improving environmental quality by

26–38% in the IEA countries. However, a number of barriers affect the optimal exploitation of this environmentally sustainable potential.

The results of long-run estimates show that environmental sustainability and renewables and waste (primary energy supply from renewables and waste) are negatively associated with CO_2 emissions in the thirty IEA member countries. It is realistic for these countries' governments to improve environmental quality and promote renewable energy consumption to decrease CO_2 emissions. Policy analysts and economists emphasize the use of renewable energy to improve the quality of the environment (Schober et al. 2018; Zafar et al. 2019), and these countries should prioritize lowering CO_2 emissions by increasing the efficiency of energy use and optimizing the use of renewable resources. However, the expected gains from such technological transformations may lead to a rebound or take-back effect. To avoid such an undesirable situation, policymakers in the IEA economies are encouraged to limit CO_2 emissions and environmental trade-offs. Imposing energy and CO_2 emission taxes, along with setting a ceiling and floor for CO_2 emissions, may also prove helpful.

The long-run estimates shown in Table 7 reveal that socio-economic sustainability and economic growth are positively associated with CO_2 emissions in the thirty IEA member countries. It is not practical for any government to reduce CO_2 emissions at the expense of socio-economic sustainability and economic growth or to make changes to the entire socio-economic structure to attain CO_2 emission reduction targets. Further, the transfer of labor force from rural to urban areas also increases the demand for energy consumption, producing more CO_2 emissions. Thus, strategic socio-economic sustainability planning to control land development, expand the efficiency of land use, and curtail damage to the environment is necessary for IEA economies. Asymmetric land development may lead to higher energy consumption to maintain transport and related infrastructure.

Since a well-planned socio-economic structure is necessary for conservation and controlling emissions, the governments of IEA countries should reassert the tertiary due diligence of the environmental management system to encourage high technology manufacturing, financial development, services, and internet businesses, which have low energy demands and low CO_2 emissions. The transformation from high energy consumption and high CO_2 emissions to low energy consumption and low CO_2 emissions can decrease CO_2 emissions while maintaining rapid economic growth in these countries. Considering the possible socio-economic and environmental benefits, the shift to lowering CO_2 emissions may prove a win–win situation for sustainability.

This research's statistical estimations find that socio-economic sustainability is positively associated with CO_2 emissions, and environmental sustainability is negatively related to CO_2 emissions in thirty IEA member countries. These findings suggest that policymakers in the IEA economies establish policies that promote a sustained lifestyle, ecological awareness, and clean technological innovations, and cut subsidies that are associated with non-renewables in favor of backing investment in renewables. At the initial stage of transformation, a substantial investment is a prerequisite for technological upgrades and the development of renewable energy. These shifts from non-renewable to renewable energy sources will create multiple positive externalities for these economies.

Appendix 1

See Table 9.

Table 9 List of IEA countries

Member countries		
Australia	Germany	Norway
Austria	Hungry	Poland
Belgium	Ireland	Portugal
Canada	Italy	Slovak Republic
Czech Republic	Japan	Spain
Denmark	Korea	Sweden
Estonia	Luxembourg	Switzerland
Finland	Mexico	Turkey
France	New Zealand	United Kingdom
Greece	Netherlands	United States

Appendix 2

See Tables 10 and 11.

Table 10 Principal components for socio-economic sustainability indicators

Numbers	Values	Differences	Proportions	Cumulative-values	Cumulative-proportions
Eigenvalues: (sum = 7, average = 1) *Extracting 7 of 7 possible components*					
1	2.593334	0.740361	0.3705	2.593334	0.3705
2	1.852973	0.704084	0.2647	4.446307	0.6352
3	1.148889	0.458553	0.1641	5.595197	0.7993
4	0.690336	0.302903	0.0986	6.285533	0.8979
5	0.387433	0.086315	0.0553	6.672966	0.9533
6	0.301118	0.275203	0.0430	6.974085	0.9963
7	0.025915	–	0.0037	7.000000	1.0000

Variable	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7
Eigenvectors (loadings)							
Population growth	−0.148746	0.410914	0.574871	−0.486792	−0.423935	0.235362	0.080399
Research and development expenditures	−0.264176	0.551651	−0.106779	−0.182533	0.742549	0.129625	−0.113974
Labor force	0.485648	0.406900	0.036002	0.285373	−0.167446	0.035492	−0.697529
Inflation, consumer prices	0.066434	−0.220624	0.801191	0.376210	0.402866	−0.030959	0.014536
Imports of goods and services	−0.487625	0.080900	−0.087332	0.586275	−0.203645	0.601957	0.022553
Final consumption-expenditure	0.475748	−0.304814	−0.062082	−0.276038	0.192454	0.750205	0.029258
Gross fixed capital formation	0.451336	0.461663	−0.058622	0.294666	−0.007092	−0.020618	0.701729

Ordinary correlations	Population growth	Research and development expenditures	Labor Force	Inflation, consumer prices	Imports of goods and services	Final consumption-expenditure	Gross fixed capital formation
Population growth	1.000000						
Research and development expenditures	0.399744	1.000000					
Labor force	0.078923	−0.001888	1.000000				

Table 10 (continued)

Ordinary correlations	Population growth	Research and development expenditures	Labor Force	Inflation, consumer prices	Imports of goods and services	Final consumption-expenditure	Gross fixed capital formation
Inflation, consumer prices	0.140787	−0.302079	−0.002151	1.000000			
Imports of goods and services	0.071159	0.318447	−0.422018	−0.082597	1.000000		
Final consumption-expenditure	−0.342229	−0.510551	0.307412	0.100796	−0.631987	1.000000	
Gross fixed capital formation	0.040838	0.127843	0.959696	−0.089057	−0.379169	0.239470	1.000000

Table 11 Principal components for environmental economic sustainability indicators

Numbers	Values	Differences	Proportions	Cumulative- values	Cumulative-proportions
Eigenvalues: (sum = 7, average = 1) *Extracting 7 of 7 possible components*					
1	2.328754	0.012628	0.3327	2.328754	0.3327
2	2.316126	0.878661	0.3309	4.644881	0.6636
3	1.437466	0.995389	0.2054	6.082347	0.8689
4	0.442077	0.134223	0.0632	6.524423	0.9321
5	0.307854	0.166244	0.0440	6.832277	0.9760
6	0.141610	0.115498	0.0202	6.973888	0.9963
7	0.026112	–	0.0037	7.000000	1.0000

Variable	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7
Eigenvectors (loadings)							
Adolescent-fertility rate	0.126562	0.576460	0.161916	−0.017119	0.635787	−0.465314	−0.066508
Forest area	0.576126	0.129979	−0.343838	−0.065973	−0.087907	−0.022710	0.721363
Natural resource depletion	0.154955	−0.533932	−0.117999	0.644623	0.509885	0.007226	0.037523
Mortality rate	−0.059778	0.554997	0.168100	0.673795	−0.224569	0.387546	0.074322
Non-renewable energy consumption	0.278539	−0.125599	0.693989	−0.267370	0.263847	0.509884	0.154715
Renewable energy consumption	0.478335	−0.153443	0.450125	0.216594	−0.454473	−0.504960	−0.191299
Surface area	0.563993	0.135553	−0.359365	−0.086111	0.038376	0.343159	−0.638552

Ordinary correlations	Adolescent-fertility rate	Forest area	Natural resource depletion	Mortality rate	Non-renewable energy consumption	Renewable energy consumption	Surface area
Adolescent-fertility rate	1.000000						
Forest area	0.246853	1.000000					
Natural resource depletion	−0.600296	0.073564	1.000000				
Mortality rate	0.687794	−0.009626	−0.579191	1.000000			

Table 11 (continued)

Ordinary correlations	Adolescent-fertility rate	Forest area	Natural resource depletion	Mortality rate	Non-renewable energy consumption	Renewable energy consumption	Surface area
Non-renewable energy consumption	0.095726	−0.005183	0.104015	−0.102129	1.000000		
Renewable energy consumption	−0.016110	0.377093	0.275694	−0.087209	0.704198	1.000000	
Surface area	0.250229	0.963451	0.078052	−0.001812	0.003397	0.312585	1.000000

Appendix 3

See Table 12.

Table 12 Literature summary

References	Sample	Title	Source	Findings
Abdouli and Hammami (2017)	MENA countries, 1990–2012	Investigating the causality links between environmental quality, foreign direct investment and economic growth in MENA countries	International Business Review	The hypothesis of neutrality for the environment-GDP link
Adedoyin and Zakari (2020)	UK, 1985–2017	Energy consumption, economic expansion, and CO_2 emission in the UK: the role of economic policy uncertainty	Science of the Total Environment	Energy policy uncertainty reduces the growth of CO_2 emissions
Ahmad et al. (2019a)	OECD countries, 1990–2014	Can innovation shocks determine CO_2 emissions (CO_2e) in the OECD economies? A new perspective	Economics of Innovation and New Technology	The positive shocks to innovation improve, but the negative shocks disrupt environmental quality
Ahmad and Khattak (2020)	South Africa	Is Aggregate domestic consumption spending (ADCS) per capita determining CO_2 emissions in South Africa? a new perspective	Environmental and Resource Economics	The long-run effects of positive shocks influence more CO_2 emissions than the short run
Ahmad et al. (2019b)	China, 1980–2014	Does the inflow of remittances cause environmental degradation? empirical evidence from China	Economic Research-Ekonomska Istrazivanja	A positive shock in remittances causes an increase in CO_2 emissions, while a negative shock decreases it
Ameyaw and Yao (2018)	Five West African countries, 2007–2014	Analyzing the impact of GDP on CO_2 emissions and forecasting Africa's total CO_2 emissions with non-assumption driven bidirectional long short-term memory	Sustainability	There exists a unidirectional causality running from GDP to CO_2 emissions
Badeeb et al. (2020)	Resource-based countries	Are too many natural resources to blame for the shape of the environmental Kuznets curve in resource-based economies?	Resources Policy	EKC mechanism per se does not explain the growth–environment nexus

Table 12 (continued)

References	Sample	Title	Source	Findings
Balsalobre-Lorente et al. (2018)	European Union 5 (EU-5) countries, 1985–2016	How economic growth, renewable electricity, and natural resources contribute to CO_2 emissions?	Energy Policy	An N-shaped relationship exists between economic growth and CO_2 emissions
Bel and Rosell (2017)	Individuals	The impact of socioeconomic characteristics on CO_2 emissions associated with urban mobility: inequality across individuals	Energy Economics	Socioeconomic factors have different impacts on different emitting groups
Bhattacharya (2020)	India, 1981–2008	Environmental and socioeconomic sustainability in India: evidence from CO_2 emission and economic inequality relationship	Journal of Environmental Economics and Policy	The emission-inequality relationship is insignificant or negative
Brack (2019)	UN Forum	Forests and climate change, background analytical study	United Nations Forum on Forests	Healthy and resilient forests in climate change mitigation and adaptation
Cai et al. (2018)	G-7 countries	Nexus between clean energy consumption, economic growth, and CO_2 emissions	Journal of Cleaner Production	Feedbacks between clean energy consumption and CO_2 emissions
Danish et al. (2019)	BRICS countries, 1990–2015	Effect of natural resources, renewable energy and economic development on CO_2 emissions in BRICS countries	Science of the Total Environment	Energy consumption increases the ecological footprint
Erdoğan et al. (2019)	Turkey, 1971–2016	The relationship between CO_2 emissions and health indicators	Econometrics Letters	Increased carbon emissions reduce life expectancy at birth and increase the infant mortality rate

Table 12 (continued)

References	Sample	Title	Source	Findings
Hussain et al. (2020)	Belt and Road Initiative (BRI) countries, 1990–2014	The impact of natural resource depletion on energy use and CO_2 emission in belt and road initiative countries: a cross-country analysis	Energy	Increasing natural resource depletion increases CO_2 emissions
Ike et al. (2020)	G-7 countries	Environmental quality effects of income, energy prices, and trade: The role of renewable energy consumption in G-7 countries	Science of the Total Environment	The EKC hypothesis is validated at the panel and country-specific levels
Khan et al. (2019)	China, 1991–2015	Environmental regulations an option: asymmetry effect of environmental regulations on carbon emissions using nonlinear ARDL	Energy Sources, Part A: Recovery, Utilization and Environmental Effects	A significant relationship exists between environmental regulation and carbon emissions
Khan et al. (2020b)	BRICS countries, 1986–2016	On the remittances-environment led hypothesis: empirical evidence from BRICS economies	Environmental Science and Pollution Research	FDI has a positive and significant sign for BRICS economies
Le and Sarkodie (2020)	45 Emerging Market and Developing Economies, 1990–2014	The dynamic linkage between renewable and conventional energy use, environmental quality and economic growth: evidence from emerging market and developing economies	Energy Reports	Trade-off effect between environmental quality and economic growth
Lu (2017)	16 Asian countries, 1990–2012	Greenhouse gas emissions, energy consumption, and economic growth: a panel cointegration analysis for 16 Asian countries	International Journal of Environmental Research and Public Health	Economic growth is consistent with EKC

Table 12 (continued)

References	Sample	Title	Source	Findings
Ma et al. (2020)	229 listed Chinese companies	Environmental management and labor productivity: the moderating role of quality management	Journal of Environmental Management	Environmental management hurts labor productivity
Naseem et al. (2020)	BRICS countries, 1980–2016	Exploring the impact of energy consumption, food security on CO_2 emissions: a piece of new evidence from Pakistan	Environmental Science and Pollution Research	Renewable energy consumption mitigate CO_2 emissions
Nasreen et al. (2017)	South Asian countries, 1980–2012	Financial stability, energy consumption, and environmental quality: evidence from South Asian economies	Renewable and Sustainable Energy Reviews	Financial stability improves environmental quality
Nasreen et al. (2020)	18 Asian countries, 1980–2017	The long-run causal relationship between economic growth, transport energy consumption and environmental quality in Asian countries: evidence from heterogeneous panel methods	Energy	Transport energy consumption and GDP growth deteriorate the environmental quality
Qiang and Jian (2020)	China, 2005–2018	Natural resource endowment, institutional quality, and China's regional economic growth	Resources Policy	Resource curse" proposition is valid at the provincial level in China
Rahman (2017)	11 Asian populous countries, 1960–2014	Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries?	Renewable and Sustainable Energy Reviews	Energy use, exports, and population density adversely affect environmental quality

Table 12 (continued)

References	Sample	Title	Source	Findings
Zafar et al. (2019)	Asia–Pacific Economic Cooperation (APEC) countries, 1990–2015	From nonrenewable to renewable energy and its impact on economic growth: the role of research and development expenditures in Asia–Pacific economic cooperation countries	Journal of Cleaner Production	Stimulating role of energy (renewable and nonrenewable) consumption in economic growth
Zafar et al. (2020)	OECD countries, 1990–2015	How renewable energy consumption contribute to environmental quality? The role of education in OECD countries	Journal of Cleaner Production	Stimulating role of renewable energy consumption in shaping the environmental quality
Zhang et al. (2018)	112 Chinese cities from 2002–2013	Does environmental pollution affect labor supply? An empirical analysis based on 112 cities in China	Journal of Cleaner Production	The impact of pollution on labor supply is nonlinear
Zhou et al. (2018)	China, 1980–2014	Examining the socioeconomic determinants of CO_2 emissions in China: a historical and prospective analysis	Resources, Conservation and Recycling	Socioeconomic factors exerted important influences in determining the environmental quality

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