Inzinerine Ekonomika-Engineering Economics, **2023, 34(1), 32–45**

The Impact of Energy Transition and Eco-innovation on Environmental Sustainability: A Solution for Sustainable Cities and Communities of Top Ten Asian Countries

YunQian Zhang

School of Finance and Accounting, Fuzhou University of International Studies and Trade, China
E-mail: zhangyunqian@fzfu.edu.cn

crossref http://dx.doi.org/10.5755/j01.ee.34.1.32161

Environmental sustainability is an obligatory practice to conserve natural resource and safeguard eco system at present and in the future. Thereby, it is worthy to evaluate the association of energy transition and eco-innovation with environmental sustainability. The present study investigates the impact of energy transition (renewable energy output (REO) and renewable energy consumption (REC), eco-innovation, research and development (R&D) expenditures, technology exports, and industrialization on environmental sustainability (Carbon dioxide (CO2) emissions) in ten most populated countries in Asia. The data for this study collected from OECD and WDI covering the time frame 2006–2020. The study opted two methods to develop the comprehensive empirical analysis; CUP-FM and CUP-BC. Findings revealed that REO and REC, eco-innovation, R&D expenditures, and technology exports are positively associated with CO2 emissions. The findings also revealed that industrialization positively and significantly affects CO2 emissions. This study guides the policymakers that they should establish the policies related to the environmental instability by enhancing the REO and innovation adoption.

Keywords: *Energy Transition; Eco-Innovation; Research and Development Expenditures; Technology Exports; Industrialization; Environmental Sustainability; CO2 Emissions.*

Introduction

Sustainable environmental articulates that the environment we live in supposed to be clean, abundant with good-quality natural resources, home to healthy living things in the air, on land, and below the water's surface, and with a climate that is just right for people to breathe and live in. According to Sanchez et al. (2019), environmental sustainability tells about the situation which has the ability to secure the natural resources and living resources which serve as the resources for operations and raw material for production. It is to maintain humans' health so that they can prove to be active and efficient human resources to meet the present needs and make arrangement for future activities. Environmental sustainability rises healthy & active stakeholders. When inhabitants enjoy good health, a country is more likely to succeed and progress at a high rate as only these people can manage the enterprises and carry out their operations. Additionally, businesses rely on natural resources for energy and raw materials, which is feasible in a sustainable environment (Ghazali & Ali, 2019; Yousaf *et al.,* 2021). But there is a dual relation between the economy and the environment. Geographical characteristics, natural resources, and climate have an impact on corporate organizations and how well their operations perform. On the other hand, the functionality of geography, climate, and natural resources, as well as the abundance of natural resources, are found to be influenced by commercial organizations, their processes, products, and services (Mitic *et al.,* 2020; Niaz, 2021; Olah *et al.,* 2020). The integration of environmental sustainability into the economic system is the way to reduce the detrimental consequences of business activities on the environment, living and non-living natural resources, and the health of people. This idea implies that companies should implement green initiatives to reduce the business operations' negative environmental consequences and adjust their policies and strategies whenever it is required (McGain, Muret, Lawson & Sherman, 2020; Sarwar, Ming & Husnain, 2020).

Energy transition and eco-innovation are the two major initiatives to reduce the negative impacts of business functions and ensure environmental sustainability. Fossil fuels are the most common source of energy in the economic sectors to undertake different practices. But the, fossil fuels are carbon-containing elements, and whenever they are combusted, they cause CO2 emissions. The energy transition is the ongoing way to replace fossil fuels with energy sources that contain low carbon. In addition, an energy transition is a large structural adjustment to the supply and use of energy in a system (Anwar *et al.,* 2020; Murshed, 2020). Renewable energy production and renewable energy consumption are the two components of the energy transition. Renewable energy production is the production of energy from crops, crop wastes, livestock wastes, trash disposal, and natural heat. It is an effective way to reduce the CO2 emissions from the air, and thus, it improves environmental sustainability (Child, Koskinen, Linnanen & Breyer, 2018; Paraschiv *et al.,* 2021). Eco-innovation is the innovation in the organizational concept, organizational structure, processes, products, and services, with the aim to bring improvement in environmental quality by reducing CO2 emissions. Research & developmental and

technology exports are also tools of ecological friendly innovation. When the research & development activities are ecologically friendly, awareness and innovation-oriented activities are encouraged, which result in the reduction of CO2 emissions and enhance environmental sustainability (Tao, Umar, Naseer & Razi, 2021; Tiberius, Schwarzer & Roig-Dobon, 2021). Similarly, with the change in the technological structure of business organizations, ecological innovation can be brought into different organizational departments like information, risk management, operational management, production, and sales & marketing. The ecological friendly innovation reduces environmental pollution like CO2 emissions and develops environmental sustainability (Seddighi & Mathew, 2021;Sumrin et al., 2021). The current study is to examine the impacts of energy transition and eco-innovation on CO2 emissions and environmental sustainability in sustainable cities and communities of the top ten Asian countries. The selected countries for analysis are Russia, China, India, Kazakhstan, Saudi Arabia, Indonesia, Iran, Mongolia, Pakistan, and Turkey. Russia is a developing economy with an estimated nominal GDP of $1.71 trillion in 2022 and a 146,749,000 population. Though energy efficiency and sustainability initiative are being taken, the country still emits 2 billion CO2 each year (Jermsittiparsert, 2021; Shah, Zhou, Walasai, & Mohsin, 2019). China is an upper-middle-income developing economy with an estimated nominal GDP of $19.91 trillion in 2022 and a 1,411,787,240 population. China is considered the largest emitter of greenhouse gases like CO2 being an industrialized economy and excessive use of fossil fuels. China's CO2 emission was 10.67 metric tons per capita in 2020. India is a developing economy with an estimated nominal GDP of $3.535 trillion in 2022 and a 1,389,637,446 population. In India, traditional business processes are still applied, and fossil fuels are utilized. India's CO2 emission will be 1.80 metric tons per capita in 2020. Kazakhstan is a newly industrialized economy with a GDP of $3.535 trillion in 2022 and a 1,389,637,446 population. The country emitted 12.06 metric tons per capita in 2020. However, energy efficiency and sustainability initiatives are being taken (Saleem, Khan, & Shabbir, 2020; Wirsbinna, & Grega, 2021).

Saudi Arabia is a high-income economy with a GDP of $1.040 trillion in 2022 and a 35,697,522 population. Because of increasing economic activities, its total CO2 emissions were 15.27 metric tons per capita in 2020. Indonesia is also a high-income economy with a GDP of $1.29 trillion in 2022 and a 273.879.750 population in 2021. The country's total CO2 emissions were 2.18 metric tons per capita in 2018. Iran, on the other hand, is a developing economy with a GDP of $1.74 trillion in 2022 and an 85,484,011 population in 2021 (Atkociuniene & Siudikiene, 2021; Masud, Kaium, Nurunnabi, & Bae, 2018; Shibli et al., 2021). The country's total CO2 emissions were 7.69 metric tons per capita in 2018. Well, energy transition and ecological friendly undertakings are being done in sustainable communities. Mongolia is also an emerging economy with high GDP growth, as shown by $14.233 billion in 2021, but with the large use of fossil fuels, the CO2 emissions will be 6.73 metric tons per capita in 2020. Pakistan, however, is a lower-middle-income economy with 242,923,845 population. The traditional business process and fossil fuel consumption CO2 emission was 0.98 metric tons per capita in 2018. Lastly, Turkey is a highly populous country, and the use of fossil fuels in Turkey is also high. It emitted 5.2 metric tons per capita in 2018 (Hartani, Haron & Tajuddin, 2021; Kunkel & Matthess, 2020).

In these Asian countries, the most common element is a large population. The household and economic activities are also greater in number requiring a large amount of energy. Although in some cities and communities, renewable energy is preferred to be produced and utilized, and ecological-friendly improvements are being made. In the majority of the cities and communities, still nonrenewable energy ad traditional ways are applied causing CO2 emissions and jeopardizing environmental sustainability (Khan, Yu, Sharif, & Golpîra, 2020; Ojogiwa, 2021). So, it is required for scholars and authors to pay attention to this issue. The present study meets this requirement. Its objective is to analyze the influences of energy transition like renewable energy production, renewable energy consumption, and eco-innovation, including research & development expenditures, technology exports, industrialization, and environmental sustainability.

The current study makes a significant contribution to the literature. First, in most of the literature on energy transition and environmental sustainability, energy transition is measured by renewable energy consumption only. The present study makes a distinction for, here renewable energy production and consumption, and both are measures of the energy transition. Second, usually in past studies, greenhouse gas emissions have been used as the proxy for environmental sustainability while checking the contribution of energy transition and eco-innovation. The present study adds to the literature for taking CO2 emissions as the proxy for environmental sustainability as the result of energy transition and eco-innovation. Third, the issue of CO2 emissions and low environmental sustainability has been in these selected countries. But, this is for the first time that the impacts of renewable energy production and consumption, eco-innovation, research & development expenditures, technology exports, and industrialization on CO2 emissions and environmental sustainability in all these countries.

The paper is comprised of the following parts: The following part, after the introduction, deals with the relationship between energy transition like renewable energy production and consumption and eco-innovation, including research & development expenditures and technology exports, and industrialization and environmental sustainability through the lens of past authors views. The third portion states what methodology study applies for the collection and analysis of data. The study findings are supported by other studies. After the study implication and the study is described in short with a proper conclusion. Then, limitations are given.

Literature Review

The environment is an essential factor in man's life. It determines man's health, lifestyle mad economy. But these are the human activities, including the heating, cooling, and lightening the houses, agriculture, manufacturing, construction, and traveling activities which include the use of machines, plants, and energy resources al influence the

natural environment (Braslauskas, 2020; Liu, Yuan, Hafeez, & Yuan, 2018; Matuszewska-Pierzynka, 2021). Environmental sustainability is the interaction of human beings with the environment and its elements in a responsible manner. This is possible if the human activities are designed in such a manner as they do not cause depletion of the living and non-living natural resources and allow the future generation to meet their needs. With the sustainability initiatives like energy transition and eco-innovation, environmental sustainability can be achieved because they enable humans to reduce CO2 emissions (Mikelsone *et al.,* 2020; Murshed, Rahman, Alam, Ahmad & Dagar, 2021; Sell, 2020). The present article examines the two components of energy transition like, renewable energy production and consumption to analyze their role in environmental sustainability. It also checks the eco-innovation, including research & development expenditures and technology exports' role in environmental sustainability. Different authors have presented diverse views about the nexus between renewable energy production and consumption, eco-innovation, research & development expenditures and, technology exports, and, industrialization, and environmental sustainability. The past author's views have been presented below for enumerating the nexus among variables.

In a literary article, Chen, Wang, and Zhong (2019) examines the relation among EG, foreign trade, renewable, nonrenewable energy production, and CO2 emissions. The data was acquired from China covering 1980 to 2014 time span. The econometric and analytical techniques like ARDL and VECM Granger causality approach were applied for findings about relations among factors. The results showed that when renewable energy like solar power, biomass, bioenergy, wind power, and geothermal power is being produced, the CO2 emissions can be reduced from the air; in all these energy generation processes, CO2 emissions are being utilized as an ingredient or reduces the source of CO2 emission. Razmjoo et al. (2021), investigates the influences of energy sustainability using REW sources on CO2 emissions and environmental sustainability. The data was acquired from Iran thorough review of environmental issues and the meteorological organization. A technological-economic assessment was conducted with the help of HOMER software. Findings exposed that REW production and CO2 emissions are negatively correlated. Magazzino, Mele, and Schneider (2021) wrote about the connection between solar and wind energy production, GDP, and coal consumption, with CO2 emissions and environmental sustainability. A machine learning approach was applied to assess the causal relationship among factors in US and China. The REW energy production increases energy supply which eventually maximize the energy usage instead of fossil fuels. Therefore, it reduces CO2 emissions and improves environmental sustainability.

The literature workout of Zaidi, Hou, and Mirza (2018) deals with the relation of REW and non REW energy consumption to CO2 emissions and environmental sustainability. The information was acquired from the Pakistani economy from 1970-2016. The study reveals that the consumption of non REW energy causes the greenhouse gas emissions like CO2 emissions. The transition to renewable energy consumption reduces the CO2 emissions because this energy does not contain carbon particles to release during use. The study was conducted by Wolde-Rufael and Weldemeskel (2020) to investigate the relationship between environmental policy and renewable energy consumption to CO2 emissions and environmental sustainability. Empirical evidence was collected from BRIICTS countries for the period from 1993 to 2014, and the PMG-ARDL estimator was applied to assess the nexus between environmental policy, renewable energy consumption, and CO2 emissions. The study posits that traditionally, fossil fuels are used to gain energy for undertaking different business functions like manufacturing, infrastructure, transportation, and running different operational technologies. The use of REW energy reduces the consumption of nonrenewable energy within the organization for undertaking economic activities, reduces CO2 emissions, and protects the environment. Dong, Dong, and Jiang (2020), investigates the extent to which renewable energy consumption is effective in reducing CO2 emissions and achieving environmental sustainability. The information for the factors involved was acquired from 120 countries for the time 1995–2015. It also posits that the consumption of REW energy keeps the business processes clean, restraining them from spreading CO2 emissions

The authors like Fethi and Rahuma (2020) examine eco innovation, CO2 emissions and environmental sustainability. The Second-generation panel regression econometric methods were employed, and the quarterly data for eco-innovation measurements like investment, training, and research and development. The results show eco-innovation as a key solution to CO2 emissions and an effective way to achieve environmental sustainability. The eco-innovation, like the adoption of energy-efficient manufacturing technologies, does not cause any harmful gas emissions and deteriorating wastes. So, CO2 emissions are minimum. This study of Fethi and Rahuma (2019) tests the role of eco-innovation in reducing CO2 emissions and environmental sustainability. The second-generation panel econometric methods like CIPS and CADF unit root tests, DH panel causality test, and DSUR co-integrating test for the time between 2007 and 2016 and the relationship of the factors are analyzed in the top 20 export based countries. If the business organizations maintain eco-innovation, with the improvement in technology, CO2 emissions can be reduced, and their contribution to environmental sustainability can be improved. The literary article of Sun, Yesilada, Andlib, and Ajaz (2021) was to investigate the relation of eco-innovation along with globalization with reduction of CO2 emissions and environmental sustainability. The case of the USA economy for the study was taken, and the QARDL approach was applied estimation of the short and long-run nexus among the variables. In a business setup, the major cause of CO2 emissions is the use of fossil fuels, or nuclear-based energy in a large amounts. The eco-innovation either reduces the use of this sort of energy or helps to overcome the environmental consequences. So, eco-innovation has a positive association with environmental sustainability.

With empirical research, Kihombo, Saud, Ahmed, and Chen (2021) numerate the relationship between financial development, research and development expenditures, and eco-innovation with CO2 emissions and environmental

sustainability. The relevant information for factors causal and long-run nexus was taken from West Asia and Middle East economies. The study reveals that when the research & development expenditures increase, the officials, administrators, and workers get the awareness of environmental issues caused by business practices and essential undertakings for environmental sustainability. So, they can control CO2 emissions and achieve environmental sustainability. The study conducted by Mustafa, Lougou, Shuai, Wang, and Tan (2020) checks the role of research & development, technological advancement, and eco-innovation in the mitigation of CO2 emissions. The study implies that the research initiatives expand our understanding of topics vital to eco-innovation. Consider information about environmentally friendly technology and materials used in many economic activities such as agriculture, manufacturing, mining, food processing, tourism, and transportation. This information promotes environmentally friendly development in these industries, which reduces CO2 emissions and improves environmental sustainability. The research was done by Abid, Mehmood, Tariq, and Haq (2022) to integrate the relationship between research & development, eco-innovation, and FDI with CO2 emissions and environmental sustainability. The evidence for the selected factors was collected from G8 countries from 1990–2019, and the FMLOS estimator was applied for long and short-term analysis of factors association. According to the study findings, the research & development with information acquisition, processing, and developmental initiatives help implement eco-innovation and thereby control CO2 emissions.

Lin and Zhu (2019) investigates the effect of technological exports and renewable energy technological innovation on CO2 emissions and environmental sustainability. The authors examined the factors and their relationship to the Chinese economy from 2000–2015. The study implies that when the countries are engaged in exports of technology, they always try to bring improvement in the technologies to be used in businesses. The innovation of renewable energy technologies is helpful in overcoming global CO2 emissions. Hence, technological exports have a positive association with environmental sustainability. The study of Zhao, Shahbaz, Dong, and Dong (2021) integrates the relationship between technological innovation, technology exports, CO2 emissions, and environmental sustainability. The survey was done to 35 OECD countries from 1996–2015. For empirical analysis, the panel quantile regression approach was applied. The results revealed that the tendency to make technological innovations and export the technologies promotes energy-efficient technologies resulting reduction of CO2 emissions and environmental sustainability. The research by Su et al. (2021) also focuses on the same point that technology exports and technological innovation help improve the performance of all types of environmental management systems. Hence, the CO2 emissions are minimum, and the environment can be sustainable.

Mahmood, Alkhateeb, and Furqan (2020), analyzes the relationship of industrialization and urbanization to CO2 emissions and environmental sustainability. The nexus among these factors was empirically analyzed in Saudi Arabia, covering the period from 1968–2016. Industrialization has both positive and negative influences on CO2 emissions. The increasing industrial activities like infrastructure, manufacturing, transportation, etc., with the increasing use of fossil fuels, enhance the CO2 emissions. Simultaneously, with the increase in technological advancements as a result of industrialization, the use of fossil fuels and CO2 emissions can be controlled. Hence, industrialization positively contributes to environmental sustainability. Aslam et al. (2021) and Streimikiene & Akberdina (2021) analyzes the influences of industrialization and GDP growth on CO2 emissions in China. Industrialization growth improves the production of technological tools and equipment. It helps bring about technological advancements and make products more environmentally friendly so that enterprises' negative effects on the environment are reduced. As a result, rising industrialization creates opportunities for environmental sustainability. The literary workout of Wang, Hsu, Zheng, Chen, and Li (2020) identifies the relationship between industrialization, urbanization, CO2 emissions, and environmental sustainability. The data as evidence for the relationship of the factors were collected from the Chinese economy. The article states that as the increasing industrialization creates activity in the economy and improves the living standard of the people, they can benefit from energy-efficient technologies and resources. The use of such resources helps reduce environmental pollution like CO2 emissions. So, the environmental quality and productivity can be improved.

Research Methodology

The study investigates the impact of the energy transition, eco-innovation, R&D expenditures, technology exports, and industrialization on the CO2 emissions in the ten most populated Asian countries. The study has gathered secondary data from OECD and WDI from 2006 to 2020. The selected countries are Russia, China, India, Kazakhstan, Saudi Arabia, Indonesia, Iran, Mongolia, Pakistan, and Turkey. The study has developed the equation given below:

$$CO2_{it} = \alpha_0 + \beta_1 REO_{it} + \beta_2 REC_{it} + \beta_3 ECI_{it} + \beta_4 RDE_{it} + \beta_5 TEX_{it} + \beta_6 IND_{it} + e_{it} \quad (1)$$

where;
CO2 = Carbon Dioxide Emissions
t = Time Period
i = Countries
REO = Renewable Energy Production
REC = Renewable Energy Consumption
ECI = Eco-innovation Index
RDE = Research and Development Expenditures
TEX = Technology Exports
IND = Industrialization.

The study used environmental sustainability as the dependent variable and measured with CO2 emissions (metric ton per capita). The study has also taken two independent variables such as energy transition and eco-innovation. The energy transition is measured with REO and REC. In addition, eco-innovation is measured as the eco-innovation index, R&D expenditures and technology export. Finally, the study has taken industrialization as the control variable and measured with industry value added. These measurement details are given in Table 1.

Table 1

Measurements of Variables

S#	Variables	Measurement	Sources
01	Environmental Sustainability	CO2 emissions (metric ton per capita)	WDI
02	Energy Transition	REO (% of total energy output)	WDI
		REC (% of total energy consumption)	WDI
03	Eco-innovation	Eco-innovation index	OECD
		Research and development expenditures (% of GDP)	WDI
		Technology exports (% of manufactured exports)	WDI
04	Industrialization	Industry value added (% of GDP)	WDI

The study conducted descriptive to show the details of all the variables year wise. The study has also applied the correlation matrix that shows the directional linkage among variables. In addition, cross-sectional dependence (CSD) has also been analyzed with the help of the BP-LM test established by Breusch & Pagan and also with the help of the P-CD test established by Pesaran. Moreover, the CSD issue exists due to substantial interdependencies among selected countries. Hence, the LM test established by Breusch & Pagan equation is mentioned below:

$$LM_1 = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\hat{\rho}_{ij}^2 \rightarrow X^2\,\frac{N(N-1)}{2} \quad (2)$$

Moreover, the LM test projected by the Pesaran equation is mentioned below:

$$\mathrm{LM}_2 = \sqrt{\frac{1}{\mathrm{N(N-1)}}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T_{ij}\hat{\rho}_{ij}^2 - 1\right) \rightarrow N(0,1) \quad (3)$$

In contrast, the CD test established by the Pesaran equation is mentioned below:

$$CD = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\hat{\rho}_{ij}^2 \rightarrow N(0,1) \quad (4)$$

In the above equation, ρˆij represents the correlation coefficients obtained from the residuals.

In addition, the unit root among the variables has also been analyzed by the researchers. The study applied the cross-sectional Augmented Dickey Fuller (CADF) test to check the unit root. The CADF equation is mentioned below:

$$y_{it} = \alpha_i + b_i y_{it-1} + c_i \bar{y}_{it-1} + d_i \Delta\bar{y}_t + e_{it} \quad (5)$$

Moreover, Cross-Sectionally Augmented IPS (CIPS) has also been applied to check the unit root. It controls the CSD issue and provides the best results (Chang, Sickles, & Song, 2017). The CIPS equation is mentioned below:

$$\Delta W_{i,t} = \emptyset_i + \emptyset_i Z_{i,t-1} + \emptyset_i \bar{Z}_{t-1} + \sum_{l=0}^{p}\emptyset_{il}\Delta\overline{W}_{t-1} + \sum_{l=0}^{p}\emptyset_{il}\Delta W_{i,t-1} + \mu_{it} \quad (6)$$

In the above equation, $\overline{W}$ shows the average cross-section signified below:

$$W^{i,t} = \emptyset^1\,\overline{GB}^{i,t} + \emptyset^2\,\overline{SCCF}^{i,t} + \emptyset^3\overline{NRR}^{i,t} + \emptyset^4\,\overline{EG}^{i,t} + \emptyset^5\,\overline{IND}^{i,t} + \emptyset^6\,\overline{PG}^{i,t} \quad (7)$$

Moreover, the CIPS test statistics are mentioned below:

$$\widehat{CIPS} = N^{-1}\sum_{i=1}^{n} CADF_i \quad (8)$$

Furthermore, co-integration has also been examined with the help of (Westerlund & Edgerton, 2008) approach. The null hypotheses of the test exposed no co-integration. The equations have been mentioned below:

$$\mathrm{LM}_{\varphi}(\mathrm{i}) = \mathrm{T}\hat{\varphi}_{\mathrm{i}}\,(\hat{\mathrm{r}}_{\mathrm{i}}/\hat{\sigma}_{\mathrm{i}}) \quad (9)$$

$$\mathrm{LM}_{\tau}(\mathrm{i}) = \hat{\varphi}_{\mathrm{i}}/\mathrm{SE}(\hat{\varphi}_{\mathrm{i}}) \quad (10)$$

In the equations given above, $\hat{\varphi}_i$ shows the estimation against $\hat{\sigma}_i$ standard error. While $\hat{r}^2_i$ shows its assessed variance of $_{it}$ in the long run. Furthermore, $\varphi i\ (L) = 1 - \sum \varphi_{ij}Lj$ represents a scalar polynomial with L lag length. In the end, the ρ_i represents the factor loading parameters vector.

Finally, CUP-FM and CUP-BC, developed by (Bai, Kao, & Ng, 2009), have been applied to check the association among variables. This approach delivers a robust estimation. Moreover, the CUP-FM is formed by continuous parameters, factor loadings, and covariance matrix estimation until convergence is attained. The CUP-FM and CUP-BC equations are mentioned below:

$$\beta_{cup} = \left[\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{y}_{it} + \hat{\beta}_{cup})(x_{it} - \bar{X}_i)' - T\left(\lambda'_i(\hat{\beta}_{CUP})\hat{\Delta}_{F\varepsilon i}(\hat{\beta}_{CUP}) + \hat{\Delta}_{u\varepsilon i}(\hat{\beta}_{CUP})\right)\right] \times \left[\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \bar{X}_i)\,(x_{it} - \bar{X}_i)'\right] \quad (11)$$

In equation (11), $\hat{\Delta}_{F\varepsilon i}$ *and* $\hat{\Delta}_{u\varepsilon i}$ showed the one-sided estimated covariance. Moreover, CUP-BC and CUP-FM techniques deliver an unchanging estimator for dependent variables. In addition, CUP-FM and CUP-BC estimators deliver a robust estimation. Finally, these techniques are appropriate when the integration order, I(0)/I(1).

Research Findings

The study has applied descriptive statistics that show the details of all the variables. The results exposed that the study used 150 observations (10 countries x 15 years). In addition, the study findings also exposed that the CO2 average value was 6.926, REO mean value was 13.901, and REC average value was 14.685. Moreover, the study findings also exposed that the ECI average value was 136.569, RDE mean value was 0.661, TEX average value was 11.347, and IND mean value was 35.606. These values are mentioned in Table 2.

Table 2

Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO2	150	6.926	4.974	0.764	17.819
REO	150	13.901	10.167	0.000	33.704
REC	150	14.685	15.938	0.010	48.130
ECI	150	136.569	78.965	54.36	719.482
RDE	150	0.661	0.582	-0.099	2.401
TEX	150	11.347	11.396	0.544	43.430
IND	150	35.606	10.366	18.099	66.757

Moreover, the study has also run the country-wise descriptive statistics that show the details of the variables with respect to countries. The findings indicated that the highest CO2 was in Saudi Arabia, the highest REO was in Pakistan, and the highest REC was in Pakistan. In addition, the findings indicated that the highest ECI was in Iran, the highest RDE was in China, the highest TEX in Kazakhstan, and the highest IND was in Saudi Arabia. In contrast, the findings indicated that the lowest CO2 was in Pakistan, the lowest REO was in Saudi Arabia, and the lowest REC was in Saudi Arabia. In addition, the findings indicated that the lowest ECI was in Saudi Arabia, the lowest RDE was in Indonesia, the lowest TEX in Saudi Arabia, and the lowest IND was in Pakistan. These values are mentioned in Table 3.

Table 3

Descriptive Statistics by Country

	CO2	REO	REC	ECI	RDE	TEX	IND
Russia	11.377	16.238	3.344	127.732	1.080	10.556	30.129
China	6.726	21.041	13.075	109.265	1.889	30.801	43.298
India	1.511	16.177	35.484	126.224	0.727	8.479	28.429
Kazakhstan	13.001	8.352	1.610	128.321	0.167	32.816	35.442
Saudi Arabia	16.097	0.000	0.013	106.973	0.895	0.752	54.738
Indonesia	1.870	13.14	30.132	117.770	0.119	10.016	42.665
Iran	7.507	4.790	0.978	249.746	0.391	2.198	40.669
Mongolia	5.894	1.678	3.708	133.520	0.203	13.377	33.991
Pakistan	0.835	31.096	45.570	126.681	0.288	1.849	19.629
Turkey	4.438	26.493	12.937	139.455	0.851	2.626	27.071

In addition, the study has also run the year-wise descriptive statistics that show the details of the variables with respect to years. These results exposed that the highest value of CO2 was in 2020, the highest REO was in 2019, and the highest REC was in 2006. In addition, the findings indicated that the highest ECI was in 2020, the highest RDE was in 2019, the highest TEX in 2014, and the highest IND was in 2006. In contrast, the findings indicated that the lowest CO2 was in 2006, the lowest REO was in 2008, and the lowest REC was in 2020. In addition, the findings indicated that the lowest ECI was in 2006, the lowest RDE was in 2006, the lowest TEX in 2017, and the lowest IND was in 2020. These values are mentioned in Table 4.

Table 4

Descriptive Statistics by Years

	CO2	REO	REC	ECI	RDE	TEX	IND
2006	6.123	14.106	17.239	69.558	0.484	11.849	39.210
2007	6.383	13.215	16.526	75.197	0.531	10.796	38.890
2008	6.730	12.286	16.362	85.927	0.570	11.677	39.037
2009	6.549	12.555	15.870	92.532	0.596	11.984	36.388
2010	6.856	14.059	15.493	100.000	0.644	12.100	37.060
2011	7.153	13.142	14.629	109.561	0.601	10.766	37.587
2012	7.230	13.401	14.377	119.753	0.648	11.077	36.733
2013	7.299	14.183	14.671	132.752	0.639	12.276	35.815
2014	7.082	13.513	14.176	143.978	0.671	12.613	34.985
2015	6.913	14.623	14.088	154.129	0.725	11.814	32.477
2016	6.932	14.190	14.061	162.747	0.717	11.793	32.360
2017	7.045	14.371	13.464	171.196	0.802	9.420	33.546
2018	7.074	14.951	13.205	185.145	0.755	9.471	34.492
2019	7.062	15.004	13.320	209.900	0.846	11.754	33.208
2020	7.453	14.911	12.798	236.154	0.686	10.815	32.306

The study has also applied the correlation matrix that shows the directional linkage among variables. The results indicated that the REO and REC, eco-innovation, R&D expenditures, and technology exports are negatively connected with CO2 emissions. The findings also revealed that industrialization positively and significantly affects CO2 emissions. These linkages are mentioned in Table 5.

Table 5

Matrix of Correlations

Variables	CO2	REC	REO	ECI	RDE	TEX	IND
CO2	1.000						
REO	-0.565	1.000					
REC	-0.812	0.646	1.000				
ECI	-0.003	-0.104	-0.162	1.000			
RDE	-0.206	0.262	-0.158	-0.060	1.000		
TEX	-0.211	-0.047	-0.218	-0.175	0.220	1.000	
IND	0.525	-0.622	-0.469	-0.148	0.109	0.116	1.000

In addition, CSD has also been analyzed with the help of the BP-LM test established by Breusch & Pagan and also with the help of the P-CD test established by Pesaran. The results indicated that the t-values are larger than 1.96 and exposed no CSD issue. These values are mentioned in Table 6.

Table 6

CSD Test Results

Variables	Breusch-Pagan LM	Pesaran Scaled LM	Pesaran CD
CO2	463.765***	31.548***	21.244***
REO	200.858***	11.844***	20.832***
REC	221.950***	21.038***	5.923***
ECI	109.940***	20.876***	2.212***
RDE	201.848***	22.655***	3.055***
TEX	192.828***	19.958***	22.850***
IND	111.022***	20.349***	10.244***

Moreover, the study has run the CADF and CIPS tests for checking the unit root. Findings exposed that REO, REC, and ECI have no unit root at a level while CO2, RDE, TEX, and IND have no unit root at first difference. These values are mentioned in Table 7.

Table 7

CADF and CIPS Unit Root Tests Result

Variables	CIPS		CADF	
	Level	1st Difference	Level	1st Difference
CO2	----	-4.342***	----	-5.333***
REO	-5.532***	----	-4.902***	----
REC	-4.092***	----	-4.111***	----
ECI	-2.291***	----	-3.463***	----
RDE	----	-4.002***	----	-5.382***
TEX	----	-3.022***	----	-3.091***
IND	----	-4.337***	----	-3.372***

The study has also examined the co-integration, and the results exposed that the p-values are not bigger than 0.05 and t-values are not less than 1.96. These results exposed co-integration exists. These values are mentioned in Table 8.

Table 8

Co-Integration test Results

Model	No Shift		Mean Shift		Regime Shift	
	Test Stat	p-value	Test Stat	p-value	Test Stat	p-value
LM_{τ}	-3.390	0.000	-5.903	0.000	-4.302	0.000
LM_{φ}	-3.099	0.000	-5.122	0.000	-4.112	0.000

The results of CUP-FM and CUP-BC indicated that the REO and REC, eco-innovation, R&D expenditures, and technology exports are associated with CO2 emissions negatively. The findings also revealed that industrialization positively and significantly affects CO2 emissions. These associations are mentioned in Table 9.

Table 9

CUP -BC and CUP-FM Test Results

Variables	CUP-FM		CUP-BC	
	Coeff	t-stat	Coeff	t-stat
REO	-0.546***	-4.291	-0.534***	-3.102
REC	-0.288***	-4.664	-0.827***	-4.093
ECI	-1.029***	-2.299	-0.920***	-5.902
RDE	-1.992***	-3.102	-1.282***	-2.181
TEX	-0.563**	-2.716	-2.122***	-3.872
IND	0.339***	5.182	0.654***	5.227

Discussions

The study results showed that REW energy production positively influences environmental sustainability. These results are in line with Bamati and Raoofi (2020), which implies that the production of renewable energy, like the energy generation through solar panel systems, itself deduces the heat existing in the air, reduces the need for the production of electricity from fossil fuels combustion, and reduces the use of coal or wood which are the human source of CO2 emissions. Consequently, the reduction in CO2 emissions contributes to environmental sustainability. These findings are also supported by Saidi and Omri (2020), which examines the renewable energy production role in environmental sustainability. The CO2 emissions are the major cause of destroying the natural environment and its elements, serving as the scenery and resources to households and economic enterprises. REW energy production reduces CO2 emissions and improves environmental sustainability. These results are also in line with Sarkodie and Strezov (2018), which states that when in an economy, the business organizations are encouraged to carry out renewable energy production programs like the installation of wind tribes, hydroelectric power systems, solar panel systems, and bioenergy production, the use of clean energy increases within the country. So, pollution like CO2 emissions can be mitigated.

The study results showed that renewable energy consumption positively influences environmental sustainability. These results agree with Adebayo, Rjoub, Akinsola, and Oladipupo (2022), which implies that the use of energy is taken as the source of CO2 emissions polluting the environment, changing climate, and destroying nature's resilience. The use of renewable energy like wind power, hydropower, solar power, biomass, and biofuel for heating, lighting, or cooling the buildings, transportation of people or luggage from one place to another, and carrying on the production activities reduces the greenhouse gases like CO2 emissions, and so, there is higher environmental sustainability. These findings are also supported by Nathaniel and Iheonu (2019), which explores the renewable energy consumption role in environmental sustainability. The use of fossil fuels like coal, oil, ore, and petroleum during combustion emits CO2 emissions, and the wastes they leave after going through the combustion process also cause CO2 emissions. The transition from using fossil fuels to renewable energy generated from natural resources reduces the CO2 during business operations contributing to environmental sustainability. These results are also in line with Khattak, Ahmad, Khan, and Khan (2020), which states that renewable energy is a cheap source of energy. So, the energy consumption pattern is designed as both the renewable and nonrenewable energy resources are utilized in carrying on manufacturing activities and other business operations, reducing CO2 emissions. Hence, there is high environmental sustainability.

The study results showed that eco-innovation positively influences environmental sustainability. These results are in line with Dogru et al. (2020), which implies that the business processes, resources, products, and services, because of the use of machinery, plants, infrastructure, and energy sources, cause greenhouse gas emissions and affect the environmental quality and productivity. When the business firms maintain ecological friendly innovation in the form of innovation and value addition to processes, resources, products, and services with the attention to reducing the negative impacts of business on the environment, they successfully maintain the environmental sustainability. These findings are also in line with Ding, Khattak, and Ahmad (2021), which throws light on the eco-innovation influences on environmental sustainability. The study implies that the use of technologies is an essential factor to a business organization and determines its success, but it causes CO2 emissions and jeopardizes environmental sustainability. If the business organizations maintain eco-innovation, with the improvement in technology, CO2 emissions can be reduced, and their contribution to environmental sustainability can be improved. These results also agree with Amin, Zhou, and Safi (2022), which states that with the application of environmentally friendly innovations like clean energy resources, operational ecological resources, energy-efficient technologies, and ecological friendly logistics, the CO2 emissions can be controlled, and the natural environment can be protected.

The study results showed that research & development expenditures are positively linked to environmental sustainability. These results are in line with Xie and Wang (2019), which implies that research & development is an instrument for eco-innovation. The research activities enhance the knowledge that is essential for eco-innovation. For instance, the information about the ecological friendly technologies and materials used in different economic practices like agriculture, manufacturing, mining, food processing, tourism, and transportation. This knowledge encourages ecological friendly improvement in these sectors resulting in a reduction of CO2 emissions and environmental sustainability. These findings are also supported by Khezri, Karimi, Khan, and Abbas (2021). According to this, research & development is helpful in employing eco-innovation. The application of eco-innovation like employing clean energy sources, use of

wastage to recover energy, material recovery from waste utilization, use of clean fertilizers, water management, waste management, improvement in sanitation system, and ecologically friendly products improves environmental sustainability. These results are also in line with Shoaib, Rafique, Nadeem, and Huang (2020), which posits that research & development helps bring innovation in the internal business practices with an intention to have the same or more production without damaging the natural environment. The environment where the businesses operate can be sustainable with reduced CO2 emissions.

The study results showed that technology exports positively influence environmental sustainability. These results are in line with Barrows and Ollivier (2021), which implies that in any business sector, the technologies of different types are being employed to carry out different functions. These technologies use energy to run, causing CO2 emissions. With the improvement in quality and functioning of these technologies with the help of experts, the use of energy can be reduced, or renewable energy can be employed. So, there is a low rate of CO2 emissions and improved environmental sustainability. These results also agree with Huang et al. (2020), which states that the increase when an economy has the facility to export technologies of their use and find that there is some particular sort of technology which can cause relatively less amount of CO2 emissions, the technologies can be replaced, and CO2 emissions can be controlled. Hence, there is high environmental sustainability. These findings are also supported by Ahmad, Khan, Rahman, Khattak, and Khan (2021), which examines the technology exports' role in environmental sustainability. In an economy, people may have to face many environmental issues like CO2 emissions. These environmental issues can be overcome with technological advancements and technology exports.

The study results showed that industrialization positively influences environmental sustainability. These results are in line with Jin, Hao, Zhang, Yan, and Chen (2021), which implies that the increase in industrialization enhances the manufacturing of technological tools and instruments. It assists in bringing changes in technologies and making them ecological-friendly so that negative impacts of the businesses on the environment can be minimized. Consequently, the increased industrialization opens the ways to achieve environmental sustainability. These results are also in line with Ullah, Ozturk, Usman, Majeed, and Akhtar (2020), which states that successful industrialization within the country is not only restricted to achieving economic outcomes but to sustaining its overall performance. So, the industrial enterprises apply socially desirable and ecological friendly innovations. Hence, with the improvement in social and environmental performance along with economic goals achievement, CO2 emissions can be controlled, and the natural environment can be sustainable.

Conclusions

The main objective of the study was to check the influences of energy transition and eco-innovation on environmental sustainability. So, the authors were to examine the role of renewable energy production, renewable energy consumption, eco-innovation, research & development expenditures, and technology exports along with industrialization in environmental sustainability. The authors conducted a research survey of the sustainable cities and communities of the top ten Asian countries for the collection of data on renewable energy production, renewable energy consumption, eco-innovation, research & development expenditures, and technology exports, industrialization, and CO2 emissions. The empirical data from these states help find the results, according to which the relationship between renewable energy production and consumption, eco-innovation, research & development expenditures, and technology exports, and industrialization in environmental sustainability is positive. The study shows that the production of energy from renewable natural resources like wind, water, natural heat, crops, and wastes reduces CO2 emissions from the air and improves environmental sustainability. Similarly, the transition from using fossil fuels to the consumption of renewable energy help mitigate the CO2 during business operations contributing to environmental sustainability. The results revealed that the eco-innovation like clean energy resources, improved operational resources, energy-efficient technologies, and ecological friendly logistics, the CO2 emissions can be controlled, and the natural environment can be sustainable. The research & developmental activities with improved learning and developmental activities are helpful in implementing eco-innovation, facilitating better production with reduced environmental impacts. Technology is a significant factor in innovation. The countries which are engaged in technology exports have the ability to make technological advancements, and the ecological-friendly technology can lead the firms to show higher environmental performance. Thus, environmental sustainability is high.

Implications

The present study has theoretical as well as empirical implications. The study guides the authors for their further initiatives through the contribution to literature. The focus of the study is on the role of energy transition and eco-innovation in environmental sustainability. So, the authors examine the influences of renewable energy production, renewable energy consumption, eco-innovation, research & development expenditures, and technology exports along with industrialization on environmental sustainability. In past literature, the greenhouse gas emissions collectively are taken in order to measure environmental sustainability as a result of energy transition and eco-innovation. This study guides the policymakers that they should establish the policies related to the environmental instability by enhancing the REO and innovation adoption. This is the current study's initiative that takes more appropriate indicators of environmental sustainability like CO2 emissions. Moreover, usually, a single country's information has been taken to address the role of renewable energy production, renewable energy consumption, eco-innovation, research & development expenditures, and technology exports along with industrialization in achieving environmental sustainability. The present article, which sorts out the sustainable cities and communities of the top

ten Asian countries for the nexus among factors, makes a distinction in literature.

The present study is also greatly significant to populous countries like Asian countries, where because of increasing human activities create environmental issues and the sustainable country's development is endangered because the main focus of the study is the achievement of environmental sustainability. The study guides the economists, environmental regulators, and government that they must enforce energy transition by encouraging renewable energy production within the country and motivating individuals and firms to utilize renewable energy in place of nonrenewable energy so that the CO2 emissions can be reduced and environmental sustainability can be achieved. It also recommends that they must apply ecological-friendly innovation within the business organizations, which reduces the CO2 emission along with the improvement in economic practices. Hence, environmental sustainability can be achieved. The policymakers must also promote research & development so that environmental awareness can be increased and eco-innovation can be brought, reducing the CO2 emissions and helping to achieve environmental sustainability. The government must form fiscal and other economic policies to encourage technological advancements and technology experts, which are helpful in reducing CO2 emissions and assuring environmental sustainability. The study also guides that industrial activities must be properly managed to improve environmental sustainability.

Limitations & Recommendations

A number of limitations are linked to the present study. The authors, with extra efforts and literary expertise, can overcome these limitations. The study has analyzed only two main factors of the energy transition, renewable energy production, renewable energy consumption, and eco-innovation, including research & development expenditures and technology exports and industrialization to numerate environmental sustainability. There are many other factors like green finance, CSR integration, and human resource management, but these factors are missing in this study. The future authors are recommended to pay attention to here and enhance the scope of the study by including more factors under consideration. This study is based on a limited number of Asian economies for the analysis of the nexus among renewable energy production, renewable energy consumption, and eco-innovation, including research & development expenditures and, technology exports and industrialization, and environmental sustainability. These states can provide a limited set of data, and the study can be valid in a few similar economies. The authors, by collecting data from different regions of the world, can improve the study's generalizability and validity.

References

Abid, A., Mehmood, U., Tariq, S., & Haq, Z. U. (2022). The effect of technological innovation, FDI, and financial development on CO2 emission: evidence from the G8 countries. *Environmental Science and Pollution Research*, 29(8), 11654–11662. https://doi.org/10.1007/s11356-021-15993-x

Adebayo, T. S., Rjoub, H., Akinsola, G. D., & Oladipupo, S. D. (2022). The asymmetric effects of renewable energy consumption and trade openness on carbon emissions in Sweden: new evidence from quantile-on-quantile regression approach. *Environmental Science and Pollution Research,* 29(2), 1875–1886. https://doi.org/10.1007/s11356-021-15706-4

Ahmad, M., Khan, Z., Rahman, Z. U., Khattak, S. I., & Khan, Z. U. (2021). Can innovation shocks determine CO2 emissions (CO2e) in the OECD economies? A new perspective. *Economics of Innovation and New Technology*, 30(1), 89–109. https://doi.org/10.1080/10438599.2019.1684643

Amin, M., Zhou, S., & Safi, A. (2022). The nexus between consumption-based carbon emissions, trade, eco-innovation, and energy productivity: empirical evidence from N-11 economies. *Environmental Science and Pollution Research*, 29(26), 39239–39248. https://doi.org/10.1007/s11356-021-18327-z

Anwar, M., Khattak, M. S., Popp, J., Meyer, D. F., & Mate, D. (2020). The nexus of government incentives and sustainable development goals: is the management of resources the solution to non-profit organisations?. *Technological and Economic Development of Economy*, 26(6), 1284–1310. https://doi.org/10.3846/tede.2020.13404

Aslam, B., Hu, J., Shahab, S., Ahmad, A., Saleem, M., Shah, S. S. A., . . . Hassan, M. (2021). The nexus of industrialization, GDP per capita and CO2 emission in China. *Environmental technology & innovation*, 23, 101–118. https://doi.org/10.1016/j.eti.2021.101674

Atkociuniene, Z. O., & Siudikiene, D. (2021). Communication management in promoting knowledge and creativity in fostering innovations in the creative organizations. *Creativity Studies*, 14(2), 549–576. https://doi.org/10.3846/cs.2021.15550

Bai, J., Kao, C., & Ng, S. (2009). Panel cointegration with global stochastic trends. *Journal of econometrics,* 149(1), 82–99. https://doi.org/10.1016/j.jeconom.2008.10.012

Bamati, N., & Raoofi, A. (2020). Development level and the impact of technological factor on renewable energy production. *Renewable energy*, 151, 946–955. https://doi.org/10.1016/j.renene.2019.11.098

Barrows, G., & Ollivier, H. (2021). Foreign demand, developing country exports, and CO2 emissions: Firm-level evidence from India. *Journal of Development Economics*, 149, 102–129. https://doi.org/10.1016/j.jdeveco.2020.102587

Braslauskas, J. (2020). Effective creative intercultural communication in the context of business interaction: theoretical and practical aspects. *Creativity studies,* 13(1), 199–215. https://doi.org/10.3846/cs.2020.12094

Chang, Y., Sickles, R. C., & Song, W. (2017). Bootstrapping unit root tests with covariates. *Econometric Reviews,* 36(1-3), 136–155. https://doi.org/10.1080/07474938.2015.1114279

Chen, Y., Wang, Z., & Zhong, Z. (2019). CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renewable energy*, 131, 208–216. https://doi.org/10.1016/j.renene.2018.07.047

Chien, F., Hsu, C. C., Andlib, Z., Shah, M. I., Ajaz, T., & Genie, M. G. (2022). The role of solar energy and eco-innovation in reducing environmental degradation in China: Evidence from QARDL approach. I*ntegrated Environmental Assessment and Management,* 18(2), 555–571. https://doi.org/10.1002/ieam.4500

Child, M., Koskinen, O., Linnanen, L., & Breyer, C. (2018). Sustainability guardrails for energy scenarios of the global energy transition. *Renewable and Sustainable Energy Reviews*, 91, 321–334. https://doi.org/10.1016/j.rser.2018.03.079

Ding, Q., Khattak, S. I., & Ahmad, M. (2021). Towards sustainable production and consumption: assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations. *Sustainable Production and Consumption,* 27, 254–268. https://doi.org/10.1016/j.spc.2020.11.004

Dogru, T., Bulut, U., Kocak, E., Isik, C., Suess, C., & Sirakaya-Turk, E. (2020). The nexus between tourism, economic growth, renewable energy consumption, and carbon dioxide emissions: contemporary evidence from OECD countries. *Environmental Science and Pollution Research*, 27(32), 40930–40948. https://doi.org/10.1007/s11356-020-10110-w

Dong, K., Dong, X., & Jiang, Q. (2020). How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels. *The World Economy*, 43(6), 1665–1698. https://doi.org/10.1111/twec.12898

Fethi, S., & Rahuma, A. (2019). The role of eco-innovation on CO2 emission reduction in an extended version of the environmental Kuznets curve: evidence from the top 20 refined oil exporting countries. *Environmental Science and Pollution Research,* 26(29), 30145–30153. https://doi.org/10.1007/s11356-019-05951-z

Fethi, S., & Rahuma, A. (2020). The impact of eco-innovation on CO2 emission reductions: Evidence from selected petroleum companies. *Structural Change and Economic Dynamics*, 53, 108–115. https://doi.org/10.1016/j.strueco.2020.01.008

Ghazali, A., & Ali, G. (2019). Investigation of key contributors of CO2 emissions in extended STIRPAT model for newly industrialized countries: a dynamic common correlated estimator (DCCE) approach. *Energy Reports,* 5, 242–252. https://doi.org/10.1016/j.egyr.2019.02.006

Hartani, N. H., Haron, N., & Tajuddin, N. I. I. (2021). The impact of strategic alignment on the sustainable competitive advantages: Mediating role of it implementation success and it managerial resource. *International Journal of eBusiness and eGovernment Studies,* 13(1), 78–96.

Huang, R., Chen, G., Lv, G., Malik, A., Shi, X., & Xie, X. (2020). The effect of technology spillover on CO2 emissions embodied in China-Australia trade. *Energy Policy,* 144, 111544. https://doi.org/10.1016/j.enpol.2020.111544

Jermsittiparsert, K. (2021). Linkage between energy consumption, natural environment pollution, and public health dynamics in ASEAN. *International Journal of Economics and Finance Studies,* 13(2), 1–21.

Jin, S., Hao, Z., Zhang, K., Yan, Z., & Chen, J. (2021). Advances and challenges for the electrochemical reduction of CO2 to CO: from fundamentals to industrialization. *Angewandte Chemie*, 133(38), 20795–20816. https://doi.org/10.1002/ange.202101818

Khan, S. A. R., Yu, Z., Sharif, A., & Golpîra, H. (2020). Determinants of economic growth and environmental sustainability in South Asian Association for Regional Cooperation: evidence from panel ARDL. *Environmental Science and Pollution Research*, 27(36), 45675–45687. https://doi.org/10.1007/s11356-020-10410-1

Khattak, S. I., Ahmad, M., Khan, Z. U., & Khan, A. (2020). Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: new evidence from the BRICS economies. *Environmental Science and Pollution Research*, 27(12), 13866–13881. https://doi.org/10.1007/s11356-020-07876-4

Khezri, M., Karimi, M. S., Khan, Y., & Abbas, S. (2021). The spillover of financial development on CO2 emission: a spatial econometric analysis of Asia-Pacific countries. *Renewable and Sustainable Energy Reviews*, 145, 111–128. https://doi.org/10.1016/j.rser.2021.111110

Kihombo, S., Saud, S., Ahmed, Z., & Chen, S. (2021). The effects of research and development and financial development on CO2 emissions: evidence from selected WAME economies. *Environmental Science and Pollution Research,* 28(37), 51149–51159. https://doi.org/10.1007/s11356-021-14288-5

Kunkel, S., & Matthess, M. (2020). Digital transformation and environmental sustainability in industry: Putting expectations in Asian and African policies into perspective. *Environmental science & policy,* 112, 318-329. https://doi.org/10.1016/j.envsci.2020.06.022

Lin, B., & Zhu, J. (2019). Determinants of renewable energy technological innovation in China under CO2 emissions constraint. *Journal of Environmental Management,* 247, 662–671. https://doi.org/10.1016/j.jenvman.2019.06.121

Liu, J., Yuan, C., Hafeez, M., & Yuan, Q. (2018). The relationship between environment and logistics performance: Evidence from Asian countries. *Journal of Cleaner Production,* 204, 282–291. https://doi.org/10.1016/j.jclepro.2018.08.310

Magazzino, C., Mele, M., & Schneider, N. (2021). A machine learning approach on the relationship among solar and wind energy production, coal consumption, GDP, and CO2 emissions. *Renewable energy*, 167, 99–115. https://doi.org/10.1016/j.renene.2020.11.050

Mahmood, H., Alkhateeb, T. T. Y., & Furqan, M. (2020). Industrialization, urbanization and CO2 emissions in Saudi Arabia: Asymmetry analysis. *Energy Reports*, 6, 1553–1560. https://doi.org/10.1016/j.egyr.2020.06.004

Masud, M., Kaium, A., Nurunnabi, M., & Bae, S. M. (2018). The effects of corporate governance on environmental sustainability reporting: Empirical evidence from South Asian countries. *Asian Journal of Sustainability and Social Responsibility*, 3(1), 1–26. https://doi.org/10.1186/s41180-018-0019-x

Matuszewska-Pierzynka, A. (2021). Relationship between corporate sustainability performance and corporate financial performance: Evidence from US companies. Equilibrium. *Quarterly Journal of Economics and Economic Policy*, 16(4), 885–906. https://doi.org/10.24136/eq.2021.033

McGain, F., Muret, J., Lawson, C., & Sherman, J. D. (2020). Environmental sustainability in anaesthesia and critical care. *British Journal of Anaesthesia*, 125(5), 680–692. https://doi.org/10.1016/j.bja.2020.06.055

Mikelsone, E., Spilbergs, A., Volkova, T., & Liela, E. (2020). Idea management system application types in local and global context. Equilibrium. *Quarterly Journal of Economics and Economic Policy*, 15(1), 151–166. https://doi.org/10.24136/eq.2020.008

Mitic, P., Kostic, A., Petrovic, E., & Cvetanovic, S. (2020). The relationship between CO2 emissions, industry, services and gross fixed capital formation in the Balkan countries. *Inzinerine Ekonomika-Engineering Economics,* 31(4), 425–436. https://doi.org/10.5755/j01.ee.31.4.24833

Murshed, M. (2020). An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. *Environmental Science and Pollution Research*, 27(29), 36254–36281. https://doi.org/10.1007/s11356-020-09497-3

Murshed, M., Rahman, M., Alam, M. S., Ahmad, P., & Dagar, V. (2021). The nexus between environmental regulations, economic growth, and environmental sustainability: linking environmental patents to ecological footprint reduction in South Asia. *Environmental Science and Pollution Research*, 28(36), 49967–49988. https://doi.org/10.1007/s11356-021-13381-z

Mustafa, A., Lougou, B. G., Shuai, Y., Wang, Z., & Tan, H. (2020). Current technology development for CO2 utilization into solar fuels and chemicals: A review. *Journal of Energy Chemistry,* 49, 96–123. https://doi.org/10.1016/j.jechem.2020.01.023

Nathaniel, S. P., & Iheonu, C. O. (2019). Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. *Science of the Total Environment*, 679, 337–345. https://doi.org/10.1016/j.scitotenv.2019.05.011

Niaz, M. U. (2021). Socio-Economic development and sustainable development goals: a roadmap from vulnerability to sustainability through financial inclusion. *Economic Research-Ekonomska Istrazivanja*, 1–33. https://doi.org/10.1080/1331677X.2021.1989319

Ojogiwa, O. T. (2021). The crux of strategic leadership for a transformed public sector management in Nigeria. *International Journal of Business and Management Studies*, 13(1), 83–96.

Olah, J., Aburumman, N., Popp, J., Khan, M. A., Haddad, H., & Kitukutha, N. (2020). Impact of Industry 4.0 on environmental sustainability. *Sustainability,* 12(11), 4674–4689. https://doi.org/10.3390/su12114674

Paraschiv, D. M., Manea, D. I., Titan, E., & Mihai, M. (2021). Development of an aggregated social inclusion indicator. Disparities in the European Union on inclusion/exclusion social determined with social inclusion index. *Technological and Economic Development of Economy*, 27(6), 1301–1324. https://doi.org/10.3846/tede.2021.15103

Razmjoo, A., Kaigutha, L. G., Rad, M. V., Marzband, M., Davarpanah, A., & Denai, M. (2021). A Technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area. *Renewable energy*, 164, 46–57. https://doi.org/10.1016/j.renene.2020.09.042

Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. *Environmental research*, 186, 1095–1112. https://doi.org/10.1016/j.envres.2020.109567

Saleem, H., Khan, M. B., & Shabbir, M. S. (2020). The role of financial development, energy demand, and technological change in environmental sustainability agenda: evidence from selected Asian countries. *Environmental Science and Pollution Research*, 27(5), 5266–5280. https://doi.org/10.1007/s11356-019-07039-0

Sanchez, O. G., Birdja, Y. Y., Bulut, M., Vaes, J., Breugelmans, T., & Pant, D. (2019). Recent advances in industrial CO2 electroreduction. *Current Opinion in Green and Sustainable Chemistry*, 16, 47–56. https://doi.org/10.1016/j.cogsc.2019.01.005

Sarkodie, S. A., & Strezov, V. (2018). Assessment of contribution of Australia's energy production to CO2 emissions and environmental degradation using statistical dynamic approach. *Science of the Total Environment*, 639, 888–899. https://doi.org/10.1016/j.scitotenv.2018.05.204

Sarwar, B., Ming, X., & Husnain, M. (2020). Economic policy uncertainty and dividend sustainability: new insight from emerging equity market of China. *Economic research-Ekonomska istrazivanja*, 33(1), 204–223. https://doi.org/10.1080/1331677X.2019.1708769

Seddighi, H. R., & Mathew, S. (2020). Innovation and regional development via the firm's core competence: some recent evidence from North East England. *Journal of Innovation & Knowledge*, 5(4), 219–227. https://doi.org/10.1016/j.jik.2019.12.005

Sell, F. L. (2020). Static and Dynamic Price Effects Motivated by Innovation and Imitation: Novel Insights Using the Barone's Curve. *Contemporary Economics*, 14(1), 73–90. https://doi.org/10.5709/ce.1897-9254.333

Shah, S., Zhou, P., Walasai, G., & Mohsin, M. (2019). Energy security and environmental sustainability index of South Asian countries: A composite index approach. *Ecological Indicators*, 106, 1055–1068. https://doi.org/10.1016/j.ecolind.2019.105507

Shibli, R., Saifan, S., Ab Yajid, M. S., & Khatibi, A. (2021). Mediating Role of Entrepreneurial Marketing Between Green Marketing and Green Management in Predicting Sustainable Performance in Malaysia's Organic Agriculture Sector. *AgBioForum*, 23(2), 37–49.

Shoaib, H. M., Rafique, M. Z., Nadeem, A. M., & Huang, S. (2020). Impact of financial development on CO2 emissions: a comparative analysis of developing countries (D8) and developed countries (G8). *Environmental Science and Pollution Research*, 27(11), 12461–12475. https://doi.org/10.1007/s11356-019-06680-z

Streimikiene, D., & Akberdina, V. (2021). Public Views of the Economy of the Renewable Energy Sources: Evidence from Russia. *Contemporary Economics*, 15(3), 256–267. https://doi.org/10.5709/ce.1897-9254.447

Su, C.-W., Xie, Y., Shahab, S., Faisal, C. M. N., Hafeez, M., & Qamri, G. M. (2021). Towards achieving sustainable development: role of technology innovation, technology adoption and CO2 emission for BRICS. *International journal of environmental research and public health*, 18(1), 277–2993. https://doi.org/10.3390/ijerph18010277

Sumrin, S., Gupta, S., Asaad, Y., Wang, Y., Bhattacharya, S., & Foroudi, P. (2021). Eco-innovation for environment and waste prevention. *Journal of business Research*, 122, 627–639. https://doi.org/10.1016/j.jbusres.2020.08.001

Sun, Y., Yesilada, F., Andlib, Z., & Ajaz, T. (2021). The role of eco-innovation and globalization towards carbon neutrality in the USA. *Journal of Environmental Management*, 299, 1135–1153. https://doi.org/10.1016/j.jenvman.2021.113568

Tao, R., Umar, M., Naseer, A., & Razi, U. (2021). The dynamic effect of eco-innovation and environmental taxes on carbon neutrality target in emerging seven (E7) economies. *Journal of Environmental Management,* 299, 113–129. https://doi.org/10.1016/j.jenvman.2021.113525

Tiberius, V., Schwarzer, H., & Roig-Dobon, S. (2021). Radical innovations: Between established knowledge and future research opportunities. *Journal of Innovation & Knowledge*, 6(3), 145-153. https://doi.org/10.1016/j.jik.2020.09.001

Ullah, S., Ozturk, I., Usman, A., Majeed, M. T., & Akhtar, P. (2020). On the asymmetric effects of premature deindustrialization on CO2 emissions: evidence from Pakistan. *Environmental Science and Pollution Research*, 27(12), 13692–13702. https://doi.org/10.1007/s11356-020-07931-0

Wang, R., Hsu, S. C., Zheng, S., Chen, J. H., & Li, X. I. (2020). Renewable energy microgrids: Economic evaluation and decision making for government policies to contribute to affordable and clean energy. *Applied Energy*, 274, 115–128. https://doi.org/10.1016/j.apenergy.2020.115287

Westerlund, J., & Edgerton, D. L. (2008). A simple test for cointegration in dependent panels with structural breaks. *Oxford Bulletin of Economics and Statistics*, 70(5), 665–704. https://doi.org/10.1111/j.1468-0084.2008.00513.x

Wirsbinna, A., & Grega, L. (2021). Assessment of Economic Benefits of Smart City Initiatives. *Cuadernos de Economia*, 44(126), 45–56.

Wolde-Rufael, Y., & Weldemeskel, E. M. (2020). Environmental policy stringency, renewable energy consumption and CO2 emissions: Panel cointegration analysis for BRIICTS countries. *International Journal of Green Energy,* 17(10), 568–582. https://doi.org/10.1080/15435075.2020.1779073

Xie, J., & Wang, Y. (2019). Recent development of CO2 electrochemistry from Li-CO2 batteries to Zn-CO2 batteries. *Accounts of chemical research,* 52(6), 1721–1729. https://doi.org/10.1021/acs.accounts.9b00179

Yousaf, Z., Radulescu, M., Nassani, A., Aldakhil, A. M., & Jianu, E. (2021). Environmental Management System towards Environmental Performance of Hotel Industry: Does Corporate Social Responsibility Authenticity Really Matter?. *Inzinerine Ekonomika-Engineering Economics*, 32(5), 484–498. https://doi.org/10.5755/j01.ee.32.5.28619

Zaidi, S. A. H., Hou, F., & Mirza, F. M. (2018). The role of renewable and non-renewable energy consumption in CO2 emissions: a disaggregate analysis of Pakistan. *Environmental Science and Pollution Research*, 25(31), 31616–31629. https://doi.org/10.1007/s11356-018-3059-y

Zhao, J., Shahbaz, M., Dong, X., & Dong, K. (2021). How does financial risk affect global CO2 emissions? The role of technological innovation. *Technological Forecasting and Social Change*, 168, 120–137. https://doi.org/10.1016/j.techfore.2021.120751

The article has been reviewed.

Received in August 2022; accepted in November 2022.