



The Role of Sustainable Energy, Technology Adoption, and Green Finance on the Environmental Sustainability in China

Waseem Yousaf¹, Snober Fazal²

¹ Department of Business & Management Sciences, Minhaj University Lahore, Pakistan.

Email: m.waseem511@gmail.com

² PhD Scholar, Department of Economics, The Islamia University of Bahawalpur, Pakistan.

Email: snoberfazal44@yahoo.com

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ABSTRACT

Environmental sustainability (ES) has gained global attention due to uncertain environmental and economic conditions, and this phenomenon needs researchers' intention. Therefore, the current article examines the impact of sustainable energy, such as renewable energy (RE) output and RE consumption, technology adoption, green finance (GF), and economic growth (EG) on environmental sustainability in China. The article has gathered the data from World Development Indicators (WDI) and the central bank from 1990 to 2020. The study employed autoregressive distributed lag (ARDL) to check the connection among the constructs. The findings exposed that the RE output and RE consumption, technology adoption, GF, and EG have positive ES in China. These findings guide the regulators in developing regulations related to improving ES using sustainable energy, GF, and technology adoption.

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Corresponding Author's Email: m.waseem511@gmail.com

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1. Introduction

The world's temperature is fluctuating at a rapid pace. High energy use, carbon emissions, air pollution, and glacier melting are all contributing factors to this trend. As climate change becomes a serious worry, the world is expressing serious concern about the problem while keeping in mind its catastrophic consequences. Global or regional climate change, an increase in the planet's average temperature, and the resulting changes in the seas, land surfaces, and ice sheets are all referred to as "climate change." (S. Gao & Jiang, 2020; Sharif, Godil, et al., 2020). The world aims to reduce and maintain the global warming to below 2 degrees Celsius. Governments, international organizations, and cities are now involved in global climate governance, as well as private entities including businesses, academic societies, and civil society groups (Lima et al., 2020; Mekhilef, 2018). To prevent environmental issues and ensure that the planet is safe for coming generations, governments are putting several programs in place to embrace sustainable energy production methods and educate their populations about green products (Ahmad et al., 2019; Sharif, Mishra, et al., 2020).

China is considered a world factory. The world prefers China for almost all sorts of manufacturing. This results in a rapid increase in industrialization which results in more demand for energy, usage of chemicals, and gas emission. These factors result in ED (Ansari, Haider, & Masood, 2021). Although the country is investing maximum efforts to balance the environment due to the high level of industrialization the efforts are far less. Although the country is switching to RE but facing numerous issues due to increasing demand of electricity. Energy production is one of the basic cause of environmental degradation as the mostly the energy is produced through traditional resources like from coal, fossil fuel (Chien, Hsu, Zhang, Vu, & Nawaz, 2022; Farooq, Gillani, Subhani, & Shafiq, 2022). This results in increase of carbon emission. Moreover, there are other forms of carbon emission like air pollution, traffic polluting, and sea pollution. The RE production in China.

The RE output growth in China is given in Figure 1. The study is also significant in terms of: 1) it highlights the importance of RE in combating climate change particularly in China; 2) it helps Chinese ecological professionals revamp their policies with the aim of betterment of ecological changes and 3) will helps researchers to explore aspects of ES with a view to promoting RE in China. The RE output increasing with the passage of time and this situation is given in Figure 1.

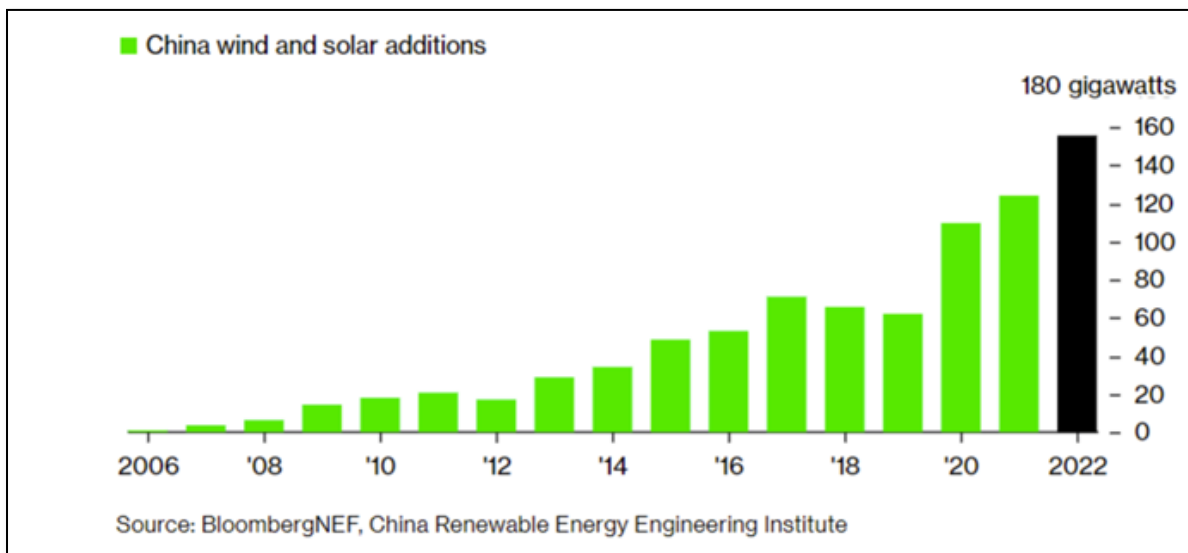


Figure 1: RE output in China

This study addresses some gaps which exist in the literature: 1) climate change is adversely affecting the world, accelerating its importance, but despite the importance of the topic research into RE has not reached its peak in the Chinese region, with a number of aspects yet to be explored; 2) Kirikkaleli and Adebayo (2021) worked on the RE consumption and ecological sustainability, whereas the present study will also work on RE and ES but with the addition of EG and technology variables in Chinese perspective using a fresh dataset; 3) the equation consist of ES, RE output, RE consumption, technology adoption, GF and EG not tested before in China context, with an up-to-date dataset; 4) O. Usman, Akadiri, and Adeshola (2020) worked on RE output and environment, whereas the present study will add the variables like EG, technology adoption and GF; 5) worked on the environment protection with GF, present study will also work on ES in China by adding the variables like RE and EG (Chien, Sadiq, Nawaz, et al., 2021).

Structurally, the paper is divided into different chapters. In the first chapter, the overall introduction of the study including the study gap and significance will be presented. The second phase will present the evidence about ES, RE output, RE consumption, technology adoption, GF and EG in connection with past studies will be discussed. The third chapter of the study will provide the methodology, i.e., the collection of data about ES, RE output, RE

consumption, technology adoption, GF, and EG. After that will, the validity of the data will be analyzed. The results received after data analysis will be presented in the fourth chapter. Finally, the study conclusion, implications, and recommendations will be presented.

2. Literature Review

Since the environmental degradation (ED) has affected the world in a real manner. The world is expressing its serious concerns to mitigate the environmental effects. Although there are numerous tools introduced in this regard but the most common and effective one is switch to RE. The countries are increasing their investment in RE vide green financing. The world is acknowledging green financing due to its positive outcomes. The investment in green financing through green bond increased to 7.15 trillion from 250 billion (US Dollars) in 2019. This states that green financing is rapidly expanding globally, which may also be related to the global warming that is occurring. In this context, Zakari and Khan (2021) worked on the association between GF and the environment. Whether GF is beneficial for the environment. The study was conducted on the top 10 countries having a maximum investment in environmental protection. The results of the study revealed that there is a significant nexus between GF and increased ES. However, the sustainability of the environment is negatively impacted by energy use and urbanization in the selected countries. Similarly, Ronaldo and Suryanto (2022) also explored GF from the sustainable development goals perspective. The study was conducted in Indonesia. The results of the study revealed that green financing is essential to attaining the SDGs in terms of both environmental and economic sustainability. Further, green financing also encourages the development of green technologies and green microenterprises, which will ultimately help to accomplish the SDGs through ES and economic sustainability (Chien, Sadiq, Kamran, et al., 2021). Moreover, Muganyi, Yan, and Sun (2021) investigated whether GF helps in protecting the environment. The study was conducted in China. The results of the study revealed that overall GF-related initiatives in China have resulted in a significant decrease in industrial gas emissions over (Baloch et al., 2022; Shafiq, ur Raheem, & Ahmed, 2020). Further, the growth of fintech positively affects investment programs for environmental protection and helps to reduce emissions of Sulphur dioxide. China is positioned to take the lead in implementing GF policies, therefore authorities must hasten the development of GF products and increase the ability of financial institutions to provide green loans. Additionally, Falcone (2020), also worked on GF from an investment and environmental regulations point of view. The results of the study revealed that GF leads to a pivot role in mitigating the adverse environmental effects (Hussain, Nawaz, Ahmad, & Bhatti, 2021).

Sustainability of the environment has become one of the most important issues for environment-related policymakers all over the world. Consequently, it is crucial for emerging countries to comprehend the causes of environmental deterioration. ED further affects EG from different perspectives. In this context, Murshed, Rahman, Alam, Ahmad, and Dagar (2021), explored the association between EG and ES. The study was conducted in four Asian nations. The results of the study revealed that environmental regulations play important roles in both, directly and indirectly, decreasing South Asia's ecological effects. Moreover, the elasticity estimates support the veracity of the pollution haven and environment Kuznets curve ideas. Further, the RE output and non-RE is proven to have a positive and negative impact on the environment, respectively. Moreover, the RE output and environmental restrictions together cut ecological footprints even more (Yu, Golpîra, & Khan, 2018). More importantly, it is anticipated that environmental laws would increase the positive environmental effects of the RE output while decreasing the negative environmental effects of EG, the RE output, and foreign direct investment. Furthermore, it is discovered that the ecological footprints affected by environmental rules in different countries are more or less uniform with the corresponding panel estimates. Similarly, Orhan, Adebayo, Genç, and Kirikkaleli (2021) also explored the association between EG and ES. The study was conducted in India. The findings proposed that, with the exception of trade openness, all factors seem to have a strong correlation with CO₂ emissions (W. Li et al., 2021). The Gradual shift causality test, which demonstrates that agriculture and energy use are significant predictors of CO₂ emissions in India, further supports this. On the basis of these findings, appropriate

policy actions are then suggested. Similarly, Long and Ji (2019), also explored the association between EG and ES. The study findings proposed that there is a significant association between EG and ES.

As a result of globalization. The world has become more advanced in terms of technology. Every sector of the economy is adopting modern-era tools which result in the betterment of its performance. Similar is the case with the environment. Over the period of time, technologies are introduced that result in supporting the environment in the past the energy was produced from traditional resources which results in ED. But the technological move has introduced the idea of RE which not only positively affects the environment but also the economy (Ochieng et al., 2022). The use of green technology can help address the growing environmental problem. The necessity for the contemporary development of environmentally friendly technology and an improvement in output levels across all agricultural crops are implications of green fertilizer technology (GFT). It is especially necessary for paddy cultivation because paddy is the major staple meal for the country and has traditionally been regarded as an essential commodity. In this context, Adnan, Nordin, Bahruddin, and Tareq (2019) and Muriithi, Menale, Diiro, and Muricho (2018) explored the association between technology adoption in terms of green fertilizer technology and ES through sustainable agriculture. The study was conducted in Malaysia. The findings proposed that that the adoption of green fertilizer technology is positively impacting ES in Malaysia. Moreover, Chan, Okumus, and Chan (2018) worked on the barriers to the adoption of environmental technology, particularly in the Hotel Industry. The results of the study revealed that there are numerous barriers to environmental-related technology adoption, particularly in the hotel industry. The most common are product-related obstacles, external obstacles, and internal obstacles. Moreover, Adenle, Wedig, and Azadi (2019), also worked on the role of innovation and technology adoption for sustainable agriculture which leads to a sustainable environment. The results of the study revealed that the technology adoption in the agriculture field results in mitigating the adverse environmental effects as the agriculture sector has a strong association with the environment.

ED is getting worsen with the passage of time. This impacts every aspect of life. Although there are many reasons behind it but the most common is energy. With the passage of time, the RE demand is accelerating at a rapid pace, which results in accelerating pressure on energy production. Sometimes, the energy produced from traditional resources lead to ED (R. Li, Wang, & Wang, 2022; M. Usman & Makhdum, 2021). Unfortunately, there is almost no nation or region is exempt from the effects of climate change as the world has seen a tremendous rise in environmental problems. Recent studies have identified unsustainable production and consumption habits as one of the primary causes of ED and climate change (Ulucak, Khan, Baloch, & Li, 2020; Weimin & Zubair Chishti, 2021). Unsustainable production and consumption are expected in emerging nations that want to advance economically quickly for the well-being of their people. However, because of increased resource demands and limited supply, even industrialized nations are experiencing ecological deficits. Similarly, Ahmed, Ahmad, Rjoub, Kalugina, and Hussain (2022) explored the nexus between RE consumption and ED. The results of the study revealed that democracy and environmental restrictions have a favorable impact on ecological sustainability by lowering EF whereas economic expansion increases EF. The results of the causative analysis show that democracy causes both EF and RE, demonstrating that democracy slows down environmental deterioration and increases the percentage of RE. Similarly, Alola, Bekun, and Sarkodie (2019) also explored the association between RE consumption and ED. The study was conducted in developed countries. The findings proposed that high energy consumption effecting the environment sustainability in a negative way (Gillani & Sultana, 2020).

The excessive usage of energy is one of the vital elements of ED. Although the world is switching to RE this transformation is in process. The developing countries are far behind in this transformation. The nexus between energy output and the environment is vital. In this context, Ansari et al. (2021) worked on RE from an output perspective and ecological footprints. The study was conducted in the top RE countries. The findings proposed that there

is an equilibrium connection over the long term between the variables. The use of non-RE and economic expansion have a favorable influence on the environment, whereas the effects of globalization, urbanization and RE consumption have a negative effect (Mohsin, Kamran, Nawaz, Hussain, & Dahri, 2021). With the use of dynamic ordinary least squares and completely modified ordinary least squares, the sensitivity of long-run elasticity has been examined. Similarly, C. Gao et al. (2021) also explored the association between RE generation methods and ED. The findings proposed that a) wind power had the lowest energy consumption, less emission of carbon, and lowest possible environmental effect, b) according to an examination of ecological footprints at the provincial level, whilst the other provinces were in ecological surplus, with the majority of them having ecological areas above 50%, c) Of the three RE sources, only wind power reduced energy consumption as compared to thermal power generation, which used 1170.911 kJ/kWh. Currently, the most effective source of RE is wind power (Wenlong et al., 2022). Similarly, Apergis and Payne (2014) also worked on RE output along with ED through carbon emission. The study was conducted in South America. The results of the study revealed that there is a significant strong association between RE output and ED. The more output of RD lead to more production. If the production is through traditional ways, then it will have a negative effect on ED (Nawaz, Ahmadv, Hussain, & Bhatti, 2020). On the other hand, if the production is from RE resources, then will lead to ES.

3. Research Methods

The article examines the impact of RE output, RE consumption, technology adoption, GF, and EG on ES in China. The article has gathered the data from WDI and the central bank from 1990 to 2020. The article has established the equation given below:

$$ENS_t = \alpha_0 + \beta_1 REO_t + \beta_2 REC_t + \beta_3 TAD_t + \beta_4 GF_t + \beta_5 EG_t + e_t \quad (1)$$

Where;

CO2E= Carbon Dioxide Emissions

t = Time Period

REO= Renewable Energy Output

REC= Renewable Energy Consumption

TAD = Technology Adoption

GF = Green Finance

EG = Economic Growth

The article has taken the sustainable environment as the dependent variable measured with CO2 emissions (metric tons per capita). The study has also used three independent variables such as sustainable energy measured with RE output and RE consumption, GF measured with the ratio of GF to total finance, and technology adoption measured with high-technology exports (% of manufactured exports). Finally, the article has also used the control variable, such as EG measured with GDP growth annual percentage. Table 1 given below highlights these measurements.

Table 1
Variables with Measurements

S#	Variables	Measurement	Sources
01	Environmental Sustainability	CO2 emissions (metric tons per capita)	WDI
02	Sustainable Energy	RE output (Percentage of total energy output) RE consumption (Percentage of total energy consumption)	WDI WDI
03	Green Finance	The ratio of GF to total finance	Central Bank
04	Technology Adoption	High-technology exports (% of manufactured exports)	WDI
05	Economic Growth	GDP growth annual percentage	WDI

The study has checked the details of the constructs using descriptive statistics that provide the details related to mean value, number of observations, standard deviation, and

maximum and minimum values of all the variables. In addition, the article has also applied the correlation matrix to test the correlation between the predictors. Moreover, the study has run the Augmented Dickey-Fuller (ADF) test to investigate the unit root among contracts. The equation for the ADF test is given below:

$$d(Y_t) = \alpha_0 + \beta t + \gamma Y_{t-1} + d(Y_t(-1)) + \varepsilon_t \quad (2)$$

The ADF test can examine the stationarity or unit root individually. Hence, the individual equation for each variable mentioned below:

Carbon Dioxide Emissions

$$d(CO2E_t) = \alpha_0 + \beta t + \gamma CO2E_{t-1} + d(CO2E_t(-1)) + \varepsilon_t \quad (3)$$

Renewable Energy Output

$$d(REO_t) = \alpha_0 + \beta t + \gamma REO_{t-1} + d(REO_t(-1)) + \varepsilon_t \quad (4)$$

Renewable Energy Consumption

$$d(REC_t) = \alpha_0 + \beta t + \gamma REC_{t-1} + d(REC_t(-1)) + \varepsilon_t \quad (5)$$

Technology Adoption

$$d(TAD_t) = \alpha_0 + \beta t + \gamma TAD_{t-1} + d(TAD_t(-1)) + \varepsilon_t \quad (6)$$

Green Finance

$$d(GF_t) = \alpha_0 + \beta t + \gamma GF_{t-1} + d(GF_t(-1)) + \varepsilon_t \quad (7)$$

Economic Growth

$$d(EG_t) = \alpha_0 + \beta t + \gamma EG_{t-1} + d(EG_t(-1)) + \varepsilon_t \quad (8)$$

The study has checked the connection between the understudy variable with the help of the ARDL model. It is suitable for time series data. It is also the best estimation approach when the situation of unit root among variables is like I(0) and I(1). It also provides the best results by controlling the effects of heteroscedasticity and auto-correlation of the results (Mensah et al., 2019). This approach provides long and short-run connections among variables. The equation for the approach is given below:

$$\Delta CO2E_t = \alpha_0 + \sum \delta_1 \Delta CO2E_{t-1} + \sum \delta_2 \Delta REO_{t-1} + \sum \delta_3 \Delta REC_{t-1} + \sum \delta_4 \Delta TA_{t-1} + \sum \delta_5 \Delta GF_{t-1} + \sum \delta_6 \Delta EG_{t-1} + \varphi_1 CO2E_{t-1} + \varphi_2 REO_{t-1} + \varphi_3 REC_{t-1} + \varphi_4 TA_{t-1} + \varphi_5 GF_{t-1} + \varphi_6 EG_{t-1} + \varepsilon_1 \quad (9)$$

4. Study Results

The study has checked the details of the constructs using descriptive statistics that provide the details related to mean value, number of observations, standard deviation, and maximum and minimum values of all the variables. The findings exposed that the CO2E average value was 4.656 metric tons per capita, while RE output mean value was 19.338 percent and RE consumption average value was 21.182 percent. In addition, the findings also exposed that GF average value was 4.019 percent while TAD mean value was 30.542 percent, and EG average value was 9.112 percent. These outputs are mentioned in Table 2.

Table 2
Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO2E	31	4.656	2.181	1.915	7.822
REO	31	19.338	3.456	15.037	27.549
REC	31	21.182	8.653	11.34	34.084
GF	31	4.019	5.453	-1.401	24.257
TAD	31	30.542	0.609	29.364	32.124
EG	31	9.112	2.783	2.240	14.231

In addition, the article has also applied the correlation matrix to test the correlation between the predictors. The findings exposed that the RE output and RE consumption, technology adoption, GF, and EG have positive ES in China. These outputs are mentioned in Table 3.

Table 3
Matrix of Correlations

Variables	CO2E	REO	REC	GF	TAD	EG
CO2E	1.000					
REO	-0.638	1.000				
REC	-0.960	-0.422	1.000			
GF	-0.301	-0.107	0.318	1.000		
TAD	-0.483	0.286	-0.461	-0.273	1.000	
EG	-0.419	-0.713	0.254	0.484	-0.228	1.000

Moreover, the study has run the ADF test to investigate the unit root among contracts. The findings revealed that the RE consumption and TAD are stationary at a level while CO2E, RE output, GF, and EG are stationary at first difference. These outputs are mentioned in Table 4.

Table 4
Unit Root Test

Augmented Dickey-Fuller Test (ADF)	Level	t-statistics	p-values
CO2E	I(1)	-5.893	0.000
REO	I(1)	-4.782	0.000
REC	I(0)	-2.663	0.031
GF	I(1)	-6.993	0.000
TAD	I(0)	-2.511	0.034
EG	I(1)	-5.611	0.000

The findings exposed that the RE output and RE consumption, technology adoption, GF, and EG have positive ES in China in the short-run. The findings also exposed that 56.4 percent of changes are due to the selected predictors. These outputs are mentioned in Table 5.

Table 5
Short Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(REO)	-2.711	1.001	-2.708	0.031
D(REC)	-1.902	0.282	-6.745	0.000
D(GF)	-0.384	0.093	-4.129	0.000
D(TAD)	-1.777	0.671	-2.648	0.034
D(EG)	-1.773	0.476	-3.725	0.012
CointEq(-1)*	-1.251	0.111	-11.270	0.000
R-squared	0.564	Mean dependent var		-0.030
Adjusted R-squared	0.561	S.D. dependent var		2.263

The findings exposed that the RE output and RE consumption, technology adoption, GF, and EG have positive ES in China in the long-run. These outputs are mentioned in Table 6.

Table 6
Long Term Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
REO	-1.904	0.251	-7.586	0.000
REC	-3.845	1.211	-3.175	0.011
GF	-1.877	0.419	-4.479	0.000
TAD	-3.945	1.110	-3.554	0.001
EG	-2.883	1.121	-2.572	0.031
C	0.962	0.200	4.810	0.000

4.1 Discussions

The results showed that RE output has a positive link with ES. These results are supported by Kirikkaleli and Adebayo (2021), which highlights that the increase in the RE output promotes clean energy consumption and reduces carbon-containing fossil fuel consumption, improving ES. These results are also in line with the study of Sarkodie and Adams (2018), which shows that the increase in RE production increases sustainable energy supply. The replacement of non-RE with assures the protection of the environment. So, there is ES. The results showed that RE consumption has a positive link with ES. These results are supported by Sarkodie, Adams, Owusu, Leirvik, and Ozturk (2020), which shows that in the country where RE is being consumed for economic functions and social practices, there is less release of environmental pollution. This assures ES. These results are also in line with the study of O. Usman et al. (2020). The study conducted that the increasing use of RE in order to satisfy economic needs reduces the negative influences of business functions on nature. A result of clean economic undertaking keeps the environment sustainable. The results showed that technology adoption has a positive link with ES. These results are supported by Nathaniel, Yalçiner, and Bekun (2021); (Shah, Hussain, Nawaz, & Iqbal, 2021; Wenlong et al., 2022), which claims that the tendency of firms to adopt new technologies enables them to address and mitigate environmental issues and sustains environmental productivity. These results are also in line with the study of Jimoh and Lin (2019). The study implies that the adoption of energy-efficient technologies encourages energy transition and helps sustain environmental quality.

The results showed that GF has a positive link with ES. These results are supported by Chege and Wang (2020), which highlights that GF invests the eco-friendly programs, and reduction in environmental issues like deforestation, climate change, waste emissions, GHG emissions, etc., improves the environment sustainability. These results are also in line with the study of Cui, Wang, and Wang (2020), which claims that in countries where GF is allowed for businesses or non-profit organizations, the rate of environmental pollution can be controlled, and ES can be created. The results showed that EG has a positive link with ES. These results are supported by Gilchrist, Yu, and Zhong (2021), which states that when EG is high, the country's individuals and organizations are in a better position to carry out eco-friendly practices like forestation, energy transition, energy efficiency, water management, and waste management. This encourages ES.

5. Conclusion

The goal of the research was to examine the role of RE output, RE consumption, technology adoption, GF, and EG in ES. The results were extracted with quantitative data from China. Results showed that RE output, RE consumption, technology adoption, GF, and EG positively influence ES. The results showed that the increasing RE output and RE consumption help adopt energy transition, and mitigation of the environmental pollution assures ES. The results showed that the economies with a high tendency to adopt innovative technologies contribute to ES. Likewise, authors find that the increasing GF issuance encourages investment in the projects to fight against environmental pollution. So, there is sustainability in the environment and its functioning.

5.1 Implications

The study's significance for the authors lies in the study's contribution to literature. There is simultaneous and deep exploration of the role of RE output, RE consumption, technology adoption, GF, and EG in ES. The study also contributes to the literature as it selects China for analyzing the role of RE output, RE consumption, technology adoption, GF, and EG in ES. The study has great significance in the countries which have to face environmental issues. It has a complete guidelines on how to achieve ES. It guides that regulators and economists must form polies to encourage RE output and consumption to increase ES. It also guides that GF issuance and proper use must be encouraged in order to

create ES. These findings guide the regulators in developing regulations related to improving ES using sustainable energy, GF, and technology adoption. Similarly, individuals and organizations must be motivated for technology adoption to enhance ES. Moreover, by giving rise to EG, ES can be enhanced.

5.2 Limitations

The study has some limitations that can be removed from future literature. This study addresses a few factors like RE output, RE consumption, technology adoption, GF, and EG for ES. Consequently, the study is limited, and it is expected for future authors to examine more indicators of ES. The present study takes data only from China for RE output, RE consumption, technology adoption, GF, and EG role in ES. A single economy data cannot be appropriate for general results. Therefore, future authors must collect evidence from multiple economies.

Authors Contribution

Waseem Yousaf: study design, analysis, critical revision, incorporation of intellectual content
Snober Fazal: literature search, data collection, drafting

Conflict of Interests/Disclosures

The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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