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Financial Efficiency and Its Impact on Renewable Energy Demand and CO_2 Emissions: Do Eco-Innovations Matter for Highly Polluted Asian Economies?

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Abstract: The analysis aims to examine the impact of eco-innovation and financial efficiency on CO_2 emissions and renewable energy consumption in highly polluted Asian economies, including China, India, Russia, and Japan. For empirical analysis, we have applied the ARDL pooled mean group (ARDL-PMG) model. The long-run estimated coefficient of environmental innovations is positively significant in both renewable energy models and negatively significant in the CO_2 emissions model. These results imply that environmental innovations help facilitate renewable energy consumption and reduce CO_2 emissions. On the other side, the estimates of financial development are insignificant in both renewable energy and CO_2 emissions models. However, the estimates of financial institution efficiency and financial markets are positively significant in both renewable energy and CO_2 emissions models, implying that financial institutions and market efficiency increase renewable energy consumption and decrease CO_2 emissions.

Keywords: financial efficiency; eco-innovation; CO_2 emissions; renewable energy consumption

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1. Introduction

Energy consumption is an imperative and prominent issue in political and economic policies. Over time, several types of energy have been added due to environment-related concerns [1]. Still, the share of clean energy consumption is lower than the total consumption of energy despite the various benefits it has [2]. The reason is that fossil fuels are subsidized, and the cost of fossil fuels does not comprise the cost of carbon emissions; consequently, high costs are attached to making investments in clean energy projects [3]. Additionally, the demand for energy increases slowly in developed economies; thus, it involves a longer time to change the behaviors of energy consumption and the current infrastructure of energy. Conversely, demand for energy increases rapidly in developing economies, and fossil fuels contribute significantly to fulfilling the energy demand [4]. Furthermore, due to pricing issues, the energy produced from renewable sources might not compete with fossil fuels. Hence, one single instrument is not adequate for the growth of renewable energy as the countries' attitudes differ towards energy sources due to the diverse costs of renewable technologies.

The debate about environment-related technologies, environmental tax, environmental protection, and clean energy consumption and production has gained attention and reinforced the strategy of various imperative policy measures such as regulating the energy prices, the imposition of a carbon tax for pollution-producing sectors, settling the consumption of clean energy for each sector, and elaborating several environmental and economic policy frames [5–8]. Some studies reported that an environmental pollution tax does not reduce energy consumption in all cases, but it helps in defining efficient policy measures for energy consumption [9]. However, few other studies demonstrated that environment-related technologies and innovations displayed a positive influence on renewable energy consumption [10–12].

The International Energy Agency [13] claimed that the growing CO_2 emissions due to disorganized and unproductive energy use have exposed the world to ecological challenges that are difficult to address without an association between private and public sectors. The existing literature reports a positive linkage between low CO_2 emissions and efficient technology, which further elaborates the significance of investment in technological innovations to enhance its progressive spillovers [14–18]. The emerging economies are confronting a major tradeoff between a reduction in CO_2 emissions and industrial expansion [19]. However, the developed countries are deceptively using smaller amounts of carbon emissions as compared to industrial economies. However, in reality, the developed countries are importing from emerging economies, and these economies are using larger amounts of carbon emissions as compared with industrial economies, thus indirectly involved in CO_2 emissions. Thus, the literature reveals that international trade is mainly involved in transferring consumption-based carbon emissions in economies [20]. Therefore, a sustainable solution is required to tackle these issues. The study performed by Grossman and Krueger [21] captivated the association between CO_2 emissions and trade. However, trade influences CO_2 emissions through indirect channels, as advancement in trade is required for the attainment of high economic development but it results in an upsurge of CO_2 emissions [22]. Consumption-based pollution emissions can be controlled through a reduction in total consumption and minimization in the production intensity of carbon emissions.

Since the introduction of the interdisciplinary revolution of energy to environment-friendly, efficient, economically operative environment-related technologies, the developed economies have gained benefits in the form of reduction in CO_2 emissions. Globally, most of the emerging economies have witnessed a rapid increase in clean energy consumption as well as an increment in global carbon emissions [23–25]. Over the last few decades, the policymakers and environmentalists have enclosed various agreements to promote environment-friendly production arrangements, such as the Paris Agreement and the Kyoto Protocol [26]. These agreements have emphasized the prominence of eco-friendly energy sources with such environment-related technologies and innovations that can ultimately alleviate carbon emissions. Furthermore, each economy presents diverse targets to combat CO_2 emissions. However, the sustainable decrease in carbon emissions might be comprehended through the use of environment-related technologies. The environmentally related technologies can increase production capacity and reduce carbon emissions, thus increasing industrial performance. Furthermore, environment-related technologies might help in the reduction of environmental degradation by augmenting interaction with opportunities to reduce CO_2 emissions [27]. Therefore, the implementation of environment-related technologies may lead to a reduction in CO_2 emissions by increasing production capacity [28–30]. Furthermore, energy consumption exerts a substantial influence on the environment as energy is a major factor of production in the industrial sector [31]. Additionally, clean energy consumption is relatively better in comparison to fossil fuels, but it needs extensive investment before attaining substantial gains [32,33]. The adoption of renewable energy sources/clean energy, including wind power, sunlight, biomass, waves, hydro, and geothermal, is considered the most important step toward SGDs [34]. Additionally, each country is preferring to invest in renewable energy consumption sources [35,36].

Financial sector development in a country can reduce the costs of investments in renewable energy sources, thus stimulating the consumption of renewable energy sources. Hence, financial efficiency leads to a fundamental upsurge in renewable energy consumption in the long-term. Developing economies mostly rely on imported inputs that involve the transfer of foreign exchange reserves. With the rise in renewable energy consumption and production sources, foreign exchange reserves will be saved that can be transferred to financial markets and can be utilized for deepening and diversifying energy markets. Thus, financial efficiency can support and strengthen the consumption of renewable energy sources.

Financial efficiency can improve environmental quality by reducing CO_2 emissions via eco-innovation and R&D progress [37,38]. Financial efficiency and development enable governments and enterprises to adopt eco-friendly technologies that can significantly reduce CO_2 emissions [39]. Financial efficiency can foster corporate governance and generate financial and reputational incentives that motivate enterprises to adopt eco-friendly projects, thus reducing CO_2 emissions [40]. Conversely, financial efficiency could reduce environmental quality through an increase in CO_2 emissions due to technological progress, economic growth, and energy consumption [41]. Likewise, through technological progress and risk diversification, financial efficiency enhances economic growth that in turn upsurges carbon emissions and energy consumption [42].

The current literature explored the nexus between environmental innovation, renewable energy consumption, and CO_2 emissions quite extensively, but still provides inconclusive findings and needs to be further investigated. Therefore, the literature is quite limited in investigating the role of environment-related technologies on renewable energy consumption and CO_2 emissions. The high-polluting Asian economies significantly adopt environmental technologies and renewable energy consumption. Therefore, there is a need to explore the phenomenon of carbon emissions and renewable energy consumption with the role of environment-related technologies in the high-polluting Asian economies. The study will also fill the vacuum by investigating the impact of financial efficiency on renewable energy demand and carbon emission in high-polluting Asian economies.

The study investigates the effect of financial efficiency and eco-innovation on renewable energy demand and CO_2 emissions for selected highly polluting Asian economies, namely China, India, Japan, and Russia. The top four CO_2 emitters in the Asian region are China, India, Japan, and Russia, which account for high pollution emissions in the region. It is observed that these economies also contribute significantly to the world's CO_2 emissions, such as China (28%), India (7%), Russia (5%), and Japan (3%) shares of CO_2 emissions [43]. For empirical investigation, the study will adopt a panel ARDL approach. In order to obtain results for short-run and long-run dynamics between variables, the study adopted the panel ARDL technique. The panel ARDL technique offers more flexible findings for cointegration association between variables. Another advantage of the panel ARDL technique is that it can be used at I(0) and I(1) integrated variables. The study will contribute to the existing literature in the following ways. Firstly, to the best of the authors' knowledge, this study makes the first attempt in investigating the impact of environmental innovation and financial efficiency on renewable energy demand and CO_2 emissions in highly polluted Asian economies. Secondly, the study delivers new implications and novel findings regarding cleaner energy consumption and production and sustainable environmental development.

The rest of the study is organized as follows. Section 2 describes the details of the model, methods, and data. Section 3 reports the findings and discussion of estimated models. The last section provides a conclusion of the study with policy suggestions and some future directions.

2. Model, Methods, and Data

According to Grossman and Krueger [21], any endogenous change in technological development can reduce the costs of achieving targets of reducing environmental pollution. Modern growth theories have also highlighted that technological change can lead the economy toward the path of sustainability [44]. Hence, the greater the number of technological innovations in the economy better the environmental quality. However, the correct estimate of the environmental impact of technologies on CO_2 emissions is yet to be disclosed. Increasing energy efficiency is the important channel through which technological innovations can improve quality; however, enhanced efficiency may also upsurge the demand for resources and energy, which may deteriorate the environment due to the rebound effect [45]. It is widely accepted that technological progress may reduce CO_2 emissions, but it can also increase the energy demand and, consequently CO_2 emissions due to the rebound effect. Hence, the environmental impact of technological progress through energy efficiency is minimal. However, in general, we can say that technological innovation is a factor that can affect renewable energy demand and consequently have an impact on environmental quality [46].

$$\mathbf{REC_{it}} = \varphi_0 + \varphi_1\mathbf{FE_{it}} + \varphi_2\mathbf{EI_{it}} + \varphi_3\mathbf{Education_{it}} + \varphi_4\mathbf{GDP_{it}} + \varphi_5\mathbf{EPS_{it}} + \varepsilon_{\mathbf{it}} \tag{1}$$

$$\mathbf{CO_{2,it}} = \varphi_0 + \varphi_1\mathbf{FE_{it}} + \varphi_2\mathbf{EI_{it}} + \varphi_3\mathbf{Education_{it}} + \varphi_4\mathbf{GDP_{it}} + \varphi_5\mathbf{EPS_{it}} + \varepsilon_{\mathbf{it}} \tag{2}$$

where renewable energy consumption (REC) and CO_2 emissions (CO_2) are dependent variables, which are determined by financial efficiency (FE), environmental innovations (EI), educational attainment (Education), GDP per capita (GDP), environmental policy stringency (EPS), and error term (ε_{it}). In the next step, we re-arrange the above speciation in the form of the error correction modeling proposed, which converts model (1) into the ARDL-PMG model proposed by Pesaran et al. [47] as explained underneath:

$$\begin{aligned}\Delta\mathbf{REC_{it}} = \varphi_0 &+ \sum_{i=1}^{p}\pi_{1k}\Delta\mathbf{REC_{it-i}} + \sum_{i=0}^{p}\pi_{2k}\Delta\mathbf{FE_{it-i}} + \sum_{i=0}^{p}\pi_{3k}\Delta\mathbf{EI_{it-i}} \\ &+ \sum_{i=0}^{p}\pi_{4k}\mathbf{Education_{it-i}} + \sum_{i=0}^{p}\pi_{5k}\mathbf{GDP_{it-i}} + \sum_{i=0}^{p}\pi_{6k}\mathbf{EPS_{it-i}} \\ &+ \varphi_1\mathbf{REC_{it-1}} + \varphi_2\mathbf{FE_{it-1}} + \varphi_3\mathbf{EI_{it-1}} + \varphi_4\mathbf{Education_{it-1}} \\ &+ \varphi_5\mathbf{GDP_{it-1}} + \varphi_6\mathbf{EPS_{it-1}} + \lambda.\mathbf{ECM_{it-1}} + \varepsilon_{\mathbf{it}}\end{aligned} \tag{3}$$

$$\begin{aligned}\Delta\mathbf{CO_{2,it}} = \varphi_0 &+ \sum_{i=1}^{p}\pi_{1k}\Delta\mathbf{CO_{2,it-i}} + \sum_{i=0}^{p}\pi_{2k}\Delta\mathbf{FE_{it-i}} + \sum_{i=0}^{p}\pi_{3k}\Delta\mathbf{EI_{it-i}} \\ &+ \sum_{i=0}^{p}\pi_{4k}\mathbf{Education_{it-i}} + \sum_{i=0}^{p}\pi_{5k}\mathbf{GDP_{it-i}} + \sum_{i=0}^{p}\pi_{6k}\mathbf{EPS_{it-i}} \\ &+ \varphi_1\mathbf{CO_{2,it-1}} + \varphi_2\mathbf{FE_{it-1}} + \varphi_3\mathbf{EI_{it-1}} + \varphi_4\mathbf{Education_{it-1}} \\ &+ \varphi_5\mathbf{GDP_{it-1}} + \varphi_6\mathbf{EPS_{it-1}} + \lambda.\mathbf{ECM_{it-1}} + \varepsilon_{\mathbf{it}}\end{aligned} \tag{4}$$

There are several techniques that can handle panel data. However, these techniques are appropriate when the number of cross-sections is greater than the number of years. However, our data is comprised of long time series; hence, the ARDL-PMG is an appropriate model. This technique is superior compared to other techniques in many ways. For instance, this technique can obtain short- and long-run effects at once, whereas all other techniques only focus on the long-term effects. The above Equation (2) separates the short- and long-run estimates easily because first-difference variables represent short-run estimates, and φ_2–φ_6 represents the long-run estimates. However, we need to prove cointegration among the long-run estimates that are considered cointegrated if the estimate (λ) attached to ECM is significantly negative. Another superiority of this method over other methods is its power to deal with integrating properties of the series and can also produce efficient estimates if the variables in the model are a mixture of I(0) and I(1). Moreover, the ARDL-PMG is an efficient method when the number of time observations is not long enough. Finally, this is a dynamic model that can also account for the problems of serial correlation, endogeneity, and heteroskedasticity due to the insertion of a short-run adjustment process.

The study examines the impact of environment-related technologies and financial efficiency on renewable energy consumption and carbon emissions in Asian high-pollution economies. The sample of study includes China, India, Japan, and Russia and the data period is from 1995 to 2020. Table 1 contains details about variables' symbols, definitions, and sources of data. In the study, data for renewable energy consumption is extracted from the energy information administration (EIA). However, the data source for carbon emissions is the World Development Indicators (WDI). Environment-related technologies id measured through environmental data and the data is obtained from the Organisation for Economic Co-operation and Development (OECD). The educational attainment variable is proxied through school enrollment at the secondary level, and the data is taken from the WDI. Data series for the financial development index, financial institutions efficiency index, and financial markets efficiency index have been obtained from the International Monetary Fund (IMF). Besides these, GDP per capita and environmental policy stringency have been included in the model as control variables, and their data is obtained from the WDI. The descriptive statistics are also reported in Table 2.

Table 1. Definitions and data sources.

Variables	Symbol	Definitions	Sources *
Renewable energy consumption	REC	Total energy consumption from nuclear, renewables, and other (quad Btu)	https://www.eia.gov/international/data/world
CO_2 emissions	CO_2	CO_2 emissions (kt)	https://databank.worldbank.org/source/world-development-indicators
Environment innovation	EI	Development of environment-related technologies, % all technologies	https://stats.oecd.org/Index.aspx?DataSetCode=green_growth
Educational attainment	Education	School enrollment, secondary (% gross)	https://databank.worldbank.org/source/world-development-indicators
Financial development	FD	Financial development index	https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B
Financial institutions efficiency	FIE	Financial institutions efficiency index	https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B
Financial markets efficiency	FME	Financial markets efficiency index	https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B
GDP per capita	GDP	GDP per capita (constant 2015 US$)	https://databank.worldbank.org/source/world-development-indicators
Environmental policy stringency	EPS	Environmental policy stringency index	https://databank.worldbank.org/source/world-development-indicators

* Accessed on 1 May 2022.

Table 2. Descriptive statistics.

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque–Bera	Probability
REC	3.792	2.968	21.02	0.800	3.789	2.848	10.97	463.9	0.000
CO_2	6.283	6.189	7.062	5.800	0.316	1.143	3.362	25.88	0.000
EI	8.677	8.670	15.71	3.730	2.265	0.216	2.589	1.715	0.424
Education	1.894	1.957	2.030	1.624	0.124	−0.834	2.274	15.98	0.000
FIE	0.635	0.673	0.834	0.265	0.141	−0.933	3.060	16.85	0.000
FME	0.818	0.904	1.015	0.280	0.223	−1.006	2.749	19.88	0.000
GDP	3.738	3.780	4.561	2.737	0.575	−0.040	1.805	6.932	0.031
EPS	1.175	0.854	3.500	0.310	0.793	1.247	3.852	33.56	0.000

3. Results and Discussion

Our study adopted the LLC, IPS, and ADF-Fisher methods to detect the unit-root properties of data. The output of these techniques is given in Table 3. The IPS and ADF-Fisher techniques produced similar outcomes, while the LLC technique revealed different results. In the LLC method, GDP is reported as level-stationary, and other variables are reported as first-difference stationary. In IPS and ADF-Fisher techniques, CO_2 and FME are reported level stationary, while REC, EI, Education, FD, FIE, GDP, and EPS are reported first difference stationary. Table 4 contains the short-run and long-run outcomes of REC models and CO_2 emissions models.

Table 3. Unit root tests.

	LLC		IPS		ADF-Fisher	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
REC	1.225	−3.321 ***	1.821	−3.785 ***	1.897	−3.752 ***
CO_2	−1.098	−3.875 ***	−1.654 *		−1.565 *	
EI	0.278	−8.021 ***	−0.578	−8.412 ***	−0.512	−6.845 ***
Education	−0.654	−4.854 ***	0.534	−3.977 ***	0.542	−3.598 ***
FD	−0.324	−1.621 *	0.785	−3.785 ***	0.857	−3.758 ***
FIE	−1.152	−3.321 ***	−1.195	−6.245 ***	−1.132	−5.745 ***
FME	−1.187	−2.145 *	−1.625 *		−1.675 *	
GDP	−1.565 *		0.432	−1.987 **	0.534	−1.875 **
EPS	0.189	−5.321 ***	1.023	−5.321 ***	1.123	−4.225 ***

Note: *** $p < 0.01$; ** $p < 0.05$; and * $p < 0.1$.

Table 4. Estimates of REC and CO_2 emissions.

	REC				CO_2			
	(1)		(2)		(3)		(4)	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Long-run								
EI	0.164 ***	2.852	0.212 ***	3.747	−0.046 **	−2.204	−0.052 ***	−3.316
Education	1.151 **	2.328	1.283 ***	6.391	−0.306 **	−2.098	−0.470 **	−1.976
FD	0.656	0.502			0.942	0.925		
FIE			0.735 ***	2.844			1.514 ***	5.796
FME			0.045 *	1.695			0.109 ***	2.960
GDP	4.883 ***	3.046	3.521 ***	5.144	0.526	1.150	0.918 ***	9.346
EPS	1.782 ***	9.772	1.370 ***	3.013	−0.498 **	−2.355	−0.137 **	−2.384
Short-run								
D(EI)	0.106	0.798	0.162 *	1.724	−0.011	−1.388	−0.021	−0.170
D(EI(-1))			0.163 **	1.964			−0.010	−0.233
D(EI(-2))			0.101 ***	2.600				
D(EDUCATION)	1.002	1.064	0.719	0.141	−0.354	−1.322	−0.220	−0.667
D(EDUCATION(-1))			0.999	1.175			−0.792	−1.636
D(EDUCATION(-2))			0.037	0.584				
D(FD)	1.355	1.114			0.034	0.453		
D(FIE)			−1.012	−0.915			0.047	0.219
D(FIE(-1))			−0.455	−0.095			0.011	0.061
D(FIE(-2))			−0.166	−0.504				
D(FME)			−0.981	−0.975			0.008 **	2.516
D(FME(-1))			0.641	1.188			0.065	1.123
D(FME(-2))			0.875	1.081				
D(GDP)	2.728	1.223	1.757	1.117	0.753 ***	3.505	0.837 *	1.906
D(GDP(-1))			0.865	0.666			0.049	0.171
D(EPS)	0.289	0.991	0.969	1.171	0.505	0.189	0.203	0.111
D(EPS(-1))			0.340	0.901			0.009	1.396
C	7.501 **	2.367	9.851 **	2.416	−2.584	−1.479	−1.186 **	−2.040
Diagnostics								
Kao cointegration	−3.141 ***		−1.678 *		−2.817 ***		−3.255 ***	
ECM(-1)	−0.393 **	−2.217	−0.565 *	−1.828	−0.416 **	−2.434	−0.392 **	−1.900
Log-likelihood	20.71		127.3		347.6		407.5	

Note: *** $p < 0.01$; ** $p < 0.05$; and * $p < 0.1$.

The long-run findings of these models describe that environmental innovation increases REC in both models and reduces carbon emissions in both models as well. These results describe that improvement in environment-related technologies enhances REC and improves the quality of the environment significantly in the long-term. As expected, a 1% enhancement in environmental innovation increases REC by 0.164% in the first model and 0.212% in the second model and reduces carbon emissions by 0.046% in the third model and 0.052% in the fourth model in the long-term. The findings of the study confirmed the supporting role of eco-innovations in promoting renewable energy consumption and reducing CO_2 emissions [45]. Another name for eco-innovation is green innovation, which is crucial for attaining a sustainable environment. Environment-related technologies help improve economic and environmental efficiency, increasing green production and consumption activities [48]. One of the significant advantages of eco-innovations is that they are pro-environment and inexpensive methods of combating environmental pollution due to their ability to reduce emissions caused by trading and economic activities [49]. Utilizing green innovations helps attain a high pace of economic growth without compromising environmental quality [50]. Furthermore, eco-innovations also encourage individuals and businesses to increase renewable energy consumption because technological innovation also plays a crucial role in deploying renewable energy projects [27]. Several other empirics also confirmed that eco-innovations not only enhance the economy's productive capacity but also protect the environment from the destruction caused by such activities.

Educational attainment produces a positive impact on REC in both models and a negative impact on CO_2 emissions in both models as well. It demonstrates that an upsurge in education level contributes effectively in raising the consumption of renewable energy sources and declines pollution emissions significantly in the long-term. A 1% upsurge in educational level enhances REC by 1.151% in first model and 1.283% in the second model and mitigates carbon emissions by 0.306% in the third model and 2.098% in fourth model in the long-term. However, financial development does not report any significant effect on REC and carbon emissions in the long-term. Financial institution efficiency and financial market efficiency produce a positive impact on renewable energy consumption and carbon emissions. It is confirmed that financial efficiency enhances renewable energy consumption, hence the carbon emission increase. It shows that a 1% increase in financial institution efficiency increases REC by 0.735% and enhances CO_2 emissions by 1.514% in the long-term. However, a 1% increase in financial market efficiency reports 0.045% increase in REC and 0.109% increase in CO_2 emissions in the long-term.

Another important result of our analysis is that financial efficiency is crucial for the promotion of renewable energy consumption and better environmental quality. Hu et al.'s [51] study confirmed that positive shocks in financial institutions enhance renewable energy consumption, whereas, the negative shock in financial institutions reduces renewable energy consumption. Conversely, Anton and Nucu's [52] study demonstrated an insignificant association between capital market development and renewable energy consumption in the case of EU Member States. On one side, the financial system allows people to avail of credit facilities at a very affordable cost that will raise their living standards. On the other side, it can also lead to an increase in the consumption of energy and emissions of greenhouse gases [53]. However, due to the enhanced efficiency of the financial system, ample financial resources are available that contribute to the development of more advanced, sophisticated, and environment-friendly production methods. It also facilitates the procurement of green technologies that are less energy-intensive and consume fewer resources during production activities. Moreover, an efficient and well-functioning financial system is crucial for meeting the high initial cost of renewable energy projects, thereby increasing renewable energy consumption and improving environmental quality. However, Li et al. [38] reported that market development and financial institutions have increased carbon emissions in developed countries, but the nexus is reported insignificant in developing countries.

GDP reported a positive effect on both models of REC and in one model of CO_2 emissions. It infers that an increase in GDP per capita intensifies REC that in turn escalates carbon emissions. In contrast, environmental policy stringency is positively associated with REC in both models and negatively associated with carbon emissions in both models. It shows that environmental policy stringency contributes effectively to enhancing renewable energy consumption and the deterioration of carbon emissions in the long-term.

The short-term results display that environmental innovation reports a positive association with REC in one model only; however, the correlation between environmental innovation and CO_2 emissions is reported as insignificant in both models. The effect of educational attainment on REC and carbon emissions is reported as insignificant in all four models in the short-term. Similarly, the influence of financial development and financial institution's efficiency on REC and carbon emissions is reported as insignificant in all four models in the short-term.

However, financial markets efficiency reports increasing effect on carbon emissions in the short-term, but the effect on REC is reported insignificant in the short-term. GDP per capita reports a positive impact on carbon emissions in both models, but the influence on REC is found insignificant in both models in the short-term. The effect of environmental policy stringency on REC and carbon emissions is found insignificant in all four models in the short-term. In order to confirm the validity of the results, our study performed some important diagnostic tests, such as the Kao cointegration test, ECM test, and log-likelihood test. The cointegration association among variables is confirmed through the findings of the Kao cointegration test and ECM test. Additionally, the results of the log-likelihood ratio confirm the overall goodness of fit of models. In Table 5, the results of the causality test for Asian high-polluting nations show that unidirectional causality exists between EI and REC's and EI and CO_2's emissions, while causality does not exist from financial efficiency to REC and financial efficiency to CO_2 emissions.

Table 5. Results of causality tests.

REC Model Null Hypothesis:	**F-Stat**	**Prob.**	**CO_2 Model Null Hypothesis:**	**F-Stat**	**Prob.**
EI → REC	4.450	0.018	EI → CO_2	2.836	0.063
REC → EI	0.535	0.587	CO_2 → EI	0.627	0.536
EDUCATION → REC	0.325	0.723	EDUCATION → CO_2	6.434	0.002
REC → EDUCATION	3.980	0.016	CO_2 → EDUCATION	4.838	0.010
FIE → REC	0.442	0.644	FIE → CO_2	0.729	0.485
REC → FIE	0.358	0.700	CO_2 → FIE	0.989	0.376
FME → REC	0.175	0.840	FME → CO_2	0.330	0.720
REC → FME	0.043	0.958	CO_2 → FME	1.592	0.209
GDP → REC	1.494	0.229	GDP → CO_2	4.621	0.012
REC → GDP	0.306	0.737	CO_2 → GDP	3.061	0.051
EPS → REC	0.168	0.845	EPS → CO_2	1.494	0.229
REC → EPS	0.174	0.841	CO_2 → EPS	1.326	0.270
EDUCATION → EI	1.673	0.193	EDUCATION → EI	1.673	0.193
EI → EDUCATION	0.175	0.840	EI → EDUCATION	0.175	0.840
FIE → EI	0.120	0.887	FIE → EI	0.120	0.887
EI → FIE	3.884	0.024	EI → FIE	3.884	0.024
FME → EI	0.326	0.722	FME → EI	0.326	0.722
EI → FME	1.800	0.170	EI → FME	1.800	0.170
GDP → EI	0.527	0.592	GDP → EI	0.527	0.592
EI → GDP	2.008	0.140	EI → GDP	2.008	0.140
EPS → EI	0.182	0.834	EPS → EI	0.182	0.834
EI → EPS	0.727	0.486	EI → EPS	0.727	0.486
FIE → EDUCATION	0.440	0.646	FIE → EDUCATION	0.440	0.646
EDUCATION → FIE	0.254	0.776	EDUCATION → FIE	0.254	0.776
FME → EDUCATION	0.386	0.681	FME → EDUCATION	0.386	0.681
EDUCATION → FME	0.807	0.449	EDUCATION → FME	0.807	0.449
GDP → EDUCATION	0.947	0.391	GDP → EDUCATION	0.947	0.391
EDUCATION → GDP	2.222	0.114	EDUCATION → GDP	2.222	0.114
EPS → EDUCATION	0.402	0.670	EPS → EDUCATION	0.402	0.670
EDUCATION → EPS	0.478	0.622	EDUCATION → EPS	0.478	0.622
FME → FIE	0.124	0.884	FME → FIE	0.124	0.884
FIE → FME	4.455	0.014	FIE → FME	4.455	0.014
GDP → FIE	0.031	0.969	GDP → FIE	0.031	0.969

Table 5. *Cont.*

REC Model Null Hypothesis:	F-Stat	Prob.	CO_2 Model Null Hypothesis:	F-Stat	Prob.
FIE → GDP	1.034	0.359	FIE → GDP	1.034	0.359
EPS → FIE	0.641	0.529	EPS → FIE	0.641	0.529
FIE → EPS	1.361	0.261	FIE → EPS	1.361	0.261
GDP → FME	0.786	0.459	GDP → FME	0.786	0.459
FME → GDP	1.502	0.228	FME → GDP	1.502	0.228
EPS → FME	0.333	0.718	EPS → FME	0.333	0.718
FME → EPS	0.272	0.763	FME → EPS	0.272	0.763
EPS → GDP	0.261	0.771	EPS → GDP	0.261	0.771
GDP → EPS	0.532	0.589	GDP → EPS	0.532	0.589

4. Conclusions and Implications

Since the industrial revolution, growing anthropogenic activities have given rise to the problem of climate change and global warming. Such anthropogenic activities heavily depend on fossil fuel-based energy consumption, the primary source of greenhouse gas emissions, which is the root cause of environmental degradation. As a result, the world has experienced a sharp temperature rise, melting glaciers, heavy floods, sea storms, and a decline in agriculture production. There is consensus among policymakers, environmentalists, and civil society that reducing greenhouse gas emissions is the primary target of any mitigating policy. Increasing the share of renewable energy sources such as solar, wind, hydel, and biomass in the country's total energy mix is a widely accepted policy to combat the issue of climate change and global warming. The initial cost of renewable projects is too high and requires public and private sector support. An efficient and dynamic financial sector can facilitate the deployment of renewable energy plants by providing funds at an affordable cost. Similarly, green technological innovations are crucial in reducing greenhouse gas emissions, and such technologies refer to the products and procedures based on carbon-free technologies and methods. Green technological innovations can also help to develop renewable energy sources more conveniently. Therefore, we aim to investigate the impact of green technological innovations and financial efficiency on CO_2 emissions and renewable energy consumption in highly polluted Asian economies, including China, India, Russia, and Japan.

For empirical analysis, we have applied the ARDL-PMG model. The long-run estimated coefficient of environmental innovations is positively significant in both renewable energy models and negatively significant in the CO_2 emissions model. These results imply that environmental innovations help facilitate renewable energy consumption and reduce CO_2 emissions. On the other side, the estimates of financial development are insignificant in both renewable energy and CO_2 emissions models. However, the estimates of financial institution efficiency and financial markets are positively significant in both renewable energy and CO_2 emissions models, implying that financial institutions and market efficiency increase renewable energy consumption and decrease CO_2 emissions. The long-run estimates of education and EPS are significantly positive in renewable energy and significantly negative in CO_2 emissions models. Nevertheless, the estimates of GDP are positively significant in both energy and environment models.

On the basis of our findings, we have proposed some important policy suggestions. First, our findings suggest that green technologies are crucial in increasing renewable energy consumption and reducing CO_2 emissions. Hence, policymakers should try to increase the share of environment-related technologies by supporting R&D activities that are crucial for implementing environmental innovations. Secondly, the policymakers should induce the financial institutions to provide funds and credits at an affordable cost for deploying renewable energy projects and promoting green practices. Thirdly, integrating financial and energy policies is crucial for fostering green investments, such as renewable energy development and innovations.

The main limitation of the study is that the countries selected for the analysis are just four; hence, the implication of the study has a limited scope. Therefore, in the future, the empirics should also include other developed and emerging economies to analyze the said relationship. Moreover, the researchers should also analyze the said relationship using methods that can also account for the cross-sectional dependence. This study used the panel ARDL technique; however, future studies can be performed by using the NARDL approach and the quantiles regression approach.

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