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Exploring the role of coal consumption, solar and wind power generation on ecological footprint: Evidence from India using Fourier ADL cointegration test

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Abstract

In this study, we aimed to assess whether the intensive investments done for renewable energy sources work for reducing environmental deterioration level in India to reach its sustainable development goals and raise environmental quality. To this end, using data from 1995 to 2018, a novel methodology, the Fourier ADL cointegration test, and Bounds test were employed to empirically analyze the long-term steady-state relationship between ecological footprint and renewable and nonrenewable energy sources. Our empirical findings demonstrate the long-run steady-state associations between coal consumption, solar power generation, wind power generation, and ecological footprint in India. Moreover, the magnitude of the long-term effects of these resources were estimated by employing FMOLS method and the results indicated that solar and wind power generation have a statistically significant positive effect on environmental sustainability. In other words, increasing the share of wind and solar power generation in the energy mix led to mitigating the environmental deterioration in India. The findings also revealed an adverse effect of coal consumption on environmental sustainability in India. These results suggest that the share of solar and wind power generation in the energy mix should be increased in order to mitigate the energy-import dependency and environmental pollution in India.

Jel codes: P18; P48; Q28; Q42

1. Introduction

Renewable energy sources play a crucial role on environmental and sustainable development issues, such as mitigating environmental degradation, improving traditional primary energy-related carbon dioxide (CO_2) emissions, growing efficiency, and increasing economies of scale. Given that traditional ways of using primary energy sources in the production process have detrimental effect on the environment and cause climate change all over the world. Therefore, according to sustainable development goals and international treaty agreements on climate change such as the Paris agreement, countries have begun to prioritize environmental sustainability and increase the share of renewable energy generations in the energy mix by investing more in their potential renewable energy sources (IRENA, 2020; BP Energy Outlook, 2020; Rahman et al. 2022). In this context, the integration of new generation renewable energy sources into power generation systems has rapidly increased in the world. According to International Energy Agency (IEA, 2019), the power generation system which uses traditional energy sources accounts for almost 40% of carbon emissions throughout the world, and, nowadays, it continuously declining depending on increasing the investment in renewable energy generation. In 2019, renewable energy generations accounted for 26.2% of total generation globally. This proportion raises in the energy mix of the countries mainly depending on the rapid increase in the investment in solar and wind energy capacities. Solar power generation becomes the most utilized power generation in the world and in 2021, it was accounted for around over 50% of total renewable energy expansion and followed by wind power generation. Furthermore, it is predicted that these renewable energy sources will take over the place of using traditional energy sources for power generation by 2035 (IEA, 2018; REN21, 2019; IEA, 2019; BP Energy Outlook 2020; IEA, 2021).

As the third-largest CO_2 emitter country in the world, India emitted 6.8% of the global CO_2 level in 2019. Besides, it was also positioned as the third-largest energy consumer due to rapid population and economic growth with high industrialization level. Rapid growth and intensive industrialization have created enormous demand for energy in the country. Hence, India satisfies 80% of its energy needs by heavily utilizing traditional fossil fuels such as coal and oil (Franco et al 2017; Crippa et al 2020; IEA, 2021). On the one hand, although India is the second-largest coal-abundant market in the world, its coal reserves are insufficient to satisfy its increasing energy demand. The domestic demand for coal rose more than double and reached to 60% in 2019, up from 25% in 1990 in its energy mix. Consequently, more than 80% of coal-fired plants in India faced with critical stock availability level in 2021. Thus, increasing demand for energy and facing with the scarcity of coal resources have led India to invest in its potential alternative energy sources for power generation (Kumar and Majid, 2020; IEA, 2021; Arshian et al 2021; IEA, 2022). On the other hand, utilizing coal-fired technologies for power generation deteriorate the environmental sustainability and air quality in India. The level of GhG emissions caused by these technologies is accounted for almost 45% of total energy-related CO_2 in India (Sholapurkar and Mahajan, 2015; Crippa et al 2020). Consequently, energy policies in India plays vital role to mitigate the GhG emissions and improve local and global environmental quality in line with global environmental agreements and its own sustainable development goals.

Although coal-fired generations still have massive share in India's energy mix, India is highly endowed with the remarkable potential of renewable energy sources such as wind and solar power. In this regard, India aims to increase the utilization of solar and wind power to reduce the rising dependency on importing coal and accordingly try to mitigate environmental problems created by coal (Wang and Liu, 2021). Besides, they are fully cost-competitive and cost-effective green energy resources compared to fossil-fuel fired technologies. Especially, wind power approximately costs 35% cheaper compared to the coal-fired power plant, where this number is accounted as

30% for solar power generations. (GWEC, 2020; Indian Institute of Science, 2021). Accordingly, the Indian government intensified its project developments and investment in increasing the capacity of power generation from its potential renewable energy incorporation with the Ministry of New and Renewable Energy (MNRE) (IRENA, 2019; REN21, 2021; Shekhar et al 2021). Since 2014, the share of renewables in terms of installed capacity has doubled while the share of coal capacity regressed. Owing to the remarkable progress of India's energy transition by renewables deployment, the total installed capacity of solar and wind power reached 49 GW in the 2015–2019 period (IEA, 2021). Moreover, according to a report by the Indian Institute of Science (2021), the total installed capacity in renewable energy reached to 86 GW, of which solar power accounted for 34 GW, with wind power adding a further 37.5 GW by the end of 2019. Additionally, in 2020, wind power installed capacity accounted for 43.3% of the total energy mix, that is followed by solar power with a share of 39.8%. According to the Renewable Global Status Report (2020), India become one of the world's top leading investor economies on renewable energy. At the end of 2020, India was ranked 4th according to its wind power installed capacity and 5th country according to solar power installed capacity (Energy Statistics, 2021).

Acceleration in investment and rapid increase in installed capacity of renewables has led the Indian government to set a target to raise its renewable energy generation capacity to 450 GW by 2030 under the conditions of the Paris Agreement (IEA, 2022). In addition, they committed to an emission mitigation target to reduce harmful GhG emissions and their intensity by 43% and 60% in 2030, respectively. According to the IEA report published in 2018, the share of renewable energy sources in India is expected to rise to 38% by 2040 due to the priority given to new power generations, led by solar and wind power in particular. Aside from this, the coal-fired power generations are targeted to decline from 74% in 2017 to 57% by 2030 (IEA, 2020). To this end, according to 2030 development goals, the upward trend of solar and wind power generation systems will keep growing in near future. Therefore, depending upon these expectations, it is important to see how far India can go beyond its targeted level to make the new power generation pathway consistent.

Based upon the given information above, this paper contributes to the existing energy economics literature with several novelties: initially, to date, according to the best knowledge of authors, this is the first attempt to answer the question of how environmental sustainability varies depending on the use of renewable (solar and wind generations) and non-renewable (coal consumption) energy sources in India. This is important to be determined to assess whether the intensive investments done for renewable energy sources work for reducing environmental deterioration level in India to reach its sustainable development goals and raise environmental quality. To this end, the exhaustive indicator, i.e. ecological footprint, was firstly used for environmental sustainability for India and regressed on different renewable energy potentials. Secondly, India is one of the biggest contributors to the world's GhG emissions and environmental deterioration due to its dependence on fossil-fuels fired based generation system and CO_2 emissions from fossil-fuel generation which grew ten-fold from 181 MtCo2 in 1971 up to 2161 MtCo2 in 2017 (IEA, 2019). Therefore, mitigating carbon emissions in India in fact is very important globally. Also, the findings of this study could be especially useful for the continuity of renewable generation target and to lessen the adverse environmental effect of fossil fuels in India on the world. Thirdly, although few studies have investigated the wind power-carbon emissions nexus in the literature, no studies yet examined the wind power-ecological footprint nexus for India. Fourth, this is the very first study that employs the newly developed Fourier ADL cointegration test to empirically analyze the steady-state association among ecological footprint and renewable and non-renewable energy sources. This empirical technique differs from traditional cointegration techniques by considering the number of structural breaks and gives robust results accordingly. Lastly, this study extends the data set used in the literature and covers the years from 1995–2018 that is also the whole available data.

The organization of this paper is listed below: After the introduction, Section 2 introduces the previous studies and their findings in the literature and followed by Section 3 which assesses the data and the econometric methodology applied. Section 4 discusses the findings of the study and Section 5 delivers the conclusion and policy implication.

2. Literature Review

The excessive use of fossil-fuel to meet high energy demand threats the environment and contributes to the GhGs. To combat climate change and reduce the harmful GhG emissions, it is very crucial to increase the integration of renewable energy. Therefore, there is much attention to renewable energy sources as environmentally friendly energy sources across the countries. Accordingly, this part of the study reviews the previous studies which have analyzed the environmental impacts of coal consumption, wind generation, and solar generation. In this regard, review of the literature is categorized into three sections in view of the selected studied parameters. The first section focuses on the works that assessed the association between coal consumption and the environment, while the second

section covers the solar energy-environment nexus. The last section comprises the relationship between wind power and environmental sustainability.

The first section emphasizes the association between coal consumption and the environment. Coal consumption is widely discussed indicator of environmental degradation and there are numerous studies done on this subject matter in the literature (Long et al 2015 Pata 2018; Jin and Kim, 2018; Joshua et al. 2020; Magazzino et al. 2020; Kanat et al. 2022). These studies have reported that coal consumption drives environmental degradation for the national or cross-national level. However, the Indian case studies have empirically investigated that coal consumption contributes deterioration level of the environment (Tiwari et al 2013; Ahmad et al 2016; Gyamfi et al 2021; Pata and Kumar, 2021; Magazzino et al 2021). As a summary, the existing literature completely agrees that the negative effect of coal consumption on the sustainability of environment.

The second section argues about the nexus between solar power and the environment. For G-7 countries, the role of solar energy use on carbon emissions was investigated by Destek and Aslan (2020) and concluded that solar power consumption reduces the carbon emissions in France, UK, Italy and US, while according to the overall panel, there was no significant effect of the use of solar energy on carbon emission. Based on the estimation of the vector autoregressive approach (VAR) for China for the years between 1970 and 2017, Zhang et al. (2020) revealed solar energy technology lessens carbon emissions. Moreover, Sharif et al. (2021) conducted quantile-on-quantile (QQ) regression to investigate the effect of solar power consumption on ecological footprint for top ten solar energy consuming nations. Using data over the period of 1990–2017, findings showed that the use of solar energy diminishes the ecological footprint for investigated countries excluding India and United Kingdom. This means that solar energy contributes to environmental sustainability for investigated countries. In another study, Sharif et al (2021) investigated the same question and found that solar power consumption mitigates environmental degradation in the USA. Another study, Yasmeen et al (2022), done for same countries using data covering the years between 1990–2018, indicated that solar energy decreases the carbon emission level for selected countries. Similar findings were obtained by Yu et al (2022) for top-ten solar energy-consuming countries except for France by employing QQ regression over the period of 1991–2018. Likewise, Güney (2022) found solar energy consumption decreases the carbon emissions level for 35 countries. In contrast to the aforementioned studies, Magazzino et al (2021) examined the causal link among solar energy and carbon emissions for India, throughout the years between 1986–2017. The empirical results, for which they employed Machine Learning Approach, revealed that solar power energy has no statistically significant causal relationship with carbon dioxide emission in India. By considering these studies, although having a conflict with the results of these studies, a statistically positive and significant long-term association is expected amongst solar power and the environment, which means that a rise in the use of solar energy in the power generation mix has a statistically significant effect and cause an enhancement in environmental quality.

The third section covers the effect of wind power on the environment. Although few studies have investigated the wind power-carbon emissions nexus, no study is available in the existing literature that test the relationship between wind power and ecological footprint for India. For instance, Destek and Aslan (2020) conducted augmented mean group (AMG) estimator and panel bootstrap causality method for the period 1991–2014 in G-7 countries to scrutinize the impact of wind power consumption on carbon emissions. Their outcomes presented that wind power consumption reduces CO2 emissions in all G7 countries. Likewise, Sharif et al. (2021) tested the effect of all forms of renewable energies on carbon emission in the USA during the period of 1995–2017. QQ regression results confirmed that wind power energy reduces the environmental degradation. Aydin and Pata (2020) stated that there is path dependence in energy demand for wind power in the USA by meaning of innovations in the wind power will have long-term effects in USA and energy policies can be implemented on this energy source. Li et al. (2020) investigated the environmental emissions caused by wind power generation in China. Life cycle assessment method revealed that wind power generation diminish the environmental emissions which are carbon emissions, sulfur dioxide (SO_2), nitrojen oxide (NO_x), and carbon monoxide (CO). Hereby, in this study, the significance of the effect of wind energy sources on the environment is tested by using comprehensive indicators for the environment to get robust and more reliable results for policymakers. The results of this study will help policymakers to set better rules and regulations to get fast responses from the actors in the country to mitigate environmental degradation in the shorter term.

3. Data And Methodology

The role of renewable energy sources to alternate the traditional energy sources, to meet increasing demand in energy, to decline the energy import-dependency, and to heal the environmental degradation has an increasing concern for the environmentalists and policymakers. Given the expectation of increasing global energy demand by 3 times higher due to an increase in population, productivity, and living standards by 2050, most of the countries rapidly invest in their potential renewable energy sources to increase

their capacity of production in their energy mix. For instance, the government of India continuously and heavily invests in wind and solar energy to enhance the share of renewable energy sources in the energy production mix, and India reached 4th place with the largest installed wind power capacity and 5th globally in terms of installed capacity of solar power in the world. In this context, in this study, we aim to explore the long-run association amongst coal, solar, and wind energy generation with environmental sustainability for India. The investigated relations can be presented as below:

$$lnEFP_t = \alpha + \beta_1 lnCOAL + \beta_2 lnSOLAR + \beta_3 lnWIND + \epsilon_t \quad (1)$$

Therefore, a comprehensive indicator for environmental sustainability, i.e. ecological footprint (EFP), was used and measured as global hectares per person (gha). It comprises forestry, cropland, fishery, and grazing land along with CO_2 emissions. The data has obtained from the ecological footprint network official website (2022). Besides, the data for coal consumption (COAL), solar energy generation (SOLAR), and wind energy generation (WIND) was acquired from British Petroleum statistical review of world energy (2022) and measured as terawatt per hours (www.bp.com). The annual data was restricted for the time-period of 1995–2018, due to the data availability of ecological footprint. To increase the reliability of the results and decrease the heterogeneity of the series, the logarithmic forms of the variables are used for estimations. Table 1 details the descriptive statistics and correlation matrix for investigated variables.

Panel A of Table 1 shows that the mean value of EFP is -0.065, that is between 0.173 and − 0.217. The standard deviation of the ecological footprint was 0.125 which suggests low level of dispersion from the mean value. Furthermore, the means of coal, solar, and wind power generation are 2.274, -2.511, and 1.898, respectively. Additionally, the Jarque-Bera (JB) statistics designates that variable are normally-distributed, and positively skewed except for wind power generation. Besides, the correlation matrix analysis in Panel B of Table 1 presents that coal, solar, and wind energy sources have a statistically significant positively correlation at 1% significance level with ecological footprint in India whilst, they are positively and highly correlated with each other.

Table 1
Summary of Descriptive analysis and Correlation matrix

Panel A. Descriptive Statistics				
	lnEFP	lnCOAL	lnSOLAR	lnWIND
Mean	-0.065	2.274	-2.511	1.898
Median	-0.115	2.217	-4.007	2.234
Maximum	0.173	2.858	3.070	3.963
Minimum	-0.217	1.770	-6.897	-0.700
Std. Dev.	0.125	0.374	0.973	0.471
Skewness	0.413	0.206	0.603	-0.219
Kurtosis	1.632	1.587	1.966	1.609
Jarque-Bera (JB)	2.446	2.075	2.421	2.037
JB probability	0.294	0.354	0.297	0.361
Observations	23	23	23	23
Panel B. Correlation Matrix				
lnEFP	1			
lnCOAL	0.971	1		
lnSOLAR	0.955	0.958	1	
lnWIND	0.931	0.977	0.904	1
Source: authors' computation				

Furthermore, the Augmented Dickey-Fuller (ADF), developed by Dickey and Fuller (1979), and Philips and Perron (PP) (1988) stationarity tests have been employed to test the integration order of the variables as a prior condition to investigate the long-term steady state association among investigated variables. However, traditional unit root tests can prohibit structural breaks and sometimes give ambiguous results when the data has structural breaks. Thus, the Zivot-Andrews unit root test has been employed to check the structural breaks and test the stationarity level of variables under this condition. Furthermore, in the energy-environment literature, the authors mainly used dummy variables to avoid the possibility of having misleading results and to capture the effect of sudden changes in data, however, this is not enough to capture the slower changes, such as economic reforms, in series. Economic reforms, e.g. supply-side policies, are long-term policies and has small and long-term effect on other variables. Therefore, they may not be captured with traditional unit root tests. To avoid these deficiencies and improve the strength of the results while testing the cointegration relationship among examined variables, newly developed model, i.e. Banerjee et al. (2017), has been utilized. This method uses the Fourier function to estimate the results and can capture multiple breaks (Gallant,1981; Gallant and Souza, 1991). It was developed model of Banerjee et al. (1998) and can be presented with the following equation (Eq. 1).

$$\Delta y_{it} = d(t) + \emptyset_1 y_{1,t-1} + \delta' y_{2,t-1} + \beta \Delta y_{2t} + \epsilon_t$$

2

where deterministic trend is depicted with $d(t)$ and can be defined as below.

$$d(t) = \propto_0 + \theta_1 sin\left(\frac{2\pi\kappa t}{N}\right) + \theta_1 cos\left(\frac{2\pi\kappa t}{N}\right)$$

3

Where t depicts for trend, and N indicates for the no of observations. Moreover, κ stands for particular number of frequencies. It can be determined with the minimum sum of squares method. Then, Eq. 2 was implemented into equation one and the following model was generated.

$$\Delta y_{it} = \propto_0 + \theta_1 sin\left(\frac{2\pi\kappa t}{N}\right) + \theta_1 cos\left(\frac{2\pi\kappa t}{N}\right) + d(t) + \emptyset_1 y_{1,t-1} + \delta' y_{2,t-1} + \beta \Delta y_{2t} + \epsilon_t$$

4

Then, the null hypothesis of no cointegration relationship among investigated variables ($\emptyset_1 = 0$) was tested against the alternative hypothesis which states for cointegration association among investigated variables ($\emptyset_1 < 0$). The following test statistic was used for this purpose.

$$t_{adl} = \frac{\hat{\emptyset}_1}{se(\hat{\emptyset}_1)} \emptyset_1 \qquad (5)$$

where $\hat{\emptyset}_1$and se ($\hat{\emptyset}_1$)indicates for ordinary least squares estimators and standard error term of $\emptyset_1$, respectively. This test is recently commenced to the literature and yet none of the studies investigated the cointegration relationship of renewable energy potentials of India i.e. coal, solar and wind energy, with its environmental sustainability indicators, i.e. ecological footprint by employing Fourier model estimation. Therefore, this technique distinguishes our paper from the previous studies in the energy-environment literature. Moreover, Bounds test has been utilized to confirm our results obtained from Fourier cointegration test. Lastly, to capture the direction and magnitude of the effect of wind power generation on environmental sustainability in India, fully modified ordinary least squares (FMOLS) model has been utilized. This model was applied to examine the robustness of the outcomes under the condition of small sample size and serial correlation and endogeneity problems in the regressors.

4. Empirical Results

As mentioned before, ADF and PP unit root tests have been utilized to determine the integration order of the variables as a prior condition for the cointegration test. The minimum value of the AIC criterion is used to determine the optimal lag length for these tests. Table 2 provides the details about the outcome of the unit root tests. Consequently, all the investigated variables have a unit root at their level form, and they are stationary at integration order one, I(1), at different significance level. Moreover, the Zivot-Andrews unit

root test is also performed, and the structural break for ecological footprint occurs in 2013, coal consumption occurs in 2014, solar power energy occurs in 2007 and lastly wind power generation occurs in 2004. In these years, India has reiterated its reforms on the economy and eliminated its rules and deregulated the market for more foreign direct investments. To this end, India aims to catalyze economic growth which causes significant deteriorations on environment and energy sector. These results satisfy the precondition of the Fourier ADL cointegration test.

Table 2
Unit Root Test Results.

	ADF		**PP**		**Zivot-Andrews**			
	Level	Δ	Level	Δ	Level	Break date	Δ	Break date
lnEFP	0.822	-3.49*	0.913	-3.425**	-2.929	2000	-4.431*	2013
lnCOAL	0.781	-3.728*	0.647	-3.756*	-3.125	2007	-4.949**	2004
lnSOLAR	0.107	-5.419*	0.268	-5.419*	-3.612	2011	-7.547*	2007
lnWIND	-1.468	-5.623*	-1.550	-5.519*	-4.576	2004	-7.942*	2004

Notes: (1) All unit root tests were employed for only intercept. (2) * and ** depicts for 1% and 5% significance levels, respectively. (3) **Δ** signifies the first difference.

Source : authors' computation

As a second step, the verification of long run equilibrium associations among the variables examined with newly established, Fourier ADL Cointegration Test. Also, Fourier ADL test results are verified by conducting the ARDL Bounds test. Table 3 gives the outcome of the cointegration tests. Accordingly, the trace statistics show the cointegration relationships among investigated energy sources with ecological footprint level at 1% significance level for both tests. In other words, these results indicate that coal consumption, solar power generation, wind power generation and environmental sustainability have long run steady state relationship in India.

Table 3
Results of Cointegration Tests

Panel A. Fourier ADL Coint. Test								
Result	**Frequency (k)**	**Test Statistics**	**AIC**		**Dy**		**Dx**	
Cointegration	1	-5.469*	-5.457		1		2	
Panel B. Bounds Test Results								
			1%		**5%**		**10%**	
			B_L	**B_U**	**B_L**	**B_U**	**B_L**	**B_U**
Cointegration	1	9.732*	5.17	6.36	4.01	5.07	3.47	4.46

Notes: (1) Critical value for cointegration test are − 4.44 for 1%, significance level. (2) * depicts for 1% significance level (3) B_L and B_U indicate for lower bound and upper bounds, respectively.

Source : authors' computation

To test the significance and the magnitude of the effect of studied energy sources on ecological footprint in long run, FMOLS model has been utilized. The empirical outcomes are tabulated in Table 4 and show that estimated long-run coefficients of the studied variables are statistically significant.

According to the results, coal consumption is negatively related with the ecological footprint, which infers that the consumption of coal leads to environmental degradation. A rise in coal consumption by 1% causes a surge in environmental pollution by 0.713% in the long run. This is an expected outcome since India is heavily dependent on coal to meet country's high energy demand and it shows that use of coal is the major contributor to environmental degradation in India. This outcome is in the vein of Magazzino et al. (2021); Gyamfi et al. (2021) and Pata and Kumar (2021).

Regarding the ecological effects of solar power, the results designate that it is statistically significant and positively related with environmental sustainability. A 1% rise in the proportion of solar energy generation in the total energy mix leads to a 0.016% decline in the environmental degradation level in the long run. It is obvious that solar power is an effective mitigation measure in diminishing the level of environmental pollution in India and it can decrease the level of dependence on fossil-fuel and environmental problems related to fossil-fuel fired generation. This finding is supported with the empirical result in the study of Wu et al (2021); in which solar energy is the promising carbon-neutral option compared to coal-fired generation. This result contrasts with the views of Destek and Aslan (2020) for G-7 countries, and Magazzino et al. (2021) for India who reported the insignificant effect of solar power on environment. However, it is in line with Zhang et al (2020) for China, Sharif et al. (2021) for USA, Yasmeen et al. (2022) for top-ten solar consuming countries and Yu et al. (2022) for top-ten solar consuming countries.

Table 4
Results of long-term estimation.

	Coefficient	Std. Error	T-statistics	P-value
lnCOAL	0.713*	0.139	5.101	0.0001
lnSOLAR	-0.016**	0.007	-2.156	0.0448
lnWIND	-0.072*	0.024	-2.954	0.0085
C	-1.591*	0.292	-5.456	0.0000
	R-Squared	0.925	Adjusted R-squared	0.913
Note: (1) * and ** depicts for 1% and 5% significance levels, respectively.				

Source : authors' computation

Finally, wind power has a significant positive effect on the ecological footprint. For every 1% increase in wind power generation, there is a decline of 0.072% in the level of environmental degradation in the investigated period. It is obvious that wind power can be suggested as the best alternative energy source among potential renewable energy sources to fossil fuels to have a better-quality environment and reach its environmental sustainability targets for India. In addition, the result support the view of wind power is an eco-friendly energy source. Furthermore, this result can be supported with the findings provided in the recent study by Li et al (2020); in which wind power generation is more effective to control the emissions than coal-fired power. The empirical finding can also be justified by study like Zhang et al. (2022) for selected 5 emerging economies including India.

Consequently, these empirical findings suggest that India started to take the advantage of clean energy sources. India's energy target for renewables has been successful in mitigating the environmental degradation and the energy transition toward solar power and wind power is well underway. Therefore, continuing in its pathways and investing in renewable energy potentials, especially increasing the proportion of solar power and wind power in its generation mix, will lead India to lower the deterioration level of environment and to reach its environmental and economic targets. Moreover, growing deployment of clean generation helps to have environmental sustainability by altering the GhG emissions which are mostly caused by domination of coal-fired generation in the country.

5. Conclusion And Policy Recommendation

India is positioned third-largest energy consumer in the world and facing continuous rise in energy demand. Thus, India predicted to have energy shortage in near future and meeting with the energy demand will indeed be impossible if no rapid investment is done in energy sector. Today, the energy sector heavily depends on fossil-fired energy generation, mostly coal-based consumption, and there is a huge concern about the future environmental role of coal-fired generations. India accounted for 11.8% of total coal consumption in the world in 2019 but in 2020, demand for coal dropped by 8% even though India was the second-largest coal importer after China in 2020 at 214 Mt (IEA, 2021). Therefore, replacing coal and other fossil-fuel energy sources with renewable energy resources in this regard is very substantial to have a better environment.

In this context, in this study, we investigated the long-term associations of India's potential renewable energy resources, i.e. wind power generation, solar power generation, and coal consumption, with its environmental sustainability, covering the period 1995–2018 to evaluate the best alternative resource to fossil fuel energy sources. To this end, Fourier ADL cointegration test and Bound test were

employed. Both tests revealed the long-run steady-state associations between coal consumption, solar power generation, wind power generation, and ecological footprint. Moreover, the long-run coefficients were estimated by employing FMOLS method and the results indicated that solar and wind power generation have a positive and significant association with environmental sustainability. In other words, increasing the share of wind and solar power generation in energy mix led to mitigating the environmental deterioration in India. Furthermore, the findings also revealed the adverse effect of coal consumption on environmental sustainability in India. These results implies that environmental pollution in India can be reduced by increasing the deployment of power generation from solar and wind power.

It is evident from this study that the investment in solar and wind power has very crucial dynamic role on sustainable environmental future for India. Hence, the Indian government should develop its strategies for the energy transition from conventional fossil fuels to green energy sources to reduce the environmental deterioration level. In this way, it will also make the country more independent on energy sector and help the country to take strong position to combat the climate change problem. To reach this target, India should prioritize environmental quality and also consider the government budget. Thus, initially, it should invest on repowering its wind turbines with new technology, which will improve capacity and efficiency in energy generation while utilizing existing infrastructure and land. Moreover, central and state-level policies should be introduced to mitigate environmental degradation and waste of energy. On the other hand, the sustainability of the projects in India is crucial problem. Thus, generation-based incentives and tax concessions can be offered to improve sustainability issues in projects. Last but not least, Indian government also needs to prioritize offshore wind and solar energy development along with the onshore energy production to achieve its desired level of renewable energy generation together with environmental sustainability.

Declarations

Ethics approval and consent to participate

The authors are giving their ethical approval and consent for this paper to be published in your Journal if found publishable

Consent for participate

The authors are giving their consent for participation in this paper to be published in your Journal if found publishable

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Availability of data and materials

Data sources are outlined in Data and methodology section and will be available on demand

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Authors collaborate for this paper in each section. Selin Karlilar worked for the introduction and literature review, Asst. Prof. Dr. Firat Emir developed the model, employed the methodology and discussed the results. All authors discussed the results and contributed to the final version of the manuscript. All authors read and approved the final manuscript.

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