A Parametric Investigation of Factors Influencing India's Renewable Energy Transition

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Abstract

Climate change has occurred as an established phenomenon with paramount ecological effects. Being the third largest emitter of carbon emission, India is among the first developing nation to have set the carbon neutrality target to combat climate change. In the realm of its burgeoning population and rising energy demand, the reliance on renewable energy is vital and has become a necessity. The present study digs deeper into the analysis of renewable energy parameters for the period spanning from 2000 to 2021. It reveals certain ups and downs in REC and REG, a continuous increase in carbon emission and GDP, and a reduction in energy intensity and carbon intensity over the period of 2000 to 2021. However, it is quite clear that the percentage of renewable electricity production is more or less increasing which signals a 'greener electricity'. Further, the enhanced energy efficiency is quite discernible from gradual decline in both carbon intensity and energy intensity which signifies a transition towards clean energy goal set out under SDG-7.The paper paves a way for policymakers to implement more sustainable use of non-fossilized energy along with newer renewable energy tools and technologies to provide better incentives for its development.

Keywords: *Renewable energy consumption, renewable electricity output, carbon intensity, energy intensity, India.*

1. Introduction

Climate change has occurred as an established phenomenon with paramount ecological effects. The onset of twenty-first century has marked its potential consequences round the globe on both physical and social environment. Due to burgeoning population and ever-increasing developmental process, the demand for energy is inevitable. In this realm, fossils contribute a bigger chunk of requirement which ultimately culminates into an unaffordable pollution level. In addition, the rise in global temperature fuels up the process of glacial transformation, inundation and various ecological disturbances.

To minimize the warming rate to 1.5 degree Celsius will bid a quick, extensive and significant adjustment in various interlinked systems, including energy, carbon emission, economic development, and several other factors. The 26th Conference of Parties and Paris Agreement lags behind the estimated schedule for implementing various strategies outlined (Yu et al., 2022). It commands further explorations by environmental scientists, policymakers and governments to

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examine as to what contributes more towards zero carbon emission transition.

India, the world's third largest emitter of GHGs after USA and China, is also vulnerable to climate change. CO2 is found as one of the most vital contributing factors to environmental deterioration. To keep up with economic growth and growing population, developing nations like, India is flooding with higher concentration of pollutants which are having its negative effects on environment and health. Therefore, the focus and reliance on renewable energy is vital and has become a necessity in the realm of rising energy demand.

In the wake of energy and oil crisis of 1970s, the countries around the world were forced to switch to non – fossilized energy sources (Suresh et al, 2022). The threatening effect of global warming and climate change accelerated the pace of these efforts. India, being the third largest consumer of oil and electricity, commenced on developing and installing renewable energy projects in the 1980s. It is interesting to emphasize that India is among the first developing nation to set forth for itself a carbon neutrality target. This illustrates the nation as a prominent voice for other developing nations as well in the domain of climate action. According to Addai et al (2022), the predicted energy demand will escalate by around 90 percent by 2035. Notably, India's allegiance and urge towards climate change alleviation is becoming more flagrant through its energy efficiency viewpoint.

Suresh et al. (2021) delved into depth to gain insights into the position of India in the renewable energy sector and its evolution over the period of time. Since, India has set an intimidating target of 450 GW capacity installation by 2030 to demonstrate its commitment towards sustainable development. Currently, India stands at the fourth position among the world leaders in terms of total installed capacity of renewables. According to Negi and Mathew (2014), the sources of renewable energy and their application in electric mobility are popularly considered as the critical measures to reduce greenhouse gas (GHG) concentration. Strong institutional frameworks enhance the effectiveness of renewable energy policies, leading to reduced emissions (Almulhim et al., 2025).

In an effort to cultivate a cleaner environment, India has set an enthusiastic target of net zero carbon emission by 2070 during 26th CoP at Glasgow in United Kingdom in 2021. In its drive towards carbon neutrality, India walked towards the five crucial elements for climate action popularly called as 'Panchamrit' by Prime Minister Narendra Modi during the event. It includes: i) the promise to attain 500GW non-fossil energy capacity, ii) ensure 50 percent of energy requirements from renewable energy sources by 2030, iii) commitment to reduce carbon emission by 1 billion tonnes (bt) by 2030, iv) set out programmes to reduce carbon intensity by 45 percent by 2030, and v) to fulfil the net zero carbon emission target by 2070. Hence, this paper seeks to roll out the factors that can help in achieving the goal of aforesaid target.

India has recently launched Lifestyle for Environment (LiFE) programme which seeks to promote lifestyles that could ensure sustainable environment in India and at the global platform (Uche). The blend of this action along with other energy transition protocols and agendas, it is expected that there will be appreciable decline in global carbon emission by around 2 billion tonnes (Gt) by 2030 (Uche et al., 2023). Furthermore, the profile of carbon emission of India depicts that its energy efficiency needs to be doubled.

Figure 1 reveals the percentage change in the four parameters of Kaya identity which determines total carbon emissions. It also includes emission from fossil fuels and industry. The importance of Kaya identity variables has been highlighted in various studies. The present study also takes into account the variables like carbon emission, carbon intensity, and energy intensity for the analysis. The figure shows an increasing trend in CO_2 emissions

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touching its height. The GDP per capita and population is also continuously increasing at a decreasing rate. However, carbon intensity and energy intensity mark a notable reduction in the recent years. Figure 2 depicts the break – up of renewable energy generation which consists of hydropower, solar, wind, and other renewables including bioenergy. Hydropower contributes highest in the renewable electricity generation from 1965 to 2022. In the year 2022, hydropower contributes above 160TWh, followed by solar at about 100TWh, wind at 40TWh and others at 40TWh.

Figure 3 depicts the India's share of primary energy consumption from renewable energy sources over the years. In the year 2022, India's share of primary energy consumption from renewable sources stands at around 10.5 percent, showing an almost increasing trend over the last ten years.

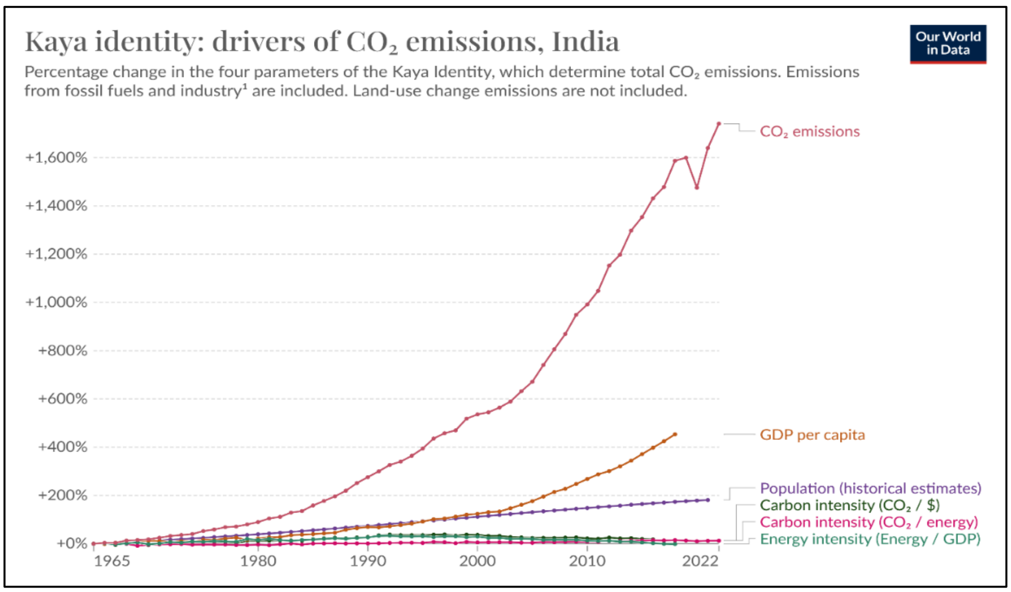

Figure 1 Drivers of CO_2 Emissions in India; Source: Our World in Data

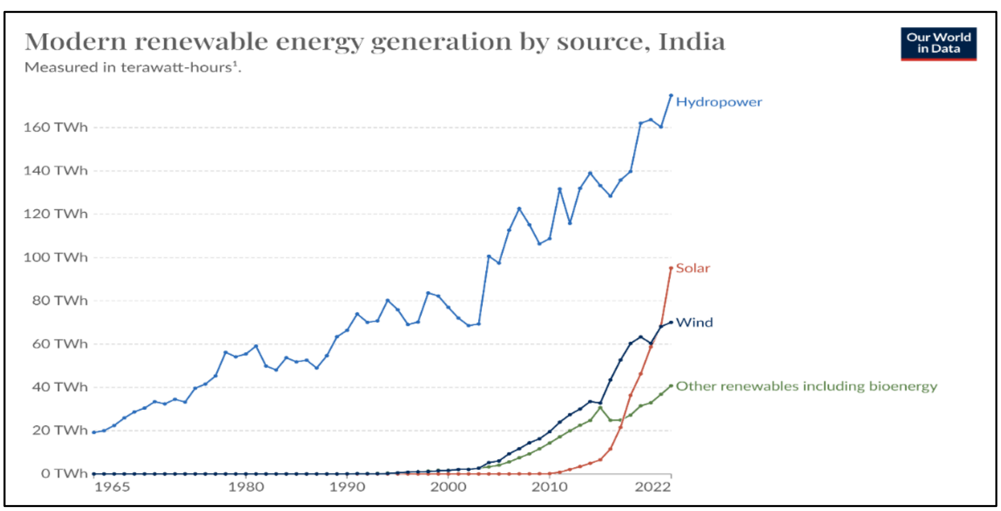

Figure 2 Renewable Energy Generation; Source: Our World in Data

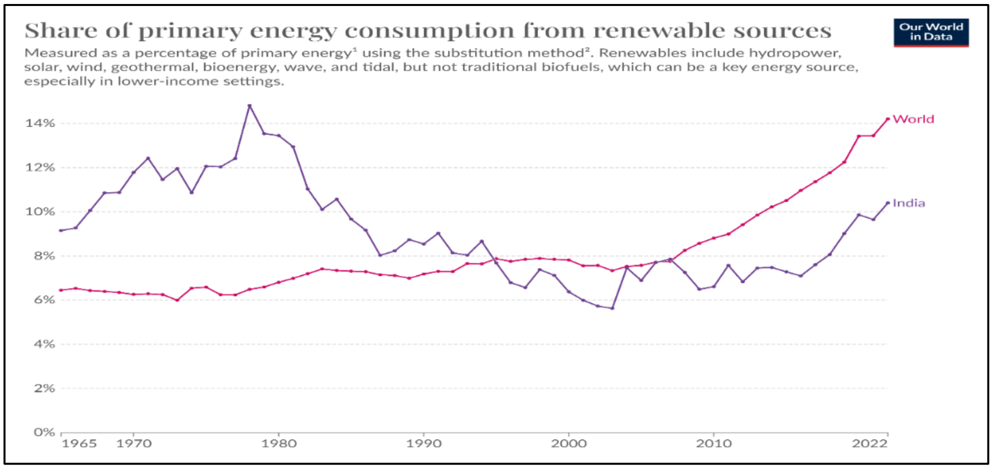

Figure 3 Share of primary energy consumption from renewable sources; Source: Our World in Data

2. Objectives of the study:

Having described the background and current scenario of energy and carbon emissions, the study sets out following objectives to investigate the empirical findings of the research:

a. To elucidate the theoretical background of energy and environmental pollution.
b. To highlight the status of renewable energy and pollution indicators.
c. To delve into the role of renewable energy and renewable electricity in enhanced energy efficiency.
d. To suggest policy implications for clean energy transition.

3. Literature Review

Over the past several decades, myriad scholarly investigations have sought to elucidate the variables that contribute significantly to the complex issue of climate change. A study by M'henni (2005) investigated a sophisticated relationship between renewable energy sources, degree of trade openness, and carbon emission in Tunisia during 1980-1997. The analysis utilized the Generalized Method of Moments (GMM) for the purpose. It did not find any evidence in line with the Environmental Kuznets Curve (EKC) hypothesis. In another study conducted by Fodha and Zaghdoud (2010), they found a positive linear relationship between per capita CO2 emissions and per capita GDP, thereby upholding the EKC hypothesis. However, they observed a non-linear and divergent pattern while evaluating link between per capita Sulphur dioxide emissions and per capita GDP. This shows the fact that EKC hypothesis does not applies uniformly across all environmental indicators.

Numerous studies utilizing diverse methodologies have explored the relationship between economic growth, CO2 emission, and energy consumption, and provided divergent findings. In the same line, Arouri et al., (2012) highlighted the relationship between CO2 emissions and economic growth on Middle East and North African (MENA) countries. They concluded that the results did not adhere to the traditional EKC pattern. All these studies have furnished evidence based multifaceted outcomes which intrigued into the nature of the relationship between the interlinked variables. Kaya Identity is identified as one of the most important IPAT identity extensions (Yamaji, Fujino, and Osada, 2000). It elucidates cleaner energy productivity technology (T) via the lens of two energy policy variables: i) carbon intensity, which measures how much carbon dioxide is released for every kilowatt hour of energy production, and ii) energy intensity measures how much energy is consumed per unit of economic strength (Lin and Ahmad, 2017).

Emmanuel et al. (2023) in their study featured the wavelet quantile correlation technique for quarterly series from 1997Q1 to 2021Q4 and found that energy intensity generated significant carbon de-escalation impacts especially in medium and long term. They narrated that countries which are naturally endowed with fossil fuels find it difficult to control carbon emissions and to approach towards a greener and cleaner environment. Various empirical studies have been conducted to test Kaya Identity metrics, carbon curse, and EKC hypothesis by analysing the relationship between environmental decay, economic growth, carbon intensity, and energy intensity. However, no unanimity in the results have been accorded for different nations (Tiba and Omri, 2017; Lin and Raza, 2019; Shokoohi, Dehbidi, and Tarazkar, 2022; Khan et al., 2022). A lot number of studies have found that increase in energy efficiency causes reduction in carbon emissions, whereas others claim it as temporary. Paul and Bhattacharya (2004), investigated India's overall and sectoral CO2 emission over the 1980 to 1996 using decomposition technique. The study reveals that economic expansion intensifies environmental deterioration in both overall and sectoral CO2, whereas energy efficiency and efficient fuel substitution mitigates it. Different scholars studied the relationship between carbon emissions and renewable energy consumption devising different methodologies and techniques such as, decomposition (Zhand and Da, 2015), cointegration method (Ahmad et al. 2016), Vector Error Correction Model (Chaabouni, Zghidi, and Ben Mbarek, 2016), cross correlation estimation technique (Narayan, Saboori, and Soleymani, 2016), panel quantile regression model (Zhu et al., 2016) and dynamic panel model (Ito, 2017).

Some of these studies have come up with a bi-directional relationship between economic growth, carbon emissions and renewable energy consumption in some countries. While others found renewable energy consumption or GDP as one of the primary drivers of CO2 emission. Bekun, Alola, and Sarkodie (2019) devised the PMG-ARDL and found that non-renewable energy utilisation elevates carbon emissions, whereas renewable energy consumption alleviates them. Conversely, Nguyen and Kakinaka (2019) in their study revealed that the relationship between carbon emissions and renewable energy consumption is dependent upon an individual country and its developmental stage. In this frame of reference, countries with lower income level showed a positive correlation between renewable energy consumption and CO2 emissions, while higher income countries exhibited an inverse relationship.

Several studies provide conflicting outcomes rather than being in line with policy objectives. For instance, Adebayo et al. (2021) evaluated the effect of renewable energy consumption on CO2 emissions in South Africa using both frequency domain causality and the ARDL approach from 1980 to 2018. He found a negligible relationship between the variables. Increased renewable energy usage is linked to lower carbon emissions, as evidenced by studies employing econometric models like ARDL and STAR (Ganie and Ahmad, 2024; Ganie et al., 2024). The findings suggest that renewable energy consumption can mitigate the adverse effects of economic growth on emissions, particularly after reaching a certain economic threshold (Ganie and Ahmad, 2024). A good number of studies have taken trade openness as one of the determinants of carbon emissions. To illustrate, Jayanthakumaran, Verma, and Liu (2012) have devised bounds test approach and ARDL method to study the association between trade openness and energy utilisation. The results demonstrated a positive influence of trade openness and energy utilisation on CO2 emission in the case of China, however, the results do not corroborate in India's case for the period 1971 to 2007. Several studies conducted in different countries during distinctive time frames to study

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the relationship between trade openness and carbon emissions came up with dissimilar results.

Now, it is appropriate to mention the literature related to the energy intensity and carbon intensity. A study of Turkey during 1990 to 2018 utilized NARDL model to look into the association between CO2 intensity and the quality of environment. It found that reduction in CO2 intensity causes reduction in environmental decay (Abbasi, Kirikkaleli, and Altuntas, 2022). In a study conducted by El Anshasy and Katsaiti (2014) utilized data between 1972 to 2010 for 131 nations. It confirmed that the energy efficiency has an inherent potential to cut down CO2 emission in the long-run. Sultana et al. (2022) examined the correlation between the level of environmental pollution and energy intensity using Panel Autoregressive Distributive Lag (PARDL) for five South Asian countries from 1974 to 2017. It demonstrated that an increase in energy intensity intensifies environmental degradation. In a similar study conducted for G7 countries between 1997 to 2015 by Chu and Le (2022), established that energy intensity amplifies environmental pollution. The study also highlighted the significance of renewable energy and energy efficiency.

In several research explorations conducted in Ireland, UK, and Finland found the increased capacity of energy efficient fuels in mitigating climate change to meet the target of carbon neutrality. Another study by Lin and Ahmad (2017) using Logarithmic Mean Divisia Index (LMDI) method conducted in Pakistan during a period of 1990-2014. The study unfurls various implications from the establishment of relationship between carbon emission, GDP per capita, population, carbon intensity, and energy intensity. It reveals a positive impact of population and GDP per capita on CO2 emission, whereas reduction in CO2 emission level causes an increase in carbon intensity. Similar kinds of results were accorded from several other studies as well. After reviewing an extensive amount of literature relevant to the topic, it is quite pertinent to bring forth the gaps observed. However, a plethora of empirical studies have indulged into the analysis of variables under study using different methodologies in distinct time frame from across the nations, still more literature is required especially, in India's case. Furthermore, a lot number of studies lack consensus in analysing relationship between energy intensity, carbon intensity, renewable energy consumption, and CO2 emission. Also, advance estimation techniques are required for such analyses particularly in India context.

4. Data and Methodology

The study is entirely based on secondary time series data from 2000 to 2021. Table 1 explicitly shows the description of variables chosen for analysis in the study. MS Excel and Eviews are utilized for the analysis and graphical representation of data sets. The study is descriptive in nature.

5. Results and discussions

The variables selected for the study are transformed into natural logarithmic form to rule out the difference in units of measurement. The variables - carbon intensity, carbon emissions, energy intensity, GDP, renewable energy consumption and renewable electricity generation - are written into logarithmic form as LCI, LCO2, LEI, LGDP, LREC and LREG, respectively.

The descriptive statistics of the variables – LCI, LCO2, LEI, LGDP, LREC and LREG - is shown in Table 2. It is observed that LGDP holds the highest mean value, indicating a larger average return as compared to other variables, while LCI records the lowest mean value. The standard deviation shows the variation in data around mean. It is highest in CO2, whereas it is quite low in carbon intensity. LCI, LCO2, LGDP and LREG shows negative skewness, denoting an asymmetry in the distribution with longer tails towards left, whereas in CEI and LREC, the longer tail is towards the right (Afjal, 2023). Further, the positive value of

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kurtosis across all the variables denotes leptokurtic distribution, which means a 'higher peak' and 'fatter tails' compared to a normal distribution. It simply means that more data values are located in the tails of the distribution rather than around the mean. Further, Jarque-Bera statistic is used to check the normality of the data set. A probability value greater than 0.5 suggests that the data is normally distributed.

Table 3 demonstrates the correlation among the selected variables under study. It shows a mix of positive and negative correlation between the variables.

Variables	Description	Code	Source
Renewable Energy Consumption	Renewable energy consumption (% of total final energy consumption)	REC	WDI
Renewable Electricity Generation	Renewables share of electricity generation	REG	IEA
Carbon Emission	Carbon dioxide (CO2) emissions (total) excluding LULUCF (Mt CO2e)	CE	WDI
Carbon Intensity	Carbon intensity of GDP (kg CO2e per 2021 PPP $)	CI	WDI
Energy Intensity	Energy intensity level of primary energy (MJ/$2017 PPP GDP)	EI	WDI
GDP per capita	GDP per capita, PPP (constant 2021 international $)	GDP	WDI

Table 1 Variables Description Source: Authors' preparation

	LCI	**LCO2**	**LEI**	**LGDP**	**LREC**	**LREG**
Mean	-1.3181	7.4354	1.6737	8.5364	3.6420	2.8041
Median	-1.2790	7.4934	1.6761	8.5474	3.5877	2.8332
Maximum	-1.1919	7.8529	1.9473	8.9934	3.8523	3.0445
Minimum	-1.4986	6.9034	1.4375	8.0390	3.4812	2.4849
Std. Dev.	0.0899	0.3395	0.1595	0.3199	0.1344	0.1478
Skewness	-0.8050	-0.2846	0.0455	-0.0687	0.3954	-0.4240
Kurtosis	2.4968	1.5719	1.9293	1.6959	1.5285	2.7340
Jarque-Bera	2.6080	2.1665	1.0584	1.5762	2.5582	0.7241
Probability	0.2714	0.3385	0.5891	0.4547	0.2783	0.6962
Sum	-28.9990	163.5789	36.8206	187.8004	80.1246	61.6904
Sum Sq. Dev.	0.1695	2.4206	0.5343	2.1494	0.3791	0.4587
Observations	22	22	22	22	22	22

Table 2 Descriptive Statistics. Source: Authors' Calculation.

	LCI	**LCO2**	**LEI**	**LREC**	**LGDP**	**LREG**
LCI	1	-0.7305	0.8809	0.5898	-0.8265	-0.7271
LCO2	-0.7305	1	-0.9630	-0.9740	0.9879	0.7076
LEI	0.8809	-0.9630	1	0.8938	-0.9906	-0.7837
LREC	0.5898	-0.9740	0.8938	1	-0.9355	-0.6095
LGDP	-0.8265	0.9879	-0.9906	-0.9355	1	0.7408
LREG	-0.7271	0.7076	-0.7837	-0.6095	0.7408	1

Table 3 Correlation. Source: Authors' Calculation

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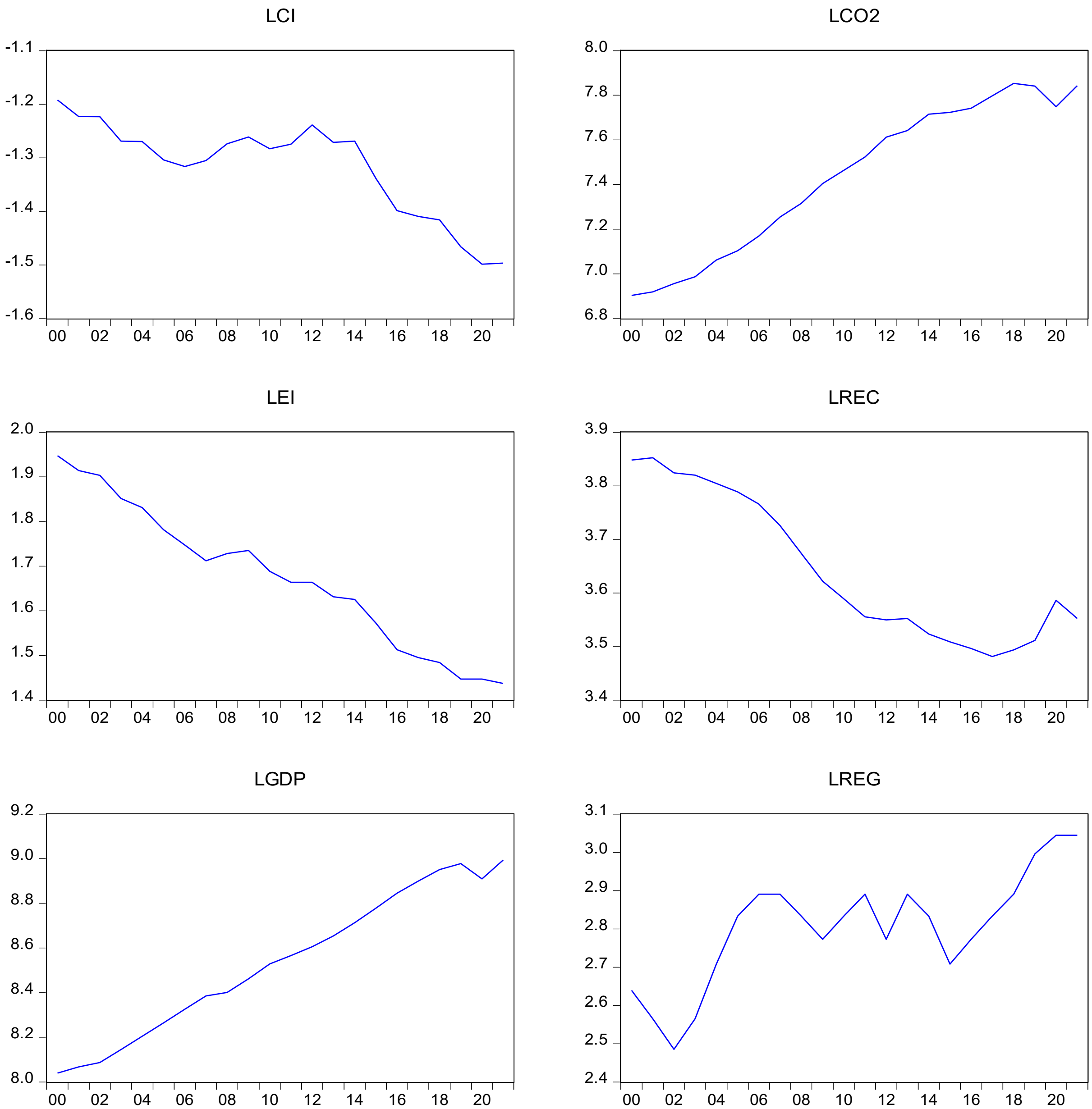

Figure 4 Trends in variables; Source: Authors' preparation

Figure 4 demonstrates the trends in variables over the period of 2000 to 2021. The decline in carbon intensity and energy intensity signifies enhanced energy efficiency. Over the period of 2000 to 2019, there has been continuous increase in economic output and carbon emissions with a quick drop in 2020 and a V-shaped pickup in 2021. Further, renewable energy consumption and renewable electricity generation resembles a continuous fluctuation during the period of study. REC as a percentage of total energy consumption has declined since 2000 with a gradual rise from 2017. However, REG demonstrates a quick increase since 2002 with sudden fluctuations from 2006 and again a sharp rise since 2015. REG accounts for 21 percent in 2020 and 2021 as a share in total electricity generation.

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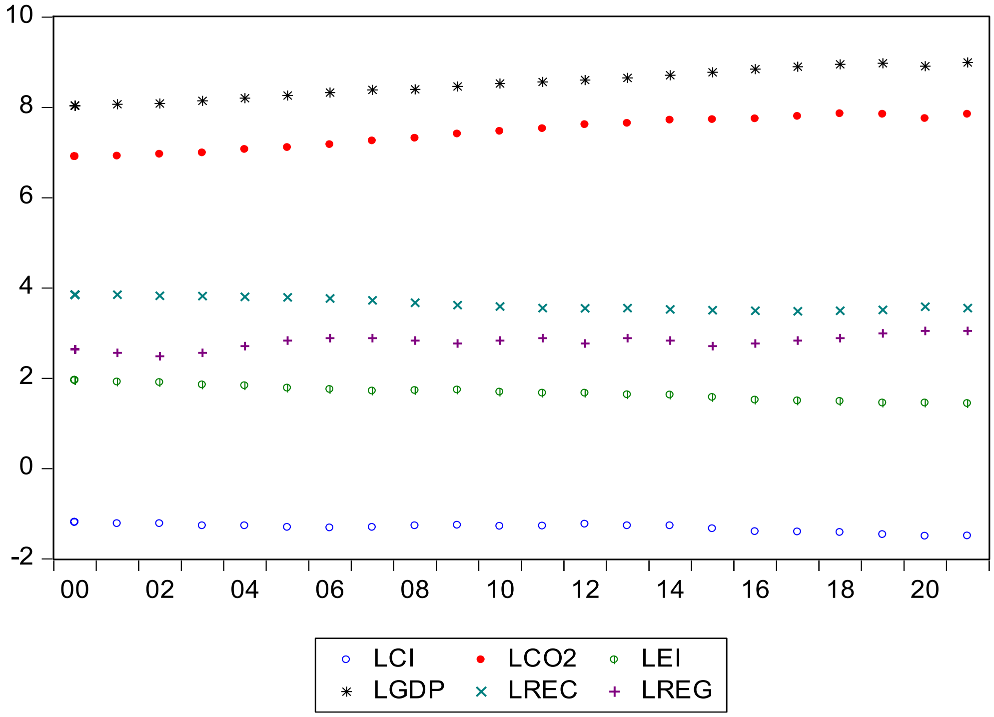

Figure 5 Stacked Dot Plot of variables; Source: Authors' preparation

The figure 5 demonstrates a stacked dot plot of all the variables under study over the period of 21 years. With the increase in GDP over the years and rising carbon emissions and energy demand, share of renewable energy accounts for a gradual rise with certain fluctuations. Renewable electricity generation resembles a continuous rise since 2015. It is quite clear that the percentage of renewable electricity production is more or less increasing which signals a greener electricity. Further, the enhanced energy efficiency discernible from gradual decline in both carbon intensity and energy intensity signifies a transition towards clean energy goal set out under SDG-7.

5. Conclusion & Policy Implications

The paper attempted to look into the potential of energy efficiency in India in its drive towards carbon neutrality. The study digs deeper into the analysis of renewable energy parameters for the period spanning from 2000 to 2021. It reveals certain ups and downs in REC and REG, a continuous increase in carbon emission and GDP, and a reduction in energy intensity and carbon intensity over the period of 2000 to 2021. Energy intensity and carbon intensity reflects an increase in energy efficiency. An increase in the proportion of renewable energy consumption and more sustainable practices can lead to reduction in climatic risks. Production of more green and clean electricity will result into reduction in carbon intensity. Increased efficiency under goal 7 of SDGs resemble clean and affordable energy. The paper paves a way for policymakers to implement more sustainable use of non-fossilized energy along with the installation of newer renewable energy tools and technologies to provide better incentives for its development. The paper demonstrates a broader scope of study and opens up avenues for further research in the area.

Data Availability Statement:

All data is available on world development indicator (WDI) and international energy agency (IEA) database.

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