Investigating The Environmental Kuznets Curve (Ekc) Hypothesis For India: Does India Have Enough Capital To Supplement Renewable Energy Usage In The Correction of Carbon Emissions?

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13 **Abstract**

14 India's sustainable development goals consist of higher economic growth through
15 strengthening of the manufacturing sector on the one hand and ambitious carbon emission
16 reduction plans through increased renewables on the other. This paper studies the dynamic
17 association between CO₂ emissions, economic growth, renewable energy (RE) consumption
18 and gross capital formation and tests for the existence of Environmental Kuznets Curve (EKC)
19 hypothesis for India over the time period 1970-2018. It also tries to see if there is any possible
20 conflict between the economic and energy goals using an interaction term between RE
21 consumption and gross capital formation. The empirical results not only confirm long run
22 relationship among the underlying variables but also indicate an 'N' shaped EKC in the long
23 run for India indicating a departure from the traditional inverted U-shaped EKC hypothesis.
24 RE consumption is found to reduce emissions, whereas gross capital formation and the
25 interaction term between RE consumption and gross capital formation are found to raise
26 emissions in the long run. The study concludes that India needs to align its economic policy of
27 'Make in India' with its energy policy so that investments under the former facilitate extensive
28 penetration, adaptation and usage of renewable energy. A policy dichotomy between the two
29 goals may defeat India's INDC objective of drastic reduction in CO₂ emissions through
30 increased renewables by 2030.

Keywords: Renewable energy (RE) consumption, economic growth, CO₂ emissions, EKC, ARDL, energy policy, India.

1. Introduction

India being one of the fastest-developing economies of the world, increasing trend of CO₂ emissions is a challenge while designing sustainable energy policy framework for India which can strike a balance between economic competitiveness, energy security and environmental protection. The anthropogenic CO₂ emissions from fuel combustion of India was estimated 2162 Mt in the year 2017, mainly attributed to the rapid expansion of energy sector and industrial sector contributing 50.9% and 26.1% of total of total CO₂ emissions respectively (IEA, 2020). Extensive research has been done till date to identify the pattern of relationship between economic growth and environmental degradation well known as Environmental Kuznets curve hypothesis based on the inverted U shape relationship between economic development and income inequality established by Nobel winner economist Simon Kuznets.

The Government of India has undertaken various policy measures to control its greenhouse gas emissions by 2030 as an integral part of its Intended Nationally Determined Contributions (INDC) commitment at the conclusion of UNFCCC Paris agreement 2015 through reduction of greenhouse emissions intensity of GDP by 33-35% by 2030 from 2005 by enhancing share of renewables by 40% in installed capacity with the help of technology transfer and forming green climate fund and aiming for additional carbon sink of 2.5-3 billion tonnes of CO₂ equivalent with the aid of forestation and plantation of tree (MoEFCC, 2015). Consequently, India's energy sector is also undergoing a transient shift towards low carbon energy pathway through enhanced capacity addition of renewables in national energy portfolio not only as a precautionary measure of air quality deterioration but also to meet the energy aspirations of 1.4 billion citizens of India. India's per capita renewable energy consumption has increased by 2.5

55 times over the year 1970 to 2018. As of 2019, India had around 118 GW renewable energy
56 (RE) generation capacity with aim to expand to 175 GW by 2022 (Energy Statistics, 2020).
57 India is the first country in the world to establish an entire ministry for promotion of renewable
58 energy and held second position in 2017 “Renewable Energy Attractiveness Index” released
59 by Ernst & Young. At the same time, Government of India took alternate action plans to
60 electrify all the census villages by 2018 and to provide 24 x 7 access to electricity by 2022
61 (NITI Aayog, 2017) to ensure 100% energy security as a supplement of SDG-7. Despite the
62 Government’s ambitious target, only 86% rural electrification was witnessed in 2018, while
63 the Ministry of Power proclaimed a power surplus of 174GW peak energy demand in the same
64 timeline (Ministry of Power, 2018). One of the reasons behind the scarcity in power supply to
65 the remaining 14% of the rural households lies in the lack of capital investment required by
66 DISCOMS to procure sufficient amount of power to serve the deprived rural households. So,
67 capital formation can be viewed as one of the major impediments in the objective of 100%
68 electrification for India and hence accelerating the economic engine of the country. Penetration
69 of renewable energy in the economy needs enormous capital along the entire innovation chain
70 of renewable energy use, starting from research and development in technology development
71 to setting up of full scale power plants (Mazzucato and Semienluk, 2018). Most of the energy
72 related capital stock and investments of the Indian economy currently is aligned toward fossil
73 fuel use which is the primary source of energy for functioning of the economy. Any attempt to
74 make a shift toward renewables to substitute fossil fuel consumption would require not only
75 investment in generation but also in entire restructuring of energy usage in the economy
76 through investment in developing transmission and distribution system and energy storage on
77 the supply side and clean energy applications and usage on the demand side (WEF, 2019).
78 Ministry of New and Renewable Energy (MNRE) has invested around USD 62.52 million over
79 2012-2017 and aiming to double the budget in the current three-year plan period. India has also

received around USD 6.84 billion FDI inflows in renewable sector over the period 2000-2018 and expecting to attract around USD 80 billion over the period 2018-22 through foreign and domestic investors (Majid, 2020). However, all of this investment is primarily aimed at increasing generation capacity and it is uncertain if investment of this magnitude would be sufficient to push usage of renewables to substitute fossil fuels in the future. IEEFA (2019) reports that India's target of 523GW of renewable energy in 2030 calls for investments to the tune of \$500to \$700 billion in renewable energy sector and grid network over the next decade. The purpose of this study is to examine the existence of an Environmental Kuznets Curve for India and scrutinizing the long run dynamics between economic growth, CO₂ emissions, RE consumption, gross capital formation and the interaction effect between RE consumption and gross capital formation. Increasing economic activity and rise in share of manufacturing is likely to be associated with increased capital formation, the impact of which on emission is uncertain. Also, adoption of RE into the economy needs adequate capital infusion to support the adoption of a RE consumption path. Hence, we have included an interaction term to test the composite impact of capital increase in the economy along with increased renewable energy usage.

The structure of the paper is organized as follows: Section 2 provides literature reviews encompassing EKC with special reference to India, Section 3 provides theoretical underpinning and econometric specifications, Section 4 describes data, Section 5 outlines the methodology, Section 6 discusses the results, and Section 7 follows with conclusion and policy implications.

2. Literature Review

The empirical investigations of growth-energy-emission nexus has been receiving wide attention over the last few decades among the environmental economists and policy scientists and has become one of the prime areas of theoretical and empirical research in the field of

environmental economics. The existing vast body of literature exploring the relationship between energy consumption, economic growth and environmental degradation can broadly be categorized into three key strands of research.

The first stream of research examines the relationship between economic growth and energy consumption. The causal linkage between economic growth and energy consumption can be classified into four key hypotheses. The first hypothesis is identified as growth hypothesis that studies the existence of long run unidirectional causality from energy consumption to economic growth (Asafu-Adjaye, 2000; Soytas and Sari, 2003; Apergis and Payne, 2009a; Iyke, 2015; Shastri et al., 2020). The second is the conservation hypothesis that shows unidirectional causality from economic growth to energy consumption (Al-Iriani, 2005; Akinlo, 2008; Tugcu et al., 2012; Bildirci, 2013; Furuoka, 2017). The third hypothesis is well known as feedback hypothesis that confirms the bidirectional causal relationship between energy consumption and economic growth (Moubarak, 2014; Apergis and Payne, 2009b; Fuinhas and Marques, 2012; Belke et al., 2011; Nazlioglu et al., 2014). Finally, the neutrality hypothesis confirms absence of any causal linkage between energy consumption and economic growth (Asghar, 2008; Cheng, 1997; Tugcu et al., 2012).

The second strand of research focuses on the dynamic relationship between economic growth and environmental degradation which is popular as ‘Environmental Kuznets Curve’ (EKC) hypothesis. There is plethora of literature examining the EKC hypothesis in region specific/ country specific/ multiple country studies utilizing different indicators of air quality assessments like CO₂, SO₂, NO_x, PM_{2.5}, etc. The relationship between environment degradation and economic growth was initially captured as a inverted U shaped curve implying that in an economy, emissions would rise with economic growth and reach a peak, after which it would start declining with further growth in national income. Some of the studies which show inverted U shape EKC include Halicioglu (2009), He and Richard (2010), Ahmed and Long

(2012), Destek and Sarkodie (2019), Nasir and Rehman (2011), Saboori et al. (2012), Wang et al. (2016), Ding et al. (2019), Apergies and Ozturk (2015), Jebli et al. (2016), Ahmed et al. (2016), Pata (2018), Işık et al. (2019), Bekun et al. (2019). Later, some studies have also estimated the existence of an N shaped EKC, like Akbostancı et al. (2009), Menéndez et al. (2014), Özokcu and Özdemir (2017), Pal and Mitra (2017), Allard et al. (2018), Churchill et al. (2018). Dinda (2004), Al-Mulali et al. (2015), and Sarkodie and Strezov (2019).

Finally, the third stream of research has taken the opportunity to merge the first two approaches exploring the dynamic relationship between economic growth, energy consumption (both aggregate and disaggregate level) and environmental degradation. These studies include Ang (2007), Soytas et al. (2007), Ghosh (2010), Sebri and Ben- Salha (2014), Jebli and Youssef (2017), Appiah (2018), Gorus and Aydin (2019).

There are some studies providing insights to the existence of EKC hypothesis for India. However, the findings related to existence of EKC hypothesis for India remains inconclusive and the shape of the curve is found to be mixture of both inverted ‘U’ shape and ‘N’ shape. Jayanthakumaran et al. (2012) examined the EKC hypothesis for both India and China for the period 1971-2007 by employing ARDL methodology and provided the evidence of inverted ‘U’ shape EKC hypothesis for both of the countries although the result of F test of ARDL bounds test of co-integration was found to be inconclusive for both the countries. The findings of this study suggest that while 1% increase of per capita GDP is associated with 1.62% increase of per capita CO₂ emissions for China, the effect is found to be more detrimental to India resulting in 3.8 times more per capita CO₂ emissions for India compared to China. Tiwari et al. (2013) confirmed the existence of inverted ‘U’ shape EKC hypothesis for India in both short run and long run while examining the dynamic relationship between coal consumption, CO₂ emissions, economic growth and trade openness for the period of 1966-2009 by employing ARDL methodology. The empirical findings of this study strongly suggest the evidence of

feedback hypothesis between CO₂ emissions and economic growth in short run and long run elasticity of per capita coal consumption and per capita trade openness was estimated 0.844 and 0.086 respectively. Kanjilal and Ghosh (2013) established regime shift co-integration between CO₂ emissions, economic growth, energy use and trade openness for the annual data of 1971-2008 by utilizing regime shift co-integration methodology. This study supported the existence of inverted ‘U’ shape EKC hypothesis for India and concluded that per capita CO₂ emission is highly elastic with respect to both per capita income and energy consumption. Sinha and Shahbaz (2018) found inverted ‘U’ shape EKC for India while examining long run relationship between CO₂ emissions, economic growth, renewable energy generation, electric power consumption and international trade for the data period of 1971-2015. While various studies provided evidence of inverted ‘U’ shape relationship between economic growth and carbon dioxide emissions for India, Pal and Mitra (2017) provided empirical evidence of existence of N shape EKC for India for the data period 1971-2012 while performing a comparative analysis between India and China in the context of EKC framework. This study revealed that N shape phenomenon was found to be more noticeable for India than China. Alam and Adil (2019) found long run relationship between economic growth, carbon emission, primary energy supply, trade openness and financial development for India for 1971-2016 although the empirical evidence does not support the holding of EKC hypothesis for India.

3. Theoretical framework and econometric specification

The dynamic association between environmental pollution and economic growth is well-known as environmental Kuznets curve hypothesis¹. According to this hypothesis, pollution increases rapidly with increase in per capita income as at this stage policy makers are more

¹¹ The hypothesis derives its name from a similar hypothesis between income and inequality proposed by Kuznets (1955)

concerned with job creation and income over paying heed to the environmental consequences. As economy expands with higher level of per capita income and more usage of environment friendly energy efficient technology, pollution level starts decreasing as people become more conscious about environment and start demanding cleaner environment and energy consumption pattern shifts toward modern cleaner energy sources. High income is also able to afford more efficient and cleaner technology. This relationship between economic growth and pollution follows an inverted U shaped curve called Environmental Kuznets Curve (Dasgupta et al., 2002; Dinda, 2004; Nasir and Rehman, 2011; Saboori et al., 2012). There are some evidences of N shaped environmental Kuznets curve that depicts that pollution level increases rapidly in the initial phase with the increase of per capita income, after reaching a peak, pollution level then starts falling with increase of per capita income. With further expansion of economic activity, pollution level is again found to exhibit steady increase. (Pal and Mitra, 2017; Churchill et al., 2018; Allard et al., 2018).

In this study, we apply the EKC framework to test the relationship between CO₂ emissions and per capita income in the long run and investigating the existence of environmental Kuznets curve hypothesis for India. Also, it is proposed that there is a dynamic linkage between renewable energy consumption and CO₂ emissions as renewable energy alternatives are becoming important in energy portfolio of most countries and emerging as one of the major contributors towards reduction of CO₂ emissions (Dong et al., 2017; Bilgili et al., 2016).

Additionally, gross capital formation has also been considered as a control variable in the EKC framework since capital formation may improve or worsen emissions in an economy. Capital formation through machinery and infrastructure for which energy usage is complementary will raise emissions (Rahman and Ahmad, 2019). Capital formation will be beneficial to the environment if capital creation is in environment friendly and energy conserving assets such as software, computer, service industry and energy efficient machineries that boost energy

efficiency while reducing energy intensity (Bekun et al., 2019). The estimation of EKC with the presence of renewable energy consumption and gross capital formation can be specified as follows:

$$C_t = f(Y_t, Y_t^2, Y_t^3, REC_t, GCF_t, REC_t \times GCF_t) \quad (1)$$

The above specification is converted into log-linear form as log-linear estimation can produce more efficient and consistent estimates as compared to linear model (Lau et al., 2014) and can be written as follows:

$$\ln C_t = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln Y_t^2 + \alpha_3 \ln Y_t^3 + \alpha_4 \ln REC_t + \alpha_5 \ln GCF_t + \alpha_6 (\ln REC_t \times \ln GCF_t) + \varepsilon_t \quad (2)$$

Where C_t represents CO₂ emission per capita, Y_t captures per capita real GDP, Y_t^2 denotes square of real GDP per capita, Y_t^3 represents cube of real GDP per capita, REC_t stands for renewable energy consumption per capita, GCF_t captures gross capital formation per capita, $(REC_t \times GCF_t)$ indicates the interaction term between renewable energy consumption per capita and gross capital formation per capita to allow for indirect effect and ε_t is the random error term.

If theoretically inverted U shaped Environmental Kuznets curve hypothesis holds true, then expected sign of α_1 should be positive and statistically significant whereas expected sign of α_2 should be negative and statistically significant. A positive and statistically significant value of α_3 signals the existence of N shaped EKC. The expected value of $\alpha_4 < 0$. The sign of α_5 can be either positive or negative. Sign of α_6 is ambiguous depending on the strength of each of the effects of both renewable energy consumption per capita and gross capital formation per capita. If gross capital formation in the economy has been conducive to RE use, then the coefficient of the interaction term can be expected to be negative. On the other hand, if the capital addition

to the economy has mostly been complementary to increased overall fuel use in the economy, the interaction term would have a positive coefficient.

4. Data

The present study uses forty-nine years of annual time series data spanning from 1970-2018 for CO₂ emissions, population, GDP, renewable energy consumption and gross capital formation. Population data is used to convert the variables into per capita form. The multivariate framework for the present study includes the CO₂ emissions per capita measured in metric tons, real GDP per capita as a proxy of economic well being measured in constant 2010 US\$, per capita gross capital formation measured in constant LCU and per capita renewable energy consumption measured in tonnes of oil equivalent. Renewable energy consumption comprises of renewable electricity consumption from hydro, solar, wind, biomass, geothermal and other types of renewable energy sources. The data for real GDP, population and gross capital formation are taken from World Bank and data for all sources of renewable energy consumption are taken from BP Statistical Review of World Energy to compute the total renewable energy consumption. The data for CO₂ emissions has been sourced from BP Statistical Review of World Energy. As the variables are in different dimensions, natural logarithmic transformation is essential for standardization purpose and to induce stationarity in the series of variables.

5. Methodology

The prime motivation behind this study is to empirically explore the relationship between CO₂ emissions and economic growth for India explicitly in the presence of renewable energy consumption, gross capital formation and interaction effect between renewable energy consumption and gross capital formation in the environmental Kuznets curve framework following the existing empirical investigations for India (Tiwari et al., 2013; Pal and Mitra,

2017; Rana and Sharma, 2018; Sinha and Shahbaz, 2018; Alam and Adil, 2019). The comprehensive econometric methodology in our present study will embrace a four-stage process. First, the order of integration of the variables will be tested using the traditional unit root test approach (i.e., ADF and PP). Second, the long run relationship among the variables will be investigated through ARDL bounds test co-integration technique and the long run coefficient estimates will be determined through the estimation of ARDL. Third, the robustness check of the ARDL bounds test co-integration technique will be validated through Bayer and Hanck's (2013) combined co-integration analysis and the robustness of the estimations of the ARDL model will be validated through the DOLS, FMOLS and CCR method. Finally, the VECM Granger causality test is employed to explore the causal relationship among the underlying variables in the present study. The detailed econometric approach for the present study is outlined in the following sub-section 5.1-5.4 and depicted through a flowchart in Figure 1.

Figure 1: Flowchart of the Econometric model analysis

5.1 Unit root test

The unit root test is done to check the stationary properties and to identify the order of integration of the variables under study. Unit root test of any time series data is essential to avoid spurious regression. Different co-integration techniques require prerequisite necessities of different order of integration of the series of variables i.e., Johansen-Juselius co-integration method demands for all the variables to be integrated of order $I(1)$ (Gunes, 2009; Nasir and Rehman, 2011; Rej and Nag, 2018) and Autoregressive distributed lag model (ARDL) requires all the variables to be integrated of $I(1)$ or mixture of both $I(1)/I(0)$ but not to be integrated of $I(2)$ (Pal and Mitra, 2017; Mahmood et al., 2020).

In the present study, Augmented Dickey-Fuller (ADF) test and Phillips Perron (PP) unit root test are done in both level and first difference to find out the degree of integration of the variables under study. Many econometric studies have emphasized the advantage of Phillips Perron (PP) test over ADF test having high power to reject the null hypothesis of having unit root in the presence of structural breaks (Hamdi et al., 2015), correction of the serial correlation and time dependent heteroscedasticity in the lagged difference terms of the variables under study (Thangavelu and Rajaguru, 2004).

5.2 Co- integration: ARDL Bounds testing approach

There is plethora of literature over the past few decades which have proposed various popular residual based econometric co-integration techniques to establish long run relationship among variables like Granger (1981), Engle-Granger (1987), Johansen-Juselius (1990), Phillips and Hansen (1990) fully modified OLS estimation, Johansen (1996) and ARDL bound testing approach (2001). The autoregressive distributive lag (ARDL) bound testing approach proposed by Pesaran, Shin and Smith (2001) is preferred over other existing co-integration techniques due to the following advantages: firstly, ARDL is most appropriate for smaller sample size.

Secondly, ARDL approach can be estimated irrespective of if the variables are stationary at level, integrated at first differences, or fractionally integrated. Thirdly, it can efficiently address the possible endogeneity issues of the explanatory variables in the model. Fourthly, consistency achieved in the estimations of both short run and long run parameters and finally, the ARDL approach allows different optimal lags associated with each of the variables which is not taken care in classical co-integration techniques.

In view of the above benefits and dealing with a data of smaller sample size of only 49 annual observations (1970-2018), we have employed the autoregressive distributive lag (ARDL) bound testing approach in equation (3) as follows:

$$\begin{aligned} \Delta \ln C_t = & \beta_0 + \beta_1 t + \beta_2 \ln C_{t-1} + \beta_3 \ln Y_{t-1} + \beta_4 \ln Y_{t-1}^2 + \beta_5 \ln Y_{t-1}^3 + \beta_6 \ln REC_{t-1} + \\ & \beta_7 \ln GCF_{t-1} + \beta_8 (\ln REC \times \ln GCF_{t-1}) + \sum_{j=1}^{k_1} \lambda_{1j} \Delta \ln C_{t-j} + \sum_{j=0}^{k_2} \lambda_{2j} \Delta \ln Y_{t-j} + \\ & \sum_{j=0}^{k_3} \lambda_{3j} \Delta \ln Y_{t-j}^2 + \sum_{j=0}^{k_4} \lambda_{4j} \Delta \ln Y_{t-j}^3 + \sum_{j=0}^{k_5} \lambda_{5j} \Delta \ln REC_{t-j} + \sum_{j=0}^{k_6} \lambda_{6j} \Delta \ln GCF_{t-j} + \\ & \sum_{j=0}^{k_7} \lambda_{7j} \Delta (\ln REC \times \ln GCF_{t-j}) + \varepsilon_{1t} \end{aligned} \quad (3)$$

Where Δ is the first difference operator, β_0 is the constant term, β_1 is the coefficient of trend component, $\beta_2 - \beta_8$ are long run coefficients, $\lambda_{1j} - \lambda_{7j}$ are short run coefficients, $k_1 - k_7$ are the lag lengths associated with each variable, ε_{1t} is noise error term and nomenclature of variables is identical to the variables as defined in equation (2).

The ARDL bound test procedure can be done with the following steps: The first step is to choose the criteria for optimal lag length selection in the model. The Akaike Information Criteria (AIC) can be employed for optimal lag length selection. The second step is to find the existence of co-integration among the variables through administering F-statistics. The null hypothesis of no co-integration, $H_0: \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$ can be tested against the alternative hypothesis, $H_1: \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq 0$. Two sets of critical F statistics were

computed for larger sample size by Pesaran and Shin (1998) and Pesaran et al. (2001). One set of critical values (lower bounds) consider that all the concerned variables under study are stationary at level, whereas another set of critical values (upper bounds) consider that underlying variables are stationary at first difference. Narayan (2005) debated that critical values designed by Pesaran et al. (2001) may mislead the results for smaller sample size and consequently another two sets of critical F statistics, upper critical bounds and lower critical bounds for smaller sample size ranging from 30 to 80 sample observations were computed by Narayan (2005). In the ARDL bound testing framework, three possible situation can be derived after the estimation of ARDL model. The first is the co-integration situation if the computed F statistics is greater than the upper critical bounds value, then the null hypothesis of no co-integration can be rejected. The second possibility is the no co-integration situation when the estimated F statistics falls below the lower critical bounds value, then the null hypothesis of no co-integration cannot be rejected. Finally inconclusive situation is possible if the computed F statistics falls within upper and lower critical bounds value. In the present study, critical values designed by both Pesaran et al. (2001) and Narayan (2005) are utilized due to the small sample size. Further, the stability of ARDL bound testing can be performed through CUSUM and CUSUMQ test.

5.3 Robustness test

The robustness check of the ARDL bounds test of co-integration has been done with Bayer and Hanck's (2013) combined co-integration analysis and the robustness of the estimations of the ARDL model will be validated through the DOLS, FMOLS and CCR method.

5.3.1 Bayer and Hanck (2013) combined co-integration analysis

The findings from the traditional co-integration models are often biased because of the time-series properties of the variables and insufficient sample size. Bayer and Hanck (2013) proposed the Bayer-Hanck combined test for non-co-integration, which overcomes the

limitations of the traditional co-integration models while providing the efficient estimations in the presence of inadequate sample size. Furthermore, this procedure integrates the results of various traditional co-integration models and generalizes the results using a Fisher statistic based on the following specification:

$$EG - J = -2[\ln(P(EG)) + \ln(P(J))]$$
 (4)

$$EG - J - B - BDM = -2[\ln(P(EG)) + \ln(P(J)) + \ln(P(BO)) + \ln(P(BDM))]$$
 (5)

Where, P denotes the probability value of each test; EG-J denotes the p values of the Fisher statistic for the combined Engle-Granger (EG) and Johansen (J) tests; while EG-J-B-BDM denotes the p values of the Fisher statistic for the combined (Engle and Granger 1987; Johansen 1988; Boswijk 1994; Banerjee et al. 1998) tests. The statistical significance of the Fisher statistic is used to refute the null hypothesis of no co-integration.

5.3.2 DOLS, FMOLS and CCR method

Phillips and Hansen (1990) devised FMOLS to provide optimal estimates of co-integration regressions. Kernel estimators of the nuisance parameters that alter the asymptotic distribution of OLS estimator are used in this method. This technique adapts OLS to account for serial correlation effects, and checks for the endogeneity in the regressors that arise from the presence of co-integrating relationships in order to attain asymptotic efficiency.

Canonical Cointegrating Regression (CCR) designed by Park (1992) utilizes single cointegration equation to eliminate the long run dependence between the cointegration equation and the stochastic regressors innovations. CCR also eradicates the endogeneity caused by the long run correlation of cointegrating equation errors and the stochastic regressors innovations.

5.4 VECM Granger causality test

If the variables are integrated of I(1) and existence of long run relationship can be confirmed from the estimations of ARDL bound testing procedure, we can move ahead to perform VECM Granger causality test to examine the short run dynamic causal relationship among the underlying variables. The VECM model can be written in equations (6 - 12) as follows:

$$\begin{aligned} \Delta \ln C_t = & \phi_0 + \sum_{i=1}^j \phi_{1i} \Delta \ln C_{t-i} + \sum_{i=1}^j \phi_{2i} \Delta \ln Y_{t-i} + \sum_{i=1}^j \phi_{3i} \Delta \ln Y_{t-i}^2 + \\ & \sum_{i=1}^j \phi_{4i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \phi_{5i} \Delta \ln REC_{t-i} + \sum_{i=1}^j \phi_{6i} \Delta \ln GCF_{t-i} + \sum_{i=1}^j \phi_{7i} \Delta (\ln REC \times \\ & \ln GCF_{t-i}) + \Psi_1 ECT_{t-1} + \mu_{1t} \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta \ln Y_t = & \theta_0 + \sum_{i=1}^j \theta_{1i} \Delta \ln Y_{t-i} + \sum_{i=1}^j \theta_{2i} \Delta \ln C_{t-i} + \sum_{i=1}^j \theta_{3i} \Delta \ln Y_{t-i}^2 + \\ & \sum_{i=1}^j \theta_{4i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \theta_{5i} \Delta \ln REC_{t-i} + \sum_{i=1}^j \theta_{6i} \Delta \ln GCF_{t-i} + \sum_{i=1}^j \theta_{7i} \Delta (\ln REC \times \\ & \ln GCF_{t-i}) + \Psi_2 ECT_{t-1} + \mu_{2t} \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta \ln Y_t^2 = & \gamma_0 + \sum_{i=1}^j \gamma_{1i} \Delta \ln Y_{t-i}^2 + \sum_{i=1}^j \gamma_{2i} \Delta \ln C_{t-i} + \sum_{i=1}^j \gamma_{3i} \Delta \ln Y_{t-i} + \\ & \sum_{i=1}^j \gamma_{4i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \gamma_{5i} \Delta \ln REC_{t-i} + \sum_{i=1}^j \gamma_{6i} \Delta \ln GCF_{t-i} + \sum_{i=1}^j \gamma_{7i} \Delta (\ln REC \times \\ & \ln GCF_{t-i}) + \Psi_3 ECT_{t-1} + \mu_{3t} \end{aligned} \quad (8)$$

$$\begin{aligned} \Delta \ln Y_t^3 = & \pi_0 + \sum_{i=1}^j \pi_{1i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \pi_{2i} \Delta \ln C_{t-i} + \sum_{i=1}^j \pi_{3i} \Delta \ln Y_{t-i} + \\ & \sum_{i=1}^j \pi_{4i} \Delta \ln Y_{t-i}^2 + \sum_{i=1}^j \pi_{5i} \Delta \ln REC_{t-i} + \sum_{i=1}^j \pi_{6i} \Delta \ln GCF_{t-i} + \sum_{i=1}^j \pi_{7i} \Delta (\ln REC \times \\ & \ln GCF_{t-i}) + \Psi_4 ECT_{t-1} + \mu_{4t} \end{aligned} \quad (9)$$

$$\begin{aligned} \Delta \ln REC_t = & \sigma_0 + \sum_{i=1}^j \sigma_{1i} \Delta \ln REC_{t-i} + \sum_{i=1}^j \sigma_{2i} \Delta \ln C_{t-i} + \sum_{i=1}^j \sigma_{3i} \Delta \ln Y_{t-i} + \\ & \sum_{i=1}^j \sigma_{4i} \Delta \ln Y_{t-i}^2 + \sum_{i=1}^j \sigma_{5i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \sigma_{6i} \Delta \ln GCF_{t-i} + \sum_{i=1}^j \sigma_{7i} \Delta (\ln REC \times \\ & \ln GCF_{t-i}) + \Psi_5 ECT_{t-1} + \mu_{5t} \end{aligned} \quad (10)$$

$$\begin{aligned}
416 \quad \Delta \ln GCF_t = & \varphi_0 + \sum_{i=1}^j \varphi_{1i} \Delta \ln GCF_{t-i} + \sum_{i=1}^j \varphi_{2i} \Delta \ln C_{t-i} + \sum_{i=1}^j \varphi_{3i} \Delta \ln Y_{t-i} + \\
417 \quad & \sum_{i=1}^j \varphi_{4i} \Delta \ln Y_{t-i}^2 + \sum_{i=1}^j \varphi_{5i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \varphi_{6i} \Delta \ln REC_{t-i} + \sum_{i=1}^j \varphi_{7i} \Delta (\ln REC \times \\
418 \quad & \ln GCF_{t-i}) + \Psi_6 ECT_{t-1} + \mu_{6t}
\end{aligned} \tag{11}$$

$$\begin{aligned}
419 \quad \Delta (\ln REC \times \ln GCF_t) = & \Pi_0 + \sum_{i=1}^j \Pi_{1i} \Delta (\ln REC \times \ln GCF_{t-i}) + \sum_{i=1}^j \Pi_{2i} \Delta \ln C_{t-i} + \\
420 \quad & \sum_{i=1}^j \Pi_{3i} \Delta \ln Y_{t-i} + \sum_{i=1}^j \Pi_{4i} \Delta \ln Y_{t-i}^2 + \sum_{i=1}^j \Pi_{5i} \Delta \ln Y_{t-i}^3 + \sum_{i=1}^j \Pi_{6i} \Delta \ln REC_{t-i} + \\
421 \quad & \sum_{i=1}^j \Pi_{7i} \Delta \ln GCF_{t-i} + \Psi_7 ECT_{t-1} + \mu_{7t}
\end{aligned} \tag{12}$$

422 Where Δ is the first difference operator, μ_{it} are white noise error term. ECT_{t-1} is the lagged error
 423 correction term derived from the long run co-integrating relationship, i.e. residuals and
 424 represents the co-integrating vector. Ψ_j represent the adjustment coefficients which measure
 425 the speed of convergence from one period to next period towards short run to long run
 426 equilibrium pathway in response to impulse shocks to the system. ECT_{t-1} should be negative
 427 and statistically significant to validate the long run causal relationship among the underlying
 428 variables in the model. Short run causality can be performed through statistical significance of
 429 joint F statistics of the coefficients of lagged value of exogenous variables. The appropriate
 430 criteria for optimal lag length selection of the restricted VAR model can be done through the
 431 lowest value of AIC, SIC and HQ statistics of the unrestricted VAR model.

432 **6. Results and discussions**

433 **6.1 Unit root test results**

434 Table 1 reports the results of unit root test by employing ADF and PP test to examine the order
 435 of integration among the underlying variables considered for present study. The result tabulated
 436 in Table 1 reveals that, the null hypothesis of unit root test (i.e., non-stationary) is accepted for
 437 all the variables at level. As the variables are converted into first difference, the null hypothesis

is rejected at 1% level of significance. This signals that all the underlying variables are integrated of order I(1).

Table 1: Unit Root test

Variables	Form	ADF (t-statistics)		PP (t-statistics)		Order of Integration
		Intercept	Trend + Intercept	Intercept	Trend + Intercept	
lnC	Level	0.24 (0.972)	-2.41 (0.375)	0.27 (0.974)	-2.55 (0.303)	I(1)
	First Difference	-7.32*** (0.000)	-7.27*** (0.000)	-7.31*** (0.000)	-7.26*** (0.000)	
lnY	Level	4.28 (1.000)	-1.69 (0.741)	5.25 (1.000)	-1.98 (0.596)	I(1)
	First Difference	-5.71*** (0.000)	-8.33*** (0.000)	-5.78*** (0.000)	-11.91*** (0.000)	
lnY ²	Level	5.35 (1.000)	-1.01 (0.933)	7.47 (1.000)	-1.01 (0.932)	I(1)
	First Difference	-5.01*** (0.000)	-8.26*** (0.000)	-5.11*** (0.000)	-12.70*** (0.000)	
lnY ³	Level	6.57 (1.000)	-0.26 (0.989)	9.92 (1.000)	0.30 (0.998)	I(1)
	First Difference	-4.33*** (0.001)	-8.04*** (0.000)	-4.39*** (0.001)	-11.79*** (0.000)	
lnREC	Level	0.28 (0.975)	-1.22 (0.895)	0.21 (0.971)	-1.33 (0.867)	I(1)
	First Difference	-6.22*** (0.000)	-6.36*** (0.000)	-6.22*** (0.000)	-6.36*** (0.000)	
lnGCF	Level	0.72 (0.991)	-2.12 (0.523)	1.05 (0.997)	-1.99 (0.589)	I(1)
	First Difference	-7.77*** (0.000)	-8.03*** (0.000)	-7.74*** (0.000)	-8.18*** (0.000)	
lnREC*lnGCF	Level	-1.56 (0.497)	-1.31 (0.873)	-1.59 (0.479)	-1.23 (0.894)	I(1)
	First Difference	-7.41*** (0.000)	-7.49*** (0.000)	-7.41*** (0.000)	-7.49*** (0.000)	

Note: *** denotes a 1% level of significance, ** denotes a 5% level of significance, * denotes a 10% level of significance.

6.2.1 ARDL bounds test of co-integration result

After confirming the stationarity level of underlying variables, the long run relationship among the underlying variables is explored through ARDL bound testing approach. Akaike Information Criteria (AIC) is utilized to identify the optimal lag order of Eq. (3) as AIC offers reliable and efficient estimates to capture the long run dynamic relationship. After identifying

the optimal lag order, bound test F-statistics is calculated as shown in Table 2. Table 2 reveals that the estimated bound test F-statistics exceeds the upper bound critical values designed by both Pesaran et al. (2001) and Narayan (2005) at 1% level of significance. This strongly suggests that we can reject the null hypothesis of no co-integration against the alternative hypothesis of existence of co-integration among the underlying variables and conforming the existence of long run relationship among CO₂ emissions, economic growth along with its square and cube term, renewable energy consumption, gross capital formation and the interaction term between renewable energy consumption and gross capital formation in case of India over the time period of 1970-2018.

Table 2: Bound F- test for co-integration

Estimated model	$\ln C = f(\ln Y, \ln Y^2, \ln Y^3, \ln REC, \ln GCF, \ln REC * \ln GCF)$			
Bound test F-statistics	8.105***			
Optimal lag length	2, 2, 2, 2, 1, 2, 1			
Pesaran et al. (2001)		Narayan (2005)		
Critical value	Lower bound I(0)	Upper bound I(1)	Lower bound I(0)	Upper bound I(1)
1%	3.6	4.9	4.31	5.881
5%	2.87	4	3.229	4.536
10%	2.53	3.59	2.75	3.944

Note: *** denotes a 1% level of significance, ** denotes a 5% level of significance, * denotes a 10% level of significance.

6.2.2 ARDL results

Table 3 demonstrates the long run coefficient estimates of the underlying variables in the ARDL model of Eq. (3) and reveals that the estimated long run coefficients of per capita GDP, square of per capita GDP and cube of per capita GDP are positive, negative and positive respectively and significant at 1% level of significance. This supports the existence of N-shape EKC for India. Our findings is in the line with the empirical findings of existence of N shaped EKC phenomenon by Pal and Mitra (2017) for India and China, Allard et al. (2018) for lower middle and high income countries, Menéndez et al. (2014) for 27 countries of the European Union.

469 The turnaround points of the N-shaped EKC are found to fall within the sample range and
470 estimated at per capita GDP of USD 643.2 in 1995 and USD 1437.9 in 2012. This indicates
471 that India attained a peak in the EKC at early stage of economic growth where it reached the
472 positive peak in the year 1995 and then reached the lowest point of turnaround in the year 2012.
473 The peak in 1995 and subsequent decline in emissions could have been a result of economic
474 liberalization which led to privatization of major part of the energy sector and adoption of
475 energy efficient technologies and emphasis on conservation as energy demand was also
476 growing. This period also saw the beginning of the information technology boom in India and
477 the gradual shift of the economy towards the service sector. The Indian software sector saw a
478 compound annual growth of about 52% between 1991 and 1996 which seems to have had a
479 direct impact on a downturn in emissions with respect to income in 1995. An upturn in CO₂
480 emissions after 2012 could be attributable to multiple factors like the Government of India
481 policies attracting FDI inflow and infusion of capital investment in the energy intensive
482 manufacturing sector of India. While the world economy was facing a economic slowdown
483 after the financial crisis of 2009, in 2011-12, FDI in India rose 34.4 per cent to \$46.84 billion,
484 compared with \$34.84 billion in the previous year. India's growth rate was forecasted to around
485 9% and India emerged as one of the most favoured destinations for investment. Also, India
486 witnessed a stagnation of service sector as a share of overall GDP during the period 2008-11
487 with 0.03% average annual negative growth rate over the same timeline. This may have also
488 contributed to rising emissions with GDP around 2012.

489 The result tabulated in Table 3 postulates that the impact of renewable energy consumption on
490 CO₂ emissions is found to be negative and significant at 1% level of significance indicating
491 that 1% increase in consumption of renewable energy can reduce the CO₂ emission by 3.7%
492 aiding the INDC commitment undertaken by the Government of India in 2015 to reduce carbon
493 emission intensity of its GDP by 33-35% by 2030 from 2005 through policy measures of

enhancing the share of renewable energy sources to 40% in total installed capacity by 2030 (MoEFCC, 2015).

The impact of gross capital formation on CO₂ emissions is found to be positive and significant at 1% level of significance. 1% increase of gross capital formation is found to be associated with 2.2% increase of CO₂ emissions for India. This finding is similar to Rahman and Ahmad (2018) findings for Pakistan that reported positive and significant impact of gross capital formation on CO₂ emission due to capital investment heavily associated with emission intensive industrial and transportation sector. Economic survey (2019-20) postulates that India has witnessed a steady growth of gross capital formation in both private and public sector by 11.8% and 16.6% respectively in the fiscal year of 2107-18 compared to previous year. The capital formation was channelized through energy intensive manufacturing sector to revive the domestic manufacturing capacity as an integral part of ‘Make in India’ platform resulting in rise in emissions in India. The interaction term between renewable energy consumption and gross capital formation is also found to be positive and significant at 1% level of significance. The result suggests that gross capital formation in India may have nullified the beneficial effect of renewable energy consumption on environmental quality in the long run.

Table 3: Long run coefficient estimates

Variables	Co-efficient	t-statistics	Prob.
lnY	118.92***	3.44	0.002
lnY ²	-17.37***	-3.33	0.003
lnY ³	0.84***	3.21	0.003
lnREC	-3.67***	-3.03	0.005
lnGCF	2.22***	3.67	0.001
lnREC*lnGCF	0.41***	3.01	0.006
Shape of the EKC	‘N’-Shaped Year: 1995 (\$643.4), Year: 2012 (\$1437.9) Year: 2004 (\$962.1)		
Turnaround Points			
Inflection Point			

Note: *** denotes a 1% level of significance. Turnaround points and Inflection point have been calculated as per Lorente and Herranz (2016).

The short run dynamics as tabulated in Table 4 postulates that none of the coefficients of GDP, and its square and cube term are significant in the short run. The error correction term (ECT) in Eq. (3) is found to be negative and significant at 1% level of significance implying that time series will have convergence in long run equilibrium and the error is corrected from one period to next period towards short run to long run equilibrium pathway at a rate of around 42.7%. R^2 value for the ARDL model is moderately high i.e., 71.4% inferring the model has quite good fit and 71.4% of variability in the endogenous variable is explained by the exogenous variables. R^2 value in equation (3) is less than Durbin-Watson (D/W) statistics indicating that the estimations do not exhibit spurious regression.

Table 4: Short run estimates

Variables	Co-efficient	t-statistics	Prob.
$\Delta(\ln Y_t)$	-7.13	-0.19	0.85
$\Delta(\ln Y_{t-1})$	-108.24***	-2.92	0.01
$\Delta(\ln Y_t)^2$	1.46	0.25	0.80
$\Delta(\ln Y_{t-1})^2$	16.97***	2.95	0.01
$\Delta(\ln Y_t)^3$	-0.09	-0.31	0.76
$\Delta(\ln Y_{t-1})^3$	-0.88***	-2.98	0.01
$\Delta(\ln REC_t)$	-0.70	-1.59	0.12
$\Delta(\ln GCF_t)$	0.32	1.59	0.12
$\Delta(\ln GCF_{t-1})$	-0.16***	-3.62	0.00
$\Delta(\ln REC_t * \ln GCF_t)$	0.07	1.52	0.14
Constant	-124.08***	-8.33	0.00
Trend	0.001	1.65	0.11
ECT (-1)	-0.427***	-8.33	0.00
R^2	0.714 0.602 6.35*** [0.000] 2.09		
Adjusted R^2			
F- Statistics [Prob.]			
D/W Statistics			

Note: *** denotes a 1% level of significance, ** denotes a 5% level of significance, * denotes a 10% level of significance.

Table 5 demonstrates the diagnostic test statistics of the estimated ARDL model and confirms that the model passes all the diagnostic tests i.e., Breusch-Godfrey serial correlation LM test, ARCH test, Ramsey RESET test (functional form misspecification) and Jarque-Bera test of normality. The underlying ARDL model is also passed through stability test as reflected in Cumulative Sum of Recursive Residual (CUSUM) and Cumulative Sum of Squares of

Recursive Residual (CUSUMQ) test (Figures 2 and 3). The dotted straight lines in both the figures indicate the critical limit at 5% level of significance. In the figures, since the plots of both CUSUM and CUSUMQ statistics are well within the critical limit, it can be concluded that the stability of all the coefficients of the ARDL model is achieved.

Table 5: Diagnostic tests for the ARDL model

Diagnostic test	Null hypothesis	Statistics	Inference
Jarque-Bera test	H ₀ : Normal distribution of error terms	χ^2 : 1.049 Prob: 0.592	Error terms are normally distributed
Breusch-Godfrey serial correlation LM test	H ₀ : No auto correlation	F (2): 1.372 Prob: 0.272	No serial correlation
ARCH test	H ₀ : Homoskedasticity	F (2): 0.296 Prob: 0.745	No heteroskedasticity
Ramsey RESET test	H ₀ : Model specification is correct	F (1): 0.063 Prob: 0.804	Model is correctly specified

Figure 2: Plot of CUSUM test

Figure 3: Plot of CUSUM of square test

6.3 Results of the robustness test

Robustness of the ARDL bounds test of co-integration has further been tested with Bayer and Hanck (2013) combined co-integration analysis and the result is presented in table 6. In table 6, Fisher statistics of both the EG-JOH and the EG-J-BO-BDM are found to be significant at 5% level of significance, thereby suggesting the co-integrating relationship among the underlying variables and validating the estimations of ARDL bounds test of co-integration.

Table 6: Results for Combined Co-integration test by Bayer-Hanck (2013)

Estimated Model		$\ln C = f(\ln Y, \ln Y^2, \ln Y^3, \ln REC, \ln GCF, \ln REC * \ln GCF)$			
Fisher Type	Test Statistics	CV@1%	CV@5%	CV@10%	Decision
EG-JOH	14.068**	15.35	10.35	8.2	Co-integrated
EG-J-BO-BDM	77.812***	29.54	19.76	15.75	Co-integrated

Note: ***, ** and * indicate the results are significant at the 1, 5, and 10% level, respectively.

Further, alternative co-integration techniques i.e., fully modified OLS, dynamic OLS and Canonical co-integration regression techniques are employed in our present study for robustness checking of the estimated ARDL model. The result tabulated in table 7 postulates the N-shape EKC relationship between CO₂ emissions and economic growth. The findings of FMOLS, DOLS and CCR is consistent with the ARDL estimations.

Table 7: Results of FMOLS, DOLS and CCR

Variable	FMOLS		DOLS		CCR	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
lnY	56.03**	0.02	89.08***	0.00	57.56**	0.03
lnY ²	-7.61**	0.03	-12.75***	0.00	-7.85**	0.05
lnY ³	0.33**	0.04	0.61***	0.00	0.35*	0.07
lnREC	-3.03***	0.00	-5.71***	0.00	-2.97***	0.00
lnGCF	1.45***	0.00	2.66***	0.00	1.43***	0.00
lnREC*lnGCF	0.36***	0.00	0.65***	0.00	0.35***	0.00

Note: *** denotes a 1% level of significance, ** denotes a 5% level of significance, * denotes a 10% level of significance.

6.4 VECM Granger causality test results

Table 8 reports the result of VECM Granger causality analysis. The error correction term in Eq. (4) is found to be negative and significant at 1% level of significance indicating the long run relationship among the underlying variables in Eq.(4) and also validating the estimations of ARDL model of Eq. (3). According to table 9, there exists unidirectional short run causality from: (1) GDP to CO₂; (2) Square of GDP to CO₂; (3) Cube of GDP to CO₂; (4) Renewable energy consumption to CO₂; (5) Interaction term between RE consumption and gross capital formation to CO₂; (6) RE consumption to GDP; and (7) Interaction term between RE consumption and gross capital formation to GDP. The short run linkages are summarized in figure 4. Fig. 4 shows that RE consumption and the interaction term between RE consumption and gross capital formation not only have direct impact on CO₂ emission but also have indirect influence on CO₂ emission through the channel of economic growth in short run.

574 **Table 8:** Results of VECM Granger causality test

Dependent variable	Short run (F- Statistics)							Long run (t-value)
	$\Delta \ln C$	$\Delta \ln Y$	$\Delta \ln Y^2$	$\Delta \ln Y^3$	$\Delta \ln REC$	$\Delta \ln GCF$	$\Delta \ln REC * \ln GCF$	ECT
$\Delta \ln C$	-	11.922*** (0.001)	12.904*** (0.001)	13.957*** (0.001)	3.032* (0.089)	1.062 (0.309)	3.136* (0.085)	-0.237*** (-4.429)
$\Delta \ln Y$	0.615 (0.438)	-	0.00988 (0.992)	0.018 (0.893)	3.308* (0.077)	2.642 (0.112)	3.004* (0.091)	-13.018 (-1.596)
$\Delta \ln Y^2$	0.659 (0.422)	0.014 (0.907)	-	0.209 (0.886)	2.488 (0.123)	1.916 (0.174)	2.248 (0.142)	22.477 (1.465)
$\Delta \ln Y^3$	0.709 (0.405)	0.009 (0.924)	0.002 (0.969)	-	1.753 (0.194)	1.278 (0.265)	1.57 (0.218)	-9.602 (-1.323)
$\Delta \ln REC$	0.146 (0.705)	0.101 (0.752)	0.111 (0.741)	0.124 (0.727)	-	0.415 (0.523)	0.122 (0.728)	0.108 (0.135)
$\Delta \ln GCF$	1.569 (0.218)	0.216 (0.645)	0.315 (0.578)	0.449 (0.507)	0.163 (0.689)	-	0.296 (0.589)	-1.306** (-2.568)
$\Delta (\ln REC * \ln GCF)$	1.067 (0.308)	0.017 (0.898)	0.012 (0.913)	0.008 (0.929)	0.013 (0.908)	0.164 (0.688)	-	0.762 (1.011)

575 *** denotes a 1% level of significance, ** denotes a 5% level of significance, * denotes a 10% level of
576 significance. The optimal lag length $j=1$ is selected through the lowest value of AIC, SIC and HQ
577 statistics of the unrestricted VAR model.

578 Figure 4: Short run linkages summarized from Granger Causality. Note: $X \longrightarrow Y$ indicates
579 changes in X Granger causes changes in Y.

7 Conclusion and policy implications

The objective of this study is three-fold: first, to examine the long run association between economic growth, CO₂ emissions, renewable energy consumption (RE), gross capital formation and the interaction term between RE and gross capital formation in the EKC framework for India for the period 1970-2018 by employing ARDL bounds test of co-integration. Secondly to investigate the existence of EKC hypothesis for India and to determine the shape of the EKC and finally to determine if capital formation has been conducive for penetration of renewable energy development in the pathway of decarbonizing Indian economy. The findings of this empirical investigations not only establishes the long run relationship among the underlying variables but also provide strong evidence of N shaped relationship between economic growth and CO₂ emissions for India in the long run. The N shape EKC implies that initially CO₂ emissions increase with economic growth, and then after having reached a peak in the year 1995 starts reducing with expansion of the economy. With further economic development emissions again start rising after plunging at a minimum in the year 2012. Both the downturn and upturns can be explained by policy reforms of the government and the role of the service sector in the national economy. The findings suggest that the present trend in economic growth policy driven by emphasis on manufacturing sector may be currently pushing India up along the upward arm of a N shaped the EKC. Hence, to have a more sustainable growth trade and FDI policies need to be redesigned in order to attain a downturn of the N shaped EKC in India near future. For this it is important to look at the impact of RE and capital formation on emissions and economic growth.

The empirical results show that RE consumption has reduced CO₂ emissions in the long run and 1% expansion of RE consumption is associated with 3.7% reduction of CO₂ emissions. This finding supports the INDC commitment of India to reduce emissions through installation of 175 GW renewable electricity capacity by 2022 and increasing the share of RE alternatives

to 40% in total installed capacity by 2030 to act against climate change (UNFCCC, 2015). The interaction term of RE consumption and gross capital formation has been found to be significant in influencing CO₂ emissions. The coefficient has been found to be positive for the data period, implying that the capital formation has not supplemented the RE use in the period of analysis. Propagation of RE alternatives in India continues to face serious policy challenges in the form of high fixed cost and maintenance cost, low reliability, and enormous land requirement for setting up of the new RE projects (Rej and Nag, 2021). Renewable energy sector of India requires huge quantum of capital investment of Rs. 5 to 6 trillion for enhancing the additional renewable capacity addition of 106 GW over the fiscal year 2018-2022 along with additional post investments to connect the renewables to the Grid (Srikanth, 2018) while the capital formation is likely to be grown by only around USD 205 billion in renewables over the same timeline suggesting a huge shortfall in the capital formation in renewable energy development of India. Our results imply that higher RE friendly investments in total capital formation may help in reducing emissions. The Government of India has undertaken alternate action plans to promote renewables by supporting a lower Goods and Services Tax (GST) rate of 5% for production of renewable energy devices while for inputs to thermal generation the rate of GST levied varying between 5% to 18% and providing subsidy on the tariff of renewable electricity consumption over USD 2.2 billion in 2017 (IEA, 2020). Foreign Direct Investment in the RE sector may bring in capital and advanced technology with easier FDI norms.

In addition, the long run outcome of per capita gross capital formation is found to have significant and positive impact on CO₂ emissions which demands for proper attention in designing the robust energy policy framework to mitigate the detrimental effect of carbon emissions while undertaking the holistic approach to integrate the capital investment in domestic manufacturing. Strengthening the environmental regulations, deploying more capital formation in R&D for invention and adoption of advanced energy efficient technologies,

639 imposing carbon tax and formation of green climate fund could be recommended for India to
640 integrate in its sustainable design of future energy policy.

641 Looking at the short run result, there exists unidirectional short run Granger causality from per
642 capita RE consumption to per capita GDP suggesting the evidence of growth hypothesis for
643 India in short run. Further, the evidence of short run unidirectional Granger causality from per
644 capita GDP to per capita CO₂ emissions suggest that policy planning for reduction of carbon
645 emissions need to be done through adoption of energy efficiency measures and incentivised
646 capital investment in environment friendly green technologies which is also evidenced through
647 the unidirectional short run causality from the interaction term between per capita RE
648 consumption and per capita gross capital formation to GDP per capita. The absence of Granger
649 causality from CO₂ emissions to economic growth implies that India can control its CO₂
650 emissions without affecting economic growth.

651 To conclude, our study indicates that based on past 49 years of data, India may have
652 experienced an N shaped environmental Kuznets curve and is currently climbing up the third
653 arm of the N. Present policy thrust on the manufacturing sector, increased investment in energy
654 intensive technologies and production, disassociation between capital formation in the
655 economy and capital requirement in the renewable sector may make it difficult for India to
656 achieve a possible downturn in emissions with economic growth in the near future. In spite of
657 India's energy policy emphasis on renewables, achieving a target reduction in emissions will
658 be possible only if investment or capital formation in the economy is complementary to
659 penetration and increased usage of renewables. Adoption and implementation of certain
660 measures like standardization of pollution standards, mandating strict energy efficiency
661 standards, and extensive capital investments in not only renewable energy generation but also
662 in ensuring a low cost but steady and reliable clean power generation, setting up advanced and
663 modernized grid transmission and distribution and heightening more capital investments in

664 energy related research may reinforce the alternate policy directions to improve the climate
665 change and aiding India to achieve the target reduction of emissions in the INDC commitment
666 by 2030.

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681

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