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Article

Exploring the impact of economic growth and sources of electricity production in India: New insights from sectoral analysis using NARDL approach

Mohammed Ahmar Uddin[1], C. Geetha[2,*], Mohammad Aamir Khan[3], K. Srividhya[4], Pachiyappan Duraisamy[5]

[1] Department of Finance and Economics, College of Commerce and Business Administration, Dhofar University, Salalah 211, Oman
[2] Department of Statistics, Government Arts College, Salem 636007, India
[3] Department of Management Science, Yanbu Industrial College, Yanbu 46452, Saudi Arabia
[4] Department of Biostatistics, School of Allied Health Sciences, Vinayaka Mission's Research Foundation-DU, Salem 636008, India
[5] Department of Statistics, Periyar University, Salem 636011, India
*** Corresponding author:** C. Geetha, geethanisha1@gmail.com

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Abstract: This study aims to explore the asymmetric impact of renewable energy on the sectoral output of the Indian economy by analyzing the time series data from 1971 to 2019. The nonlinear autoregressive distributed lag approach (NARDL) is employed to examine the short- and long-run relationships between the variables. Most studies focus on economic growth, ignoring sectoral dynamics. The result shows that the sectoral output shows a differential dynamism with respect to the type of energy source. For instance, agricultural output responds positively to the positive shock in renewable energy, whereas industry and service output behave otherwise. Since the latter sectors depend heavily on non-renewable energy sources, they behave positively towards them. Especially, electricity produced from non-renewable energy sources significantly influences service sector output. However, growing evidence across the world is portraying the strong relationship between the growth of renewable energy sources and economic growth. However sectoral dynamism is crucial to frame specific policies. In this regard, the present paper's result indicates that policies related to promoting renewable energy sources will significantly influence sectoral output in the long run in India.

Keywords: renewable energy; agriculture; industry; service sector; NARDL; India

1. Introduction

The steady decline in environmental quality is a hot topic in today's scientific literature and one of the world's most pressing problems. Excessive production of greenhouse gases (GHGs) is commonly believed to be the primary driver of ongoing climate change for the worse. Many countries' governments have taken political action to cut emissions in response to this crisis. However, most pollution still originates in emerging economies, making this goal difficult to achieve (Guan et al., 2024). The energy sector has an axiomatic positive relationship with the economic growth (Bhuiyan et al., 2022; Sharma et al., 2019; Xiong et al., 2014) showcasing the socio-economic development of the country (Abbas and Choudhury, 2013; Ghosh, 2002; Jiang et al., 2022; Khobai and Roux, 2017; Mawejje and Mawejje, 2016; Solarin and Shahbaz, 2013; Tutak and Brodny, 2022). Energy being a fundamental factor of production (Shastri et al., 2020) plays a crucial role in economic progress of the country. It is forecasted that energies usage of the world would increase about 48% by

2040 (IEO, 2016). The most striking concern is the majority of this surge up energy demand would be met by fossil fuels as they are dominating the global energy mix (IEO, 2016; Shastri et al., 2020). Due to increased global warming, issues of greenhouse gas (GHG) emissions have raised concerns over the policies on energy conservation and their impact on economic growth. Especially the increase in CO_2 emissions has attracted the policy makers to rethink on the energy sources which aid the economic activities.

Particularly India, being the major developing country of the world with huge population, rethinking on the policies related to the source of energy produced is of utmost importance. Among the energy sources, electricity is a common form used in different sectors of the economy. In India, three-fourth of energy is sourced through fossil fuels (Shastri et al., 2020). This accounts for nearly seven percent of global GHG ($GtCO_2e$) emissions, which makes the country to stand fourth highest emitter (3.9 billion metric tonnes in 2021) in the world after the US, China and EU (Friedlingstein, 2022; World Bank, 2022). As it is predicted that the economic growth of the country would increase by 4.2 percent annually by 2035, its energy production mainly by fossil fuel would certainly increase exponentially (IEO, 2016; Shastri et al., 2020). This indicates that the carbon emission from the country will further get intensified. In a report by Global Carbon Budget (Friedlingstein, 2022) published during 27th Conference of Parties of UNFCCC-United Nations Framework Convention on Climate Change (COP27) climate conference in Egypt, has estimated that, India is recording highest growth (6% in 2022) in carbon emission compared to other countries of the world. The main source of these emissions is linked to non-renewable sources. Hence, it is apparent that the source of energy produced in the country will have a direct impact on different sectors of the economy and hence, overall growth of the country. Further, it is important to consider that the sectoral output is directly influenced by the type of energy produced or consumed.

Among the energy forms, electricity is an indispensable factor for the economic development of the country. Sustained sectoral development depends heavily on the efficient electricity supply (Tiwari, 2011). Especially the agriculture and industrial development is predominantly dependent on the uninterrupted electricity supply (Dogan et al., 2016; Tiwari, 2011, 2021). India consumes 33,508 Peta-Joules (PJ) accounting for the percapita electricity consumption of 1255 kWH (MoSPI, 2023). We can observe nearly 42 percent growth in the percapita consumption of electricity from 2010 (883.6 kWH) to 2023. The most important aspect is its sectoral energy consumption. The highest electricity consumption is in the industrial sector with 41.16 percent, next by the agricultural sector with 17.67 percent and service sector with 9.82 percent in 2021 (CEA, 2023) (**Figure 1**). The rest of the energy is consumed by the residential sector and other miscellaneous activities (30.77%). One of the concerning factors is these sectors are growing remarkably, indicating huge energy demand. For instance, the commercial sector (including service) recorded the growth of 23.63, (CAGR) in electricity consumption between 2012–2013 to 2020–2021, followed by industries (4.28%), agriculture (3.48), domestic (0.96), and other sectors (MOSPI, 2023).

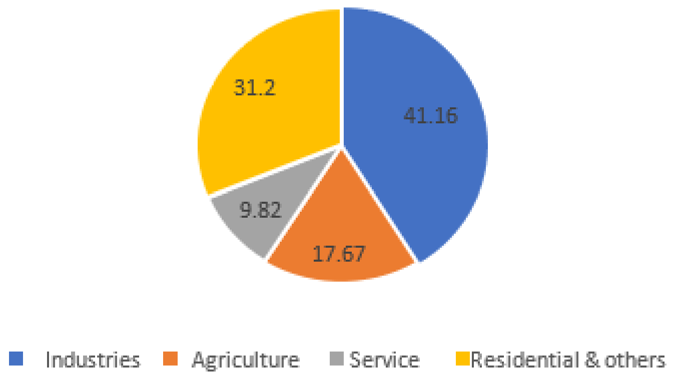

Figure 1. Sectoral consumption of electricity in India as of 2022 (% to total electricity consumption).

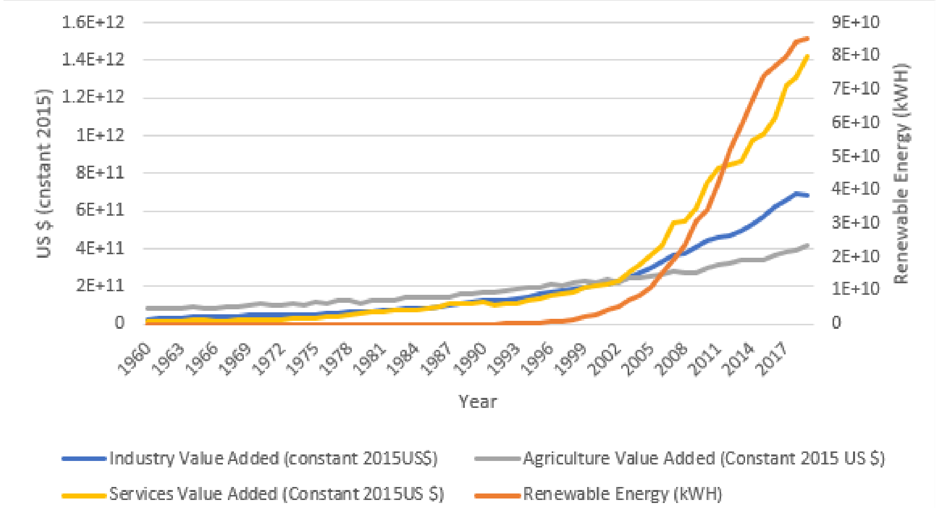

Figure 2. Renewable energy and sectoral growth in India.

The crucial aspect to highlight is the source of electricity production in the country. The major production of electricity is achieved through coal which accounts for 75 percent of total power generation (MoSPI, 2023). It is reported that electricity is the biggest consumer of non-renewable sources like coal and Lignite. The sector consumes nearly 69.04 percent of total coal and 78.9 percent of the lignite of the country (MoSPI, 2023). This highlights the heavy dependence of the country on non-renewable sources of energy. Having realized this, there is a need to shift towards renewable sources. The importance of renewable energy has been given prime importance in both developed and developing countries. India started emphasizing the development of various renewable energy sources. Since these sources are still emerging, we can observe that the economic growth in different sectors is not linearly related to renewable energy consumption sources (**Figure 2**). However, as the country's population has moving towards cities in recent decades, urban households have been switching to alternative energy sources like solar, wind, and other forms (Shastri et al., 2020). As a result, the country has made remarkable investments in renewable energy sources. The growth of renewable source of power generation recorded 16.07 percent in 2020-21 accounting for 10.66 percent of total power generated in the country (CEA, 2023). However, irrespective of the growth in renewable energy, the dependency on the non- renewable source is still persistent in the country.

It has been obvious that the energy produced from non-renewable sources tends to have detrimental effects on the environment. Given this, countries are stepping towards promoting the use of renewable energy. Though the literature is pronounced in explaining the importance of renewable energy, its economics effects are yet to be observed fully (Shastri et al., 2020). Further, the sectoral analysis of electricity production is still at nascent in India. The present paper makes an important contribution to this area. Though energy production and economic growth are linearly related, its impact on different sectors of the economy are found to have non-linearities (Arac and Hasanov, 2014; Atems and Hoteling, 2018). Even recent studies are claiming that the impact of energy production tends to have asymmetric effect on economic growth. This has not been examined in case of India. Owing to this, the present paper has examined the impact of sources of energy production on the sectoral growth of the economy. The novelty of the current study is the use of non-linearly Autoregressive distributive lag (ARDL) technique and a nonlinear causality-test that segregates the causal positive impacts and negative shocks.

The remainder of the paper is arranged as follows. Section 2 briefly discusses literature review. In Section 3, data information is provided. The empirical methodology is explained in Section 4. The findings and discussion are presented in Section 5. The conclusion is drawn in Section 6.

The remainder of the paper is arranged as follows. Section 2 briefly discusses literature review. The data and empirical methodology are explained in section 3. The presents empirical estimations in section 4 and the conclusion are drawn in section 6.

2. Related review of literature

The importance of energy as an important conducive factor of economic development has emerged in the literature more pronouncedly. The neo-classical economics stood stable about the influence of energy on financial growth (Shastri et al., 2020). Since the oil-crisis of 1975s and a study by Kraft and Kraft (1978), there emerged a vast array of literatures which have examined the association among the energy consumption and economic growth (Ghosh, 2002, 2009; Tiwari, 2011). Understanding the nexus between these two variables has important policy implications. For instance, it is imperative that energy consumption increases, exploring its relationship with financial development will aid the policy makers to design suitable energy policies for faster financial development. However, though the literature is more pronounce in explaining the overall energies use and its effect on the financial development, there is an emerging literature since 2010 which started investigating the impact of clean energies on financial development. A pioneer study by Apergis and Payne (2011) investigated the association among carbon dioxide emissions, energy (gas, electricity, coal, and oil) consumption, and financial development for India from 1970 to 2015. Their findings support the long-run cointegration of the variables and the validity of the Environmental Kuznets Curve (EKC) hypothesis. Additionally, they discovered that there is a feedback link among carbon emissions and economic growth and that energy use and carbon dioxide emissions have a positive association.

Though research studies are exorbitantly indicated the impact of renewable energy on economic growth, there exists four types of hypotheses which empirical links energy consumption and economic growth. The growth hypothesis proposes that energy consumption and economic growth have one way causality implying that economy in question in energy dependent. Studies like Holtedahl and Joutz (2004) for Taiwan, Altinay and Karagol (2005) Turkey, Shiu and Lam (2005) for China, Yoo (2005) for Korea and Appaih (2018) for Ghana have supported this hypothesis. The conservation hypothesis on the other hand, suggests that the economic don't depends on energies and energy conservation policies may be applied independent of effecting the economy. Ghosh (2009) for India, Narayan and Smyth (2005) for Australia, Ameyaw et al. (2017) for Ghana, and Halicioglu (2007) for Turkey have examined this hypothesis. The third hypothesis in the line is the neutrality hypotheses, which suggests that there is no relationship between energy consumption and economic growth (Aissa et al., 2014; Bulut and Muratoglu, 2018). Lastly, feedback hypotheses highlighted the bi-directional causality among the two variables. This shows that, energy use and financial development are inter-dependent, and one causes the other. Studies like Jumbe (2004) for Malawian economy, Acheampong et al. (2021) for Sub-Saharan African region, Tang et al. (2013) for Portuguese found the suggestion for a bidirectional causality among economic growth and energy use.

As stated earlier, though the literature has evidently established the association among the aggregate energy use and financial development, very meagre studies have examined the impact of energy use on financial growth in terms of the components of the former i.e., nonrenewable and renewable resources. Bloch et al. (2015) scrutinized the influence of nonrenewable sources like coal, oil and consumption of renewable energy on output development in China. They stated a bidirectional causality among the variables. Bhattacharya et al. (2016) examined this relationship for 38 top renewable energy consuming countries of the world and found similar results. Taghvaee et al. (2017) examined the effect of energy consumption on financial development in Iran and found an insignificant impact. Kocak and Sarkgunesi (2017) using a panel co-integration method found that green energy source's significantly rises the financial development in nine Black-Sea and Balkan nations over the 1991-2013 years. Wang and Wang (2020) revealed that the renewable energy consumption positively impacted the economic growth in OECD (Organisation of Economic Co-operation and Development) countries. Using the panel data of 174 countries during 1980–2012, Atems and Hotaling (2018) adopted a system generalized method of moments to study the relationship and found a positive relationship among non-renewable and renewable electricity generation and development.

Further, the literature is still emerging in examining the impact of sources used for energy production, mainly electricity, on the sectoral output. Some literatures have examined the financial output on the presumption that the sectoral context regulates the sources of renewable energy output dynamics (Mehdi and Maamar, 2012; Tiwari et al., 2021). Using the panel data of non-OECD and OECD nations Costantini and Martini (2010) found a uni-directional association from industrial output to energy use in non-OECD nations and reverse for OECD nations. Furthermore, the service sector has bidirectional for OECD and unidirectional for non-OECD countries. Nathan and

Liew (2013) using the ARDL model found no long-run link among sectoral results and electricity consumption for Combodia over the year from 1981 to 2011. Nevertheless, the short-term causality method with the Wald test illustrations a uni-directional link between the consumption of electricity and sectoral outcomes like industry and transport agriculture. Dogan et al. (2016) found that the positively linked agricultural electricity consumption and sectoral outputs for Turkey in 12 regions for the period from 1995 to 2013. A bi-directional link among nonrenewable and renewable sources and industrial output for OECD countries is found by Salim et al. (2014). Paramati et al. (2018) found a positively inference of both nonrenewable and renewable sources use on the total outputs for different sectors of 17 G20 countries.

Among these research studies, one common limitation are use of symmetric models. The symmetric models adopt reliability of the parameter over the sample periods. (Arac and Hasanov, 2014). This indicates that linear models contain symmetric features, which do not account for the shocks (Bayramoglu and Yildirim, 2017; Koop et al., 1996). But the energy sector and especially the different components of the energy sector face alterations in the strategies or the financial crises which affects the coefficients. If these effects are not accounted for, then the results would be spurious. Since economic growth and energy use are affected by cyclical fluctuations, linear models may be too restrictive (Shastri et al., 2020).

However, there are a few studies which have considered the nonlinearities in the growth and energy consumption. For instance, Lee and Chang (2007) and Ajmi et al. (2013) found a non- linear relationship between the energy consumption and GDP. Nazlioglu et al. (2014) examine the linkages between electricity consumption and economic growth in Turkey. The non-linear cointegration test supported net-zero emissions hypothesis which indicates that the electricity conservation policy may not adversely affect the economic development of Turkey. In the case of China, Wang et al. (2016) studied the causality relationships among the natural resources use and economic development using both symmetric and asymmetric cointegration test. Bayramoglu and Yildirim (2017) used Nonlinear ARDL for USA concluded that the impact of energy consumption is nonlinear in the long-term but not in the short-term. In Indian content, majority of empirical studies examining the effects of energy consumption on economic growth have considered the linear models (Alam et al., 2011; Ahmad et al., 2016; Ghosh, 2002, 2009; Paul and Bhattacharya, 2004; Tiwari et al., 2021). The asymmetric relationship between these variables is examined by a few studies Shastri et al. (2020) and Shahbaz et al. (2017). This study investigates the impacts of renewable and non-renewable electricity sources, labor force, and urbanization on sectorial output in India using annual data from 1971 to 2019. While previous research has assessed the impacts of various factors on sectorial output in India, this present study aims to address specific gaps in the literature. Firstly, earlier studies often used a single variable to represent sectoral output across industries, domestic agriculture, and service sectors. However, there is limited evidence on whether this relationship is non-linear. Examining potential non-linearity is crucial to understanding the inter-temporal effects of renewable and non-renewable electricity sources on sectorial output. Therefore, this study models the non-linear nexus between these electricity sources and sectorial output-related quality in the Indian context, filling a notable gap in the literature.

3. Methods

To examine the co-integration relationship between renewable energy consumption (REC), non-renewable energy consumption (NREC), gross fixed capital formation (GFCF) or the level of investment, labour force participation (LF), urbanization (URB) and sectoral outputs in India. We utilize the novel model introduced by Shin et al. (2013) i.e., the nonlinear autoregressive distributed lag approach (NARDL). This new model is an improved variant of the ARDL model. The investigation of potential negative and positive shocks between REC, NREC, GFCF, LF, URB, and Sectoral outputs is aided by nonlinear ARDL. It can be expressed as follows in Equation (1).

$$Yt = f(RECt, NREt, GFCFt, LFt, URBt) \tag{1}$$

followed by a linear Equation (2) of the form 1.

$$Y_t = \beta_0 + \beta_1(\mathrm{NRE}_t) + \beta_2(\mathrm{REC}_t) + \beta_3(GFCF_t) + \beta_4(\mathrm{LF}_t) + \beta_5(URB_t) + \varepsilon_t \tag{2}$$

where Y_t and ε_t stand for the sectoral outputs measured as service value-added (SRV), agricultural value added (AG), industrial value added (IND), and the residual term. The coefficients for the long-term are β_1, β_2, β_3, β_4, and β_5 established the non-linear ARDL model using positive and negative partial sum de-compositions that permit long and short-run identifications of nonlinear impact. According to econometrics model, the long-term relationship among variables determined by autoregressive distributed lag and error correction model based on stationary criterion; The non-linear nature of all variables used in all data series. The symmetric association between the variables is calculated by linear-regression while it is unable for asymmetric behavior. The nonlinear link of the variables was newly explored by Pachiyappan et al. (2021), the extension of the ARDL model. nevertheless, the cointegration technique would be applied for NARDL. This method can capture shorter-term fluctuations and structural breaks (non-linear). The paper regresses the sectoral outputs on REC, NREC, GFCF, LF, and URB. The explicit non-linear longer-term Equation (3) of sectoral outputs is as follows:

$$\begin{aligned} Y_t \quad &= \alpha_0 + \alpha_1\mathrm{NREC}_t^+ + \alpha_2\mathrm{NREC}_t^- + \alpha_3\mathrm{REC}_t^+ + \alpha_4\mathrm{REC}_t^- + \alpha_5\mathrm{GFCF}_t^+ \\ &+\alpha_6\mathrm{GFCF}_t^- + \alpha_7 LF_t^+ + \alpha_8 LF_t^- + \mathrm{URB}_t^+ + \alpha_6\mathrm{URB}_t^- + \varepsilon_t \end{aligned} \tag{3}$$

where $\alpha = \alpha_0$ to α_8 is a cointegrating vector to be assessed. While NREC_t^+ to URB_t^- are partial sum of positive and negative inflections. Equations (4)–(13) is partial sum of negative and positive fluctuations in NREC, REC, GFCF, LF and URB, respectively, in the sectoral outputs as applied.

$$\mathrm{NREC}_t^+ = \textstyle\sum_{i=1}^t \Delta\mathrm{NREC}_t^+ = \sum_{i=1}^t \max\Delta\mathrm{NREC}_i, 0 \tag{4}$$

$$NREC_t^- = \textstyle\sum_{i=1}^t \Delta\mathrm{NREC}_t^- = \sum_{i=1}^t \min\Delta\mathrm{NREC}_i, 0 \tag{5}$$

$$REC_t^+ = \textstyle\sum_{i=1}^t \Delta REC_t^+ = \sum_{i=1}^t \max\Delta REC_i, 0 \tag{6}$$

$$REC_t^- = \textstyle\sum_{i=1}^t \Delta REC_t^- = \sum_{i=1}^t \min\Delta REC_i, 0 \tag{7}$$

$$\mathrm{GFCF}_t^+ = \textstyle\sum_{i=1}^t \Delta\mathrm{GFCF}_t^+ = \sum_{i=1}^t \max\Delta\mathrm{GFCF}_i, 0 \tag{8}$$

$$\mathrm{GFCF}_t^- = \textstyle\sum_{i=1}^t \Delta\mathrm{GFCF}_t^- = \sum_{i=1}^t \min\Delta\mathrm{GFCF}_i, 0 \tag{9}$$

$$LF_t^+ = \textstyle\sum_{i=1}^t \Delta\mathrm{L}F_t^+ = \sum_{i=1}^t \min\Delta LF_i, 0 \tag{10}$$

$$LF_t^- = \textstyle\sum_{i=1}^t \Delta LF_t^- = \sum_{i=1}^t \max\Delta\, LF_i\,, 0 \tag{11}$$

$$URB_t^+ = \textstyle\sum_{i=1}^t \Delta URB_t^+ = \sum_{i=1}^t \min\Delta URB_i, 0 \tag{12}$$

$$URB_t^- = \textstyle\sum_{i=1}^t \Delta URB_t^- = \sum_{i=1}^t \max\Delta\, URB_i\,, 0 \tag{13}$$

In Equations (4)–(13) is positive and negative series while from Equation (2) getting Equation (15) making non-linear ARDL technique expressed as:

$$\Delta \mathrm{Y}_t = \beta_0 + \beta_1 \mathrm{Y}_{t-1} + \beta_2 N\mathrm{REC}^+_{t-1} + \beta_3 N\mathrm{REC}^-_{t-1} + \beta_4 \mathrm{REC}^+_{t-1} + \beta_5 \mathrm{REC}^-_{t-1} + \beta_6 \mathrm{GFCF}^+_{t-1} + \beta_7 \mathrm{GFCF}^-_{t-1} + \beta_8 LF^+_{t-1} + \beta_9 LF^-_{t-1} + \beta_{10} URB^+_{t-1} + \beta_{11} URB^-_{t-1} \tag{14}$$

$$\sum_{i=1}^{n} \delta_{1i} \Delta \mathrm{Y}_{t-i} + \sum_{i=0}^{o} \delta_{2i} \Delta \mathrm{N}REC^+_{t-i} + \sum_{i=0}^{p} \delta_{3i} \Delta \mathrm{N}REC^-_{t-i} + \sum_{i=0}^{q} \delta_{4i} \Delta REC^+_{t-i} + \sum_{i=0}^{r} \delta_{5i} \Delta REC^-_{t-i} + \sum_{i=0}^{s} \delta_{6i} \Delta GFCF^+_{t-i} + \sum_{i=0}^{t} \delta_{7i} GFCF^-_{t-i} + \sum_{i=0}^{u} \delta_{8i} \Delta LF^+_{t-i} + \sum^{v} \delta_{9i} \Delta LF^-_{t-i} + \sum_{i=0}^{s} \delta_{10i} \Delta URB^+_{t-i} + \sum_{i=0}^{t} \delta_{11i} URB^-_{t-i} + \mu_i \tag{15}$$

where (v to u) denotes lags orders. Conversely, β_1 to β_9 denotes long-run negative and positive shock in NREC, REC, GFCF, LF and URB on sectoral outputs. $\sum_{i=0}^{n} \delta_{1i}$ to $\sum_{i=0}^{v} \delta_{9i}$ measures the shorter-run negative and positive effects between the variables. The non-linear ARDL technique stages are expressed as:

Firstly, it tests the stationarity of all variable by Dickey and Fuller (1979) and Phillips and Perron (1988). We can use novel ARDL technique if the variables are stationary at level ($\mathrm{I}(0)$) or integrated of first order ($\mathrm{I}(1)$), or a mixed of $\mathrm{I}(0)$ and $\mathrm{I}(1)$. The novel-ARDL model has one limitation; it cannot continue in the occurrence of second order integration. The most flexible benefits of ARDL method specified by Nkoro and Uko (2016) are that it can be applied if series is stationarity at the level or first order or mixed level. Although, in an initial cointegration technique, had the compulsory pre-requisite that the full series should be stationarity in the same order. In secondly, the Equation (8) was calculated using the Ordinary Least Square technique. Furthermore, we adopted the general-to-specific method and BIC information's criteria, as observed. In thirdly, cointegration are calculated through bounds check to determine whether cointegration occurs or not. We can then continue with the nonlinear-ARDL method by proving that cointegration exist. In addition, the cumulative non-linear dynamic multipliers effects of 1% shift developed:

$$\mathrm{NREC}^+_{t-1}, \mathrm{NREC}^-_{t-1}, \mathrm{REC}^+_{t-1}, \mathrm{REC}^-_{t-1}, \mathrm{GFCF}^+_{t-1}, \mathrm{GFCF}^-_{t-1}, LF^+_{t-1}, LF^-_{t-1}, URB^+_{t-1}, URB^-_{t-1} \tag{16}$$

Correspondingly, as

$$S_h^+(\mathrm{N}REC) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial \mathrm{N}REC^+_{t-1}} \tag{17}$$

$$S_h^-(\mathrm{N}REC) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial \mathrm{N}REC^\pm_{t-1}} \tag{18}$$

$$S_h^+(REC) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial REC^+_{t-1}} \tag{19}$$

$$S_h^-(REC) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial REC^-_{t-1}} \tag{20}$$

$$S_h^+(GFCF) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial GFCF^+_{t-1}} \tag{21}$$

$$S_h^-(\mathrm{GFCF}) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial GFCF^-_{t-1}} \tag{22}$$

$$S_h^+(\mathrm{L}F) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial LF^+_{t-1}} \tag{23}$$

$$S_h^-(\mathrm{L}F) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial \mathrm{L}F^-_{t-1}} \tag{24}$$

$$S_h^+(\mathrm{URB}) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial \mathrm{URB}^+_{t-1}} \tag{25}$$

$$S_h^-(\text{URB}) = \sum_{j=0}^{h} \frac{\partial Y_{t+i}}{\partial URB_{t-1}^-} \quad (26)$$

4. Results and discussions

In this section, the association among the sectoral output and the defined independent variables are examined. To understand the basic characteristics of the dataset, the descriptive statistics of each variable is indicated in **Table 1**. The average values of agricultural value added (AG), GFCF, industrial value added (IND), Labour force (LF), SRV, renewable energy consumption (RE), NRE, and URB exceed their corresponding standard deviations, indicating an uneven distribution in India. Skewness statistics suggest that the sample data are right-skewed distribution. Jarque Bera (JB) test results indicate that AG, GFCF, IND, LF, SRV, RE, NRE, and URB are normally distributed.

Table 1. Descriptive statistics.

Variables	AG	GFCF	IND	LF	SRV	RE	NRE	URB
Mean	25.993	25.678	25.833	5.875	26.197	18.925	4.294	2.990
Median	25.987	25.494	25.809	5.944	26.119	20.088	4.377	2.841
Maximum	26.757	27.405	27.261	6.209	27.908	25.362	4.439	3.881
Minimum	25.311	24.321	24.550	5.305	24.748	11.002	4.000	2.315
Std. Dev.	0.419	1.999	6.852	0.278	4.981	4.968	0.139	0.504
Skewness	0.070	0.282	0.150	−0.55	0.156	−0.171	−0.862	0.574
Kurtosis	1.845	1.711	1.749	2.017	1.753	1.481	2.137	2.044
JB test	3.657*	19.651*	3.075*	5.365*	2.431*	5.539*	6.921*	4.026*

Notes: * indicates statistical significance at 5% level respectively.

Table 2. Summary of unit roots test.

Variables	I(1)	I(0)
AG	0.48	−12.14***
IND	0.95	−4.70***
SRV	4.19	−4.62***
GFCF	1.33	−7.50***
LF	−8.2***	−8.32***
RE	−3.02	−14.73***
NRE	−1.50	−8.95***
URB	−1.12	−7.66***

Notes: *** indicates statistical significance at 1% level respectively.

The empirical analysis of the study involves examining the stationarity of the variables as the data before conducting the cointegration test. Perron (1989) investigated that when data involves time trend then the stationary test provides biased result in favour of non- rejection of the null-hypotheses. Hence, our study employed structural break-point unit root tests (Based on improved augmented Dickey Fuller (ADF)) (Shastri et al., 2018). To capture structural break, we have introduced for the year 1991. The year marks significance in the economic history of India where the economic reforms were introduced. The dummy is found to be significant in the model. The results of the ADF test are provided in **Table 2**.

The unit root test signifies that the variables under consideration are of mixed order of I(1) and I(0). This justifies that we are restricted from using the traditional cointegration tests. Since we are trying to capture the asymmetrical relationship, we adopted the NARDL model. The outcomes are provided in **Table 3**. The lag-length of the model is based on Akaike information criterion (AIC) which has selected an optimal lag length of 4 for all the three models.

Table 3. Estimation results of NARDL model.

Long-run estimates						
Inpt-variable	**Dept Variable-AG**		**Dept Variable-IND**		**Dept Variable-SRV**	
	Coef	**Std. error**	**Coef**	**Std. error**	**Coef**	**Std. error**
RE^{+}	1.17***	0.11	−0.33	0.24	−0.51	2.10
RE^{-}	−0.15***	0.04	0.08	0.07	0.94	3.11
NRE^{+}	−0.48*	0.18	1.00***	0.28	2.7**	1.7
NRE^{-}	0.98***	0.23	−2.48**	0.42	−2.4**	1.6
GFCF	0.10***	0.03	0.19***	0.08	0.77***	0.03
URB	−0.63***	0.12	1.56***	0.60	0.02**	0.05
LF	0.21**	0.13	1.65***	0.37	0.45**	9.12
C	27.5***	0.6	18.84***	8.27	30.09***	0.60
Short-run estimates						
Convergence (δi)	−0.9	0.03	−0.90	0.01	−0.21	0.02
RE^{+}_{t-1}	1.6***	0.18	1.45***	0.22	0.04***	0.01
RE^{-}_{t-1}	−0.28	0.20	−0.41***	0.21	−0.13***	0.02
NRE^{+}_{t-1}	0.91***	0.89	5.28***	0.68	10.87***	1.95
NRE^{-}_{t-1}	0.02***	0.46	0.78***	0.49	−3.90***	1.24
$GFCF_{t-1}$	0.013***	0.05	0.14***	0.06	−0.15***	0.05
URB_{t-1}	0.46***	0.20	15.65***	7.02	0.05***	0.03
LF_{t-1}	1.06***	0.43	2.14***	0.43	2.08***	0.30
Bound test	*F*-Value I(0)	I(1)	*F*-Value	I(0) I(1)	*F*-Value I(0)	I(1)
	4.6 2.73	3.9	7.25	2.73 3.9	20.4 2.5	3.68

Note(s): *** indicate significance at the 1% level, respectively.

The non-linear bound F test in **Table 3** for the three study sectors indicates that, the models lie above the critical upper value at 1 percent significance level as according to Pesaran and Pesaran (1996) and Pesaran et al. (2001). This confirms the presence of a long-run relationship among the variables for the year 1971–2019. The Wald tests for models indicate nonlinear in short and long-run relationship. In our three model, Wald test indicate the existence of asymmetry in both short and long run. Hence, the usual ARDL model does not provide appropriate results as ARDL will assume linearity among the variables. Hence, the paper is justified to adopt NARDL to capture the asymmetry among the variables.

In the long run, both positive negative shocks in RE exert statistically significant only in agricultural sector output. The evaluated parameters (elasticities) show that one percent rise in RE would increase the output in agriculture by 1.17. However, the size of the parameters of the negatively shock (−0.15) is smaller than that of positively energy shock. This means that, a decline in RE would improve the growth by 0.51 percent. Agricultural sector is highly labour intensive in India and this sector stands third in the energy consumption (see **Figure 1**). The promotion of renewable sources of energy in this sector by the ministry of new and renewable energy has found drastic change in the energy dependence on the sector. Further, the traditional agricultural practices in India have long relied on manual labor, animal power (such as bullocks), and biomass-based fuels like wood and crop residues. These can be considered renewable in some sense. While in the case of industry and service sectoral output, electricity produced from renewable sources are found to be insignificant. This can be related to the lesser dependence of these sectors on renewable energy consumption. Authors should discuss the results, interpreting them in light of previous studies and the initial working hypotheses. The findings should be analyzed and their implications explored in the broadest possible context. Additionally, future research directions should be highlighted to guide subsequent investigations.

Though positive and negative shocks in NRE are found to be significant in all sectoral output, the direction and magnitude of these shocks are found to be different. In the case of agricultural output, there exists a negative relationship with positive shock in NRE. This means that a 1% rise in electricity produced from nonrenewable sources would decrease the agricultural output by 0.48 percent. It has a positively influence on industrial output of 1 percent and service sector output by 2.7 percent. The magnitude of the impact on the service sector is comparatively stronger as this sector is highly energy intensive, and the majority of the electricity produced in the country is from non-renewable source. In terms of negative shock in NRE, the agricultural output is showing a positive sign with 0.98% impact whereas the industrial and service sector growth would reduce significantly by 2.48 and 2.4 percent respectively. This clearly signifies the dependence of the latter sectors on the non-renewable sources of electricity generation. Similar result is found by Fotio et al. (2022) for African countries.

The other macro-economic variables like GFCF (Capital) and Labour is found to be positive and statistically significant in influencing the sectoral output. However, the URB variable, though found statistically significant, it is negatively influencing the agricultural output. That means, 1% rise in urban population would decrease the agricultural output by 0.63 percent. The urbanization in India is causing severe decrease in the agricultural land (Kalamkar, 2009) causing lower productivity. This has a significant policy implication pointing out that, agriculture should be equipped with technology, so that the productivity would increase. With respect to other sectors, namely, industry and service, urbanisation is found to have positive influence on their output. For example, increase in urbanisation would increase the industrial output by 1.56 percent whereas in case of service output, it increases by 0.02 percent.

In the short run, we can observe that the variables are statistically significant with varied magnitude and direction across different sectors. The positive shock in RE will positively influence the output of all the three sectors significantly. However, the magnitude of this influence is much stronger in agriculture (1.6) and industry (1.45) than in the service sector (0.04). The negative shock in RE is statistically significant for both industry and service sector except agriculture. In the case of industry, the reduction in RE would increase the industrial output by 0.41 percent and 0.13% in the case of the service sector. In the case of NRE, both positive and negative shocks are statistically significant. In the case of the agricultural sector, an increase in NRE would increase the output by 0.9 percent. Though NRE would increase the output, the magnitude of RE is stronger than that of NRE. In the case of industry and service sectors, the result shows similar findings, where the industrial output would increase by 5.28 percent and service sector output by 10.87 percent with an increase in NRE. In case of the negative shock in NRE, there will be an expansion in agricultural output in the short-run of 0.02 percent. The industrial output also would increase by 0.78 percent, whereas the service output would decrease by 3.90 percent. This indicates the heavy dependence of the service sector on the electricity produced by non-renewable sources of energy.

In the case of the macroeconomic variables, all the variables are found to be statistically significant and positive in influencing the sectoral output in the short run. These results are consistent with other studies which support Solows neoclassical development model that labour, and capital are important factors of financial development (Apergis and Payne, 2010; Bhattacharya et al., 2016; Fotio et al., 2022; Vural, 2020). However, the coefficients of labour are higher than those of capital, suggesting that the sector outputs in India are more labour-intensive. The convergence (δ_i) for all the three sector is statistically significant and negative, indicating that, the disequilibrium in the model will be corrected within a year (as the data is in annual series).

Table 4. Result of diagnostics test.

	***T* value**	***p*-value**	***T* value**	***p*-value**	***T* value**	***p*-value**
J-B	1.11	0.57	2.84	0.28	0.018	0.9
LM test	3.68	0.6	13.31	0.2	3.5	0.69
BP test	0.63	0.8	0.59	0.8	0.74	0.7
Ramsey	1.01	0.33	0.02	0.9	2.6	0.14
NRE—Wald long-run	−0.8	0.41	0.73	0.39	6.18	0.03
RE—Wald long-run	6.14	0.00	0.14	0.70	8.4	0.04
NRE—Wald short-run	−0.7	0.58	1.8	0.39	4.12	0.03
RE—Wald short-run	4.8	0.00	1.2	0.01	8.4	0.04
R^2	0.95		0.93		0.89	
Adj. R^2	0.90		0.84		0.70	
Durbin Watson	2.80		2.64		2.52	

Note: J-B is Jarque-bera test which tests for the normality of the data distribution; LM test is the test for serial correlation and BP test is the test for heteroskedasticity; Ramsey Reset test confirms the stability of the model. ***, ** and * indicates statistical significance at 1%, 5%, and 10% levels respectively.

The results of diagnostic study are shown empirically in **Table 4**. The diagnostic test on serial correlation (LM test), heteroskedasticity (BP test), indicates that, the models are free them. In the end, the models are tested for stability through Cumulative

Sum (CUSUM) and CUSUM squared tests (Refer Appendix). The anticipated line is well inside the critical boundaries at 5% level indicating that the parameters are found to be stable throughout the sample period.

5. Conclusion and policy implications

The study has assessed the relationship between the sectoral output, RE and NRE in India using annual time series data. Though the studies on providing evidence on this nexus is more prominent in the world literature, it is still growing in case of India. However, the majority of the study is focusing on the aggregate level analysis. The present paper made a novel attempt in bringing the sectoral level analysis for the case of India and also the paper stands first of its kind to identify the asymmetric relationship among the test variables.

- These asymmetries showcase different dimensions to the sectoral level policies. The cointegration results on all the three models confirms the existence of long run relationships among the variables. Owing to this, the study has adopted the newly developed NARDL model by Shin et al. (2014) to capture asymmetries in the short and long run.
- The positive and negative shocks in RE exert positive growth in the agricultural sector than in other sectors. In the case of NRE, the positive shocks are more pronounce in service and industrial sector output than the agricultural sector.
- The result on the sectoral output is peculiar to Indian economy, i.e., the agricultural output is positively related to the electricity produced from nonrenewable energy sources than the other two sectors.
- As India is heavily dependent on non-renewable energy sources, especially the industry and service sector output are severely correlated with non-renewable energy sources.
- Hence, policies should be diverted towards promoting renewable energy sources in the country. Especially for the service sector which is showing significant dependence on non- renewable sources of electricity and this sector is highly dependent on electricity, shifting to renewable sources will significantly reduce the dependence. For this, government should actively promote the RE to be used in the service sector.
- This can be achieved through promotion of solar energy usage, wind power and other renewable energy sources. As service sector contributes more than 50 percent of India's GDP and also the major consumer of electricity should strive towards being less dependent on NRE. For this, the government should prioritize research and development to improve energy efficiency in these sectors.

Future work

The transition to renewable energy sources has been a critical area of focus for sustainable development. Understanding the intricate relationship between renewable and non-renewable energy sources and their impact on sectorial output quality is essential for optimizing energy policies. Here, we propose a framework for future research to explore the non-linear interactions between these variables.

Author contributions: Conceptualization, MAU and PD; methodology, MAK; software, KS; validation, MAU and CG; formal analysis, PD; investigation, PD; resources, MAK; data curation, PD; writing—original draft preparation, MAU; writing—review and editing, CG; visualization, PD; supervision, CG; project administration, PD; funding acquisition, MAU. All authors have read and agreed to the published version of the manuscript.

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Appendix

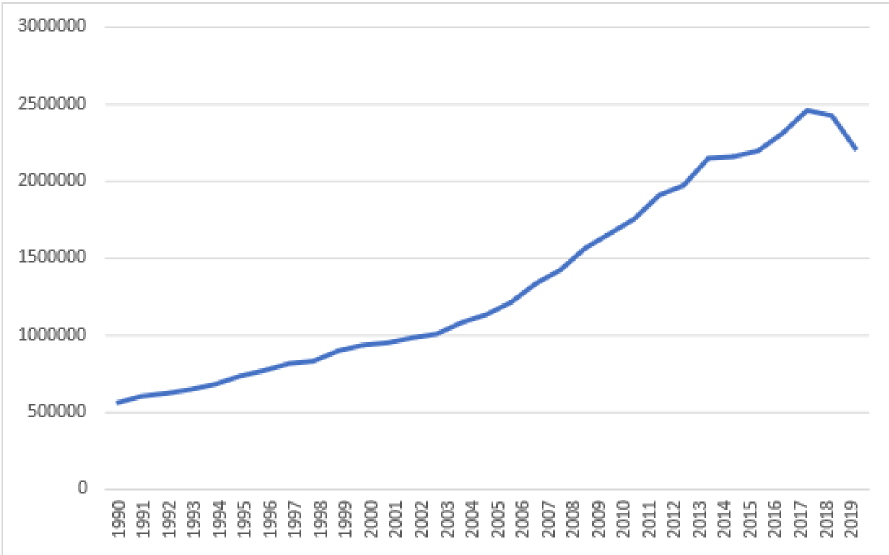

Figure A1. CO_2 emission (in kt) from 1990 to 2020.

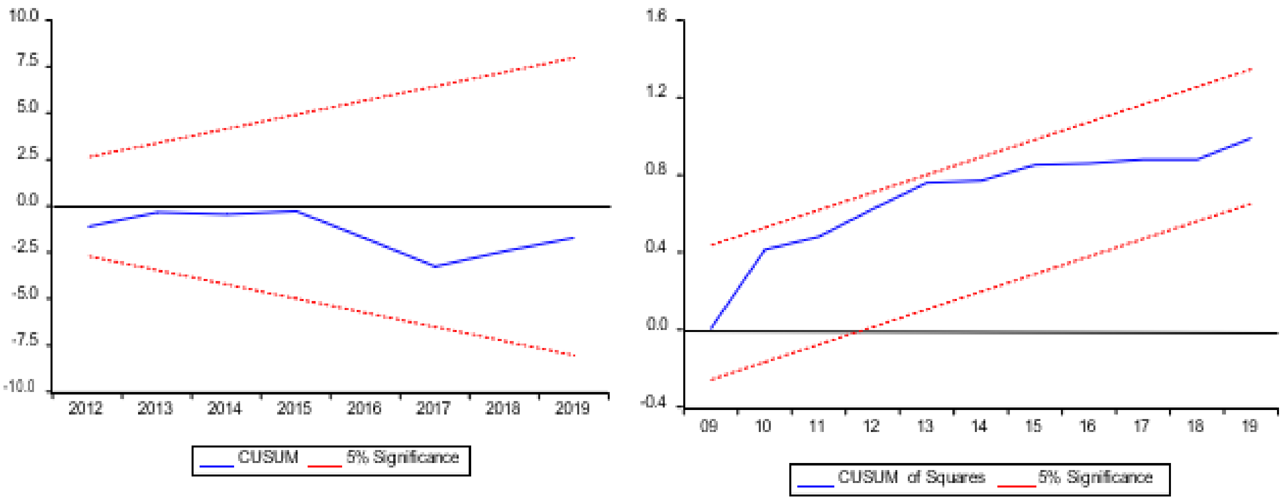

Figure A2. CUSUM and CUSUMSQ on sectoral outputs.

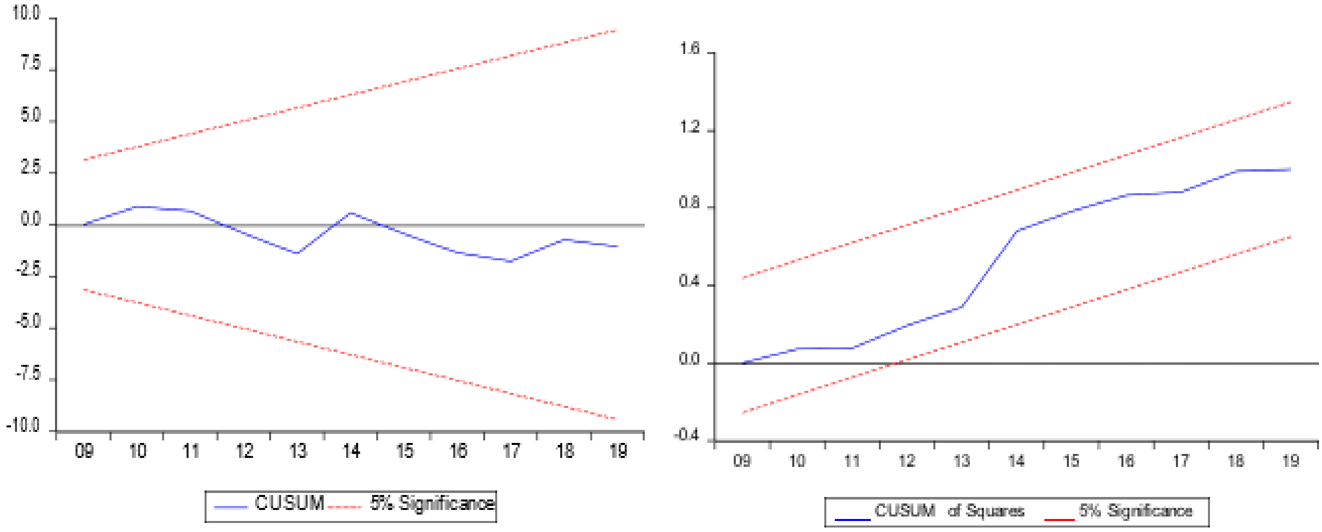

Figure A3. CUSUM and CUSUMSQ of IND.

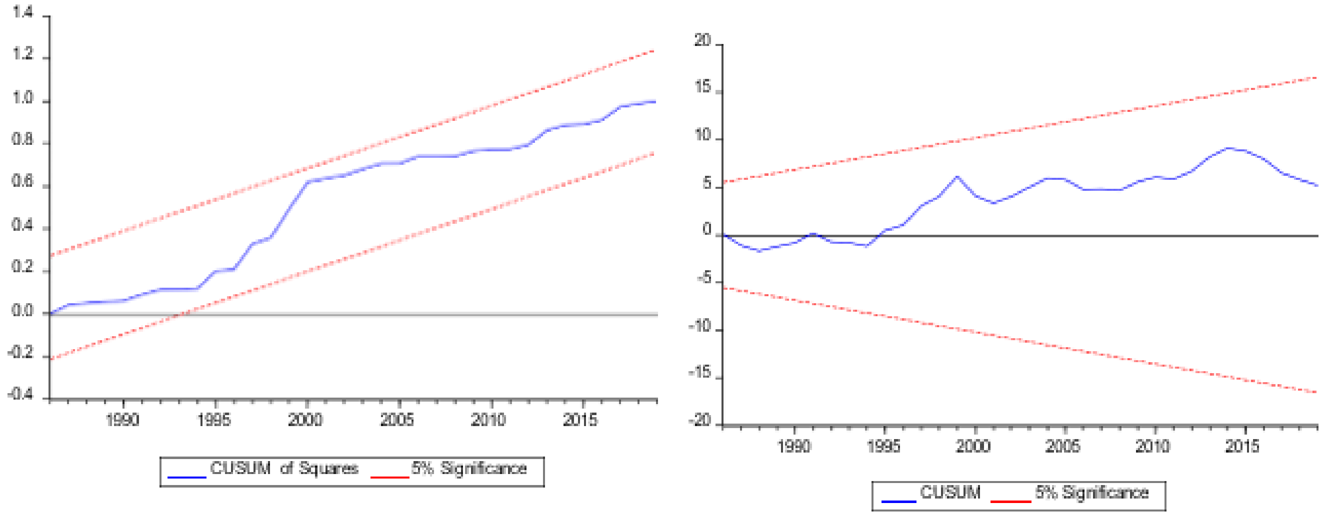

Figure A4. CUSUM and CUSUMSQ of SRV.