Effect of Remittances on Renewable Energy Consumption in India: Evidence from a Nonlinear Analysis

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Abstract

The flow of remittances is decisive in shaping India's economic and societal welfare. India is also one of the fastest-growing economies, and its energy demand has a determining impact on global energy consumption. Remittances are often seen as a crucial source of external finance for India and can play a decisive role in financing renewable energy generation projects. However, minimal exploration has been conducted on the issue of interrelationship between remittances and renewable energy consumption in India. The present study attempts to empirically test the impact of remittances on the level of consumption of renewable energy in India over the period 1990–2020, which, to the best of our knowledge, none of the previous studies has dealt with yet. The results of the nonlinear autoregressive distributed lag (NARDL) model show that a lagged negative shock of remittances positively and significantly impacts renewable energy consumption in India. The long-term result confirms that a negative shock of remittances significantly reduces renewable energy use. The reduction of remittances has a more significant impact than the increase of the same, implying the existence of an asymmetric impact of remittances over renewable energy consumption. One of the critical policy implications of these findings is that the government should promote policies that enhance the inflow of remittances as it would facilitate the use of renewable energy in India.

Keywords: remittances, renewable energy, India, asymmetric, NARDL

1. Introduction

With rapid economic growth across countries and due to the very nature of globalization, the importance of remittances in shaping the future of an economy is increasing gradually. In some developing countries, over the past few decades, they are more significant than the foreign direct investment (FDI) or gross developmental assistance their government provides [1]. According to the World Bank estimate, in the pre-pandemic era, the global remittances flow was 719 billion US dollars in 2019, of which 548 billion US dollars went to developing countries. During the

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pandemic, even after facing a global economic slowdown, the inflow of remittances to developing nations reduced marginally to 540 billion US dollars. In contrast, the reduction in FDI fell over 30 percent [2]. Indian economy is heavily dependent on remittances and is the principal recipient of remittances. USA, UAE, UK, Singapore, and Saudi Arabia are countries that have the highest share in total inward remittances in India in 2020-21. In 2019, the inflow of remittances in India was 83.3 billion US dollars, which further increased during the pandemic to 87 billion US dollars in 2021 [2]. India's growth trajectories are highly dependent on its inward flow of remittances. With its objective to become a developed nation, remittances are one of the most influential instruments.

Many studies have examined the impact of remittances on economic growth through the lenses of poverty, inequality, health education, etc. However, very few have explored the interaction or, specifically, the impact of remittances on energy consumption at the macro level. Because remittances are an addition to personal income, their impact on the level of energy consumption to improve the standard of living cannot be underestimated. Besides, channeling remittances into household energy consumption alters the family consumption pattern and reshapes the economy's overall energy demand. There are multidimensional ways through which remittances could interact with energy consumption. With the increasing trend of urbanization and industrialization in developing countries, the demand for energy in these countries is also growing exponentially [3]. Here, remittances can be used as a stable source of money flow to balance the energy demand. Though indirectly, remittances can increase the demand for energy consumption by raising the scale of economic activities in a country [4]. Inversely, remittances could be invested in setting up infrastructure for renewable technologies. This can fuel human capital formation as energy can help develop various social sectors like education, health, etc., which could propel economic growth. Given this complex yet crucial interactive role played by remittances and energy consumption in the economic growth of a country, it has become imperative to focus this relationship on India, especially when there is a concerning lack of research in this domain.

There are two major macroeconomic causes about why India should be considered for studying the remittances-energy nexus. Firstly, India's inflow of remittances is the highest in the world among low- and middle-income countries, accounting for 12.73% of the total remittances inflow of the world [2]. Secondly, being one of the largest consumers of energy (mostly fossil fuel), any change in the direction of energy use on the part of India will have a substantial long-run impact globally. India's choice of energy significantly impacts the rest of the world as it would have indirect effects through emissions, energy markets, flows of technology, etc. Additionally, India is the second-largest growth market for renewable energy after China [5], which implies that India's renewable energy policy plays a vital role in global pollution control. Hence, there are enough justifications for an in-depth study involving India's remittance inflow and its multidimensional impact on renewable energy consumption in India.

The study holds several novelties in its approach. First, very few scholarly studies relate to India's remittance inflow and energy demand. The author found no study about the nexus between remittances and renewable energy consumption in India. Another novelty of the study stands in its econometric methodology, where it has applied an asymmetric model to analyze the impact of remittances over renewable energy consumption, addressing both long-run and short-run dynamics, which none of the previous studies have dealt with to date. Hence, the present research can be considered a serious attempt to contribute to the study of energy economics by addressing the gaps. The study has been structured as follows. Section 2 deals with the status of energy consumption in India, which gives a view of energy use in India in a nutshell. Section 3 discusses various literature on this topic. The data and the empirical methodology adopted for the analysis are discussed in section 4, while the last section deals with the conclusion and policy suggestions.

2. Energy Consumption in India

World energy consumption changed intensely since the Industrial Revolution. Currently, energy consumption is rising in developing countries with exponential growth in income and population. However, net energy consumption is falling for developed countries as they are more concerned about energy efficiency [6]. Energy is an essential component when it comes to economic growth for a developing country like India. With its sustained march towards a long-run growth path, India, too, has experienced a rise in energy demand. In terms of energy consumption, India ranks third in the world [5]. With the increasing rate of urbanization and industrialization, energy demand in India is expected to rise exponentially in the coming years. Coal, oil, and biomass are India's three main energy sources. These three sources share over 80% of India's total energy demand [7]. However, these energy sources result in environmental pollution, an increasing concern for the global environment. Hence, policymakers worldwide advocate for using more renewable energy resources. India, too, framed its energy policies to reshape its energy use and promote the use of renewable energy sources in line with the UN Sustainable Development Goals (SDGs).

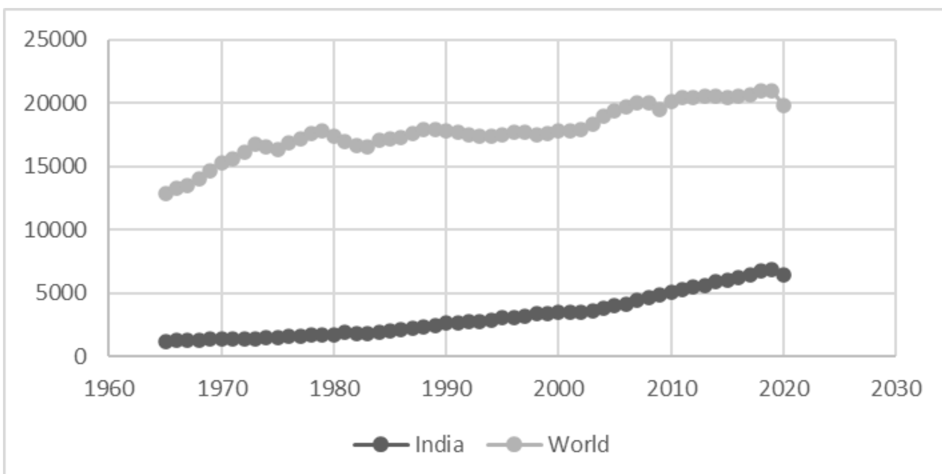

Figure 1: *India's per capita energy use (kWh) [8]*
Note: Energy refers to primary energy

Per capita energy use statistics are essential for a country like India as, over time, it has experienced a population explosion. Though the absolute value of energy use in India is very high and growing, the per capita energy use value is nowhere near the global standard (Fig. 1). Per capita energy consumption of India has increased steadily from 1965 to 2020 amidst various economic ups and downs, even though global energy consumption had a fluctuating trend during this era. Since 2000, per capita energy demand in India has increased by more than 60%. Still, India's per capita energy use is less than half the global average [5]. Per capita energy consumption in India in 2021 was 7063 kWh, one of the lowest among the developing countries, whereas the global average is 20993 kWh [9]. In addition to this, there is inequality in energy distribution across urban and rural habitats. There is evidence of disparity of distribution across socio-economic groups as well. There is also inequality at the state level as states with higher per capita income enjoy a higher share of per capita energy consumption, signifying across-state inequality.

Recently, India has shown remarkable improvement in achieving the Sustainable Development Goals (SDGs) proposed by the UN. For its commitment to move towards a sustainable environment, India is specifically motivated to use renewable energy more and more. According to a special report by IEA on India [5], India has improved remarkably regarding renewable resources, specifically in solar energy and batteries. Apart from this, sources like natural gas add fuel to the generation of renewable energy in India. This helped India even during the Covid-19 pandemic. The share of renewables in total primary energy in India has been declining till 2015 (Fig. 2). It increased continuously after 2015, though the overall share is still below the global average. 2015 can be considered a corner year for India's policy towards rapid use of renewable energy. During this time, India saw a sharp rise in its use, mainly due to the exponential use of solar energy. The capacity to use solar energy increased almost five times in 2015. In fact, during the initial phase of the pandemic, the share of renewable energy increased significantly as the use of other non-renewables like coal and other fossil fuels declined sharply (specifically oil consumption by 9.9%) due to a fall in road and transport activity [8].

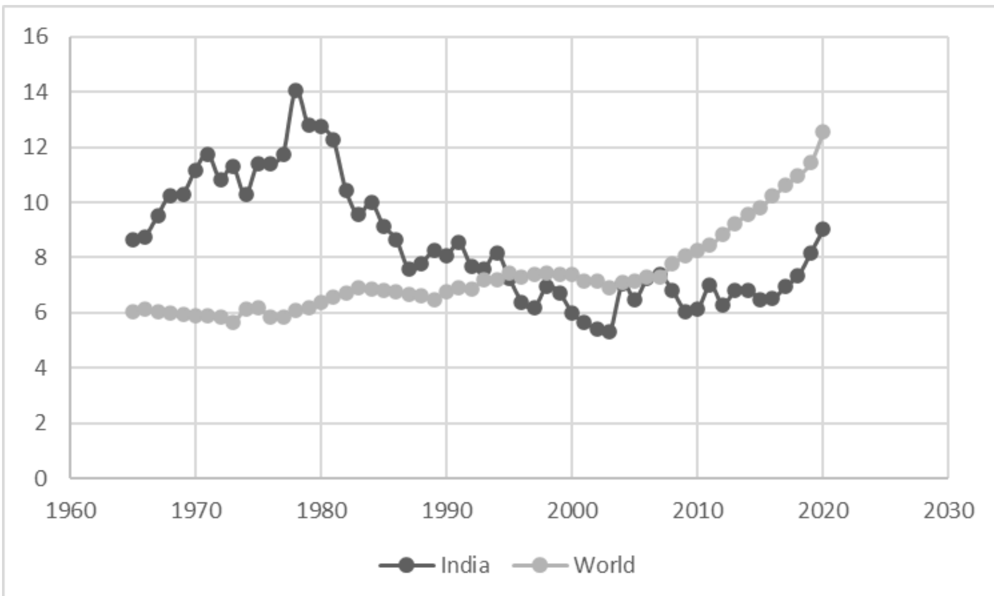

Figure 2: *% share of primary energy from renewable sources [8]*

Energy intensity is one of the most influential parameters while measuring the economic impact of energy use. It is measured by the extent of energy consumption per unit of GDP measured at PPP (constant prices). Hence, it highlights the level of efficiency through which a country utilizes its energy to produce a particular output level. India's energy intensity is gradually declining from 1990 onwards (Fig. 3). Average energy intensity in India is at a shallow level compared to its economic rival China. This also implies that China is relatively more developed, whereas India is still using more labor-intensive production techniques. Energy intensity can indicate an economy's overall standard of living, where a high value implies a higher standard of living. Low energy intensity indicates efficient use of resources like insulation, fuel-efficient transportation, and efficient energy use, etc.

With the increasing energy use in the next 20 years, India will play a crucial role in determining the world's energy mix. Therefore, policymakers have a substantial role in making India's energy use more sustainable. India's renewable energy use is gaining momentum but is still way below its potential. More energy-efficient technologies, widespread electrification, increasing use of renewables in industrial sectors, etc., are going to be the key issues that policymakers must

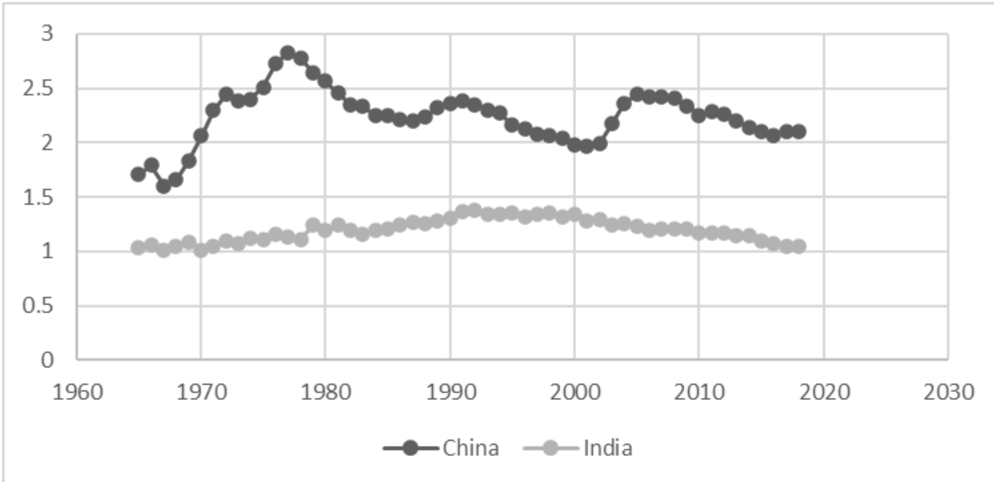

Figure 3: *India's energy intensity (MJ/$) [10]*

address. The government must frame policies to transition to clean energy for energy security and a sustainable future.

3. Literature Review

Scholarly studies are available regarding the relationship between energy consumption and macroeconomic variables like economic growth, trade openness, urbanization, etc. Similarly, ample research exists regarding the association between remittances and the aforementioned macroeconomic variables. Remittances have always been identified as an essential tool to achieve various macroeconomic goals like curbing inflation, managing finances, and reducing dependence on FDI. of a country. However, there is a dearth of serious research when it comes to connecting these two major macroeconomic variables, namely, energy consumption and remittances, and analyzing the extent of their relationship. To address this gap, the present study explicitly interrogates the effect of remittances on renewable energy consumption in India.

In recent times, increasing access to remittances has not only changed the consumption pattern of households receiving it but has also shaped their energy consumption. According to [11], remittances directly affect energy consumption both in the short and long run. Not only that, remittances can explain the variation in future energy consumption. They came up with some policy suggestions like advocating financial inclusion, lowering transfer costs of remittances, promoting formal ways of transferring remittances, etc. A similar long-run relationship between these two major macroeconomic variables can be seen in other studies, too [3, 12]. Taking four major remittances-receiving countries, India, Pakistan, Bangladesh, and Sri Lanka, [3] found a positive impact of remittances on energy consumption. It also showed a unidirectional causality from remittances to energy. While working in Haiti, [13] found that remittances are increasingly being invested in projects related to renewable energy. Remittances are often seen as a source of permanent income, and a share of it is often spent to meet household energy demands [14]. As pointed out by [15], remittances can directly affect energy demand. The direct effect works through the rise in disposable income. In search of a better standard of living, this rise in disposable income results in higher purchases of luxury goods (primarily electronics), raising household energy consumption. [16] identified both direct and indirect effects of remittances to enhance energy consumption. To them, the direct effect increases the energy demand, whereas the indirect effect considers the rise in capital demand. Similar was the argument by [17] and [18], who identified that remittances develop households financially. Financial development or economic empowerment enables them to purchase expensive items like houses, electronic gadgets, etc., escalating energy consumption. According to [19], remittance-receiving households may save a surplus of their income in commercial banks (CMBs). This will allow CMBs to create credit for the industrial sector, generating economic activities and industrial production, which will increase energy demand. Similar findings can be seen in [20–22], where they have shown that surplus remittances are used for investment, which promotes financial activities and the setting up of industries that use more energy. There is a cascading effect of all of these, too. Setting up new industries, promoting financial activities, etc., promotes economic growth, enhancing energy consumption. Study on BRICS countries reveals that remittances can have differentiated effect on renewable and non-renewable energy [23]. Russia showed a significant positive impact of remittances on renewable energy, while for India, a percentage increase in remittances resulted in a more than 4% fall in non-renewable energy consumption. [24, 25] advocated that income from remittances increases the purchasing power of the households receiving it. They can use it to purchase smart devices (earlier, they were beyond their capability) that use more renewable and resource-based technologies. This, in turn, increases the demand for renewable energy. Remittances can affect the energy consumption level through other macroeconomic variables. It boosts the GDP of a country that promotes industrial production. The rise of industrial production increases energy consumption [26].

The interrelationship between GDP and energy consumption has been well-established by introducing the growth hypothesis, conservation hypothesis, and feedback hypothesis theorem. The growth hypothesis [27, 28] complies that economic growth results from energy consumption, and any policy promoting conservation will harm economic growth. Conversely, the conservation hypothesis advocates for a reverse dependency where economic growth promotes energy consumption. According to this hypothesis, energy consumption has an indirect dependency on economic growth; hence, any attempt to conserve the environment does not necessarily reduce economic growth [29]. On the contrary, the feedback hypothesis suggests a bi-directional and complementary relationship between energy consumption and economic growth [30]. It believes that any policy formulation supporting energy efficiency will significantly affect economic growth and vice-versa.

Over time, various studies have highlighted the substantial influence of international trade on energy consumption, which can be both positive and negative. Trade allows the transfer of efficient energy-saving technologies from developed to developing countries, eventually increasing energy efficiency and reducing consumption [31]. Trade openness raises economic activities, increasing the energy demand [32]. Studies have investigated a causal relationship between energy consumption and trade. There is evidence of a unidirectional causal relationship between renewable energy and trade where causality runs from international trade to renewable energy consumption [33–35]. There is also evidence of bidirectional causality between the two [36, 37]. There is evidence of no causal relationship between the two as well [38].

4. Data and Methodology

The study explores the asymmetric impact of remittances on renewable energy for India using annual time series data from 1990-2020. The two major variables the study is centered around are renewable energy consumption (percent of total final energy consumption) and remittances (percent of GDP). The control variables are gross domestic product (in the current US dollar) and trade openness (percent of GDP). Data on all these variables have been extracted from the World Development Indicators (WDI) [39]. All the variables have been transformed into their natural logarithm scale.

Some unforeseen and unavoidable events like financial crises, economic downswing or upswing, and changes in political power are hidden in time series data. Any linear approach cannot capture these events, resulting in erroneous inferences. The best way to internalize these issues is to apply an asymmetric and nonlinear cointegration model like NARDL [40], which segregates both short-run and long-run effects of the independent and dependent variables. Hence, the present study uses the NARDL model to explore the asymmetric impact of remittances on using renewable energy in India. One additional advantage of applying NARDL is it does not depend on the order of stationarity of concerned variables. It can be applied even if the variables are integrated of order I(0), I(1), or a combination of both [41]. NARDL is an unrestricted error correction model (as its long-run terms are specified) and is a nonlinear extension of the linear ARDL model. However, unlike the ARDL model, NARDL encompasses the decomposition of regressors into positive and negative changes.

The study analyses the asymmetric impact of remittances (*remit*) on renewable energy consumption (*renergy*) in India. Control variables include gross domestic product (*gdp*) and trade openness (*trade*). The functional form can be written as:

$$renergy = f(remit, gdp, trade) \tag{1}$$

One additional advantage of the NARDL model is that it separates the changes in the dependent variable (*renergy*) into positive and negative changes in the regressors (*remit*, *gdp*, and textittrade). Each regressor is decomposed into two parts, namely, the partial sum of positive and negative changes, and they are separately included in the model. As stated earlier, NARDL takes care of both long-run and short-run asymmetric relationships; hence, the complete nonlinear model can be written as:

$$\begin{aligned} \Delta renergy_t = \alpha_0 + \gamma_1 renergy_{t-1} + \gamma_2^+ remit_{t-1}^+ + \gamma_3^- remit_{t-1}^- + \gamma_4^+ gdp_{t-1}^+ + \gamma_5^- gdp_{t-1}^- + \\ \gamma_6^+ trade_{t-1}^+ + \gamma_7^- trade_{t-1}^- + \sum_{i=1}^{p-1} \beta_1 \Delta renergy_{t-i} + \sum_{i=0}^{q} \beta_2^+ \Delta remit_{t-i}^+ + \sum_{i=0}^{q} \beta_3^- \Delta remit_{t-i}^- + \\ \sum_{i=0}^{q} \beta_4^+ \Delta gdp_{t-i}^+ + \sum_{i=0}^{q} \beta_5^- \Delta gdp_{t-i}^- + \sum_{i=0}^{q} \beta_6^+ \Delta trade_{t-i}^+ + \sum_{i=0}^{q} \beta_7^- \Delta trade_{t-i}^- + \epsilon_t \end{aligned} \tag{2}$$

β are the short-run coefficients, γ are the long-run coefficients, p and q are the lag order calculated using Akaike Information Criteria (AIC). The partial sums of positive and negative changes of the variables can be summarized as:

$$
\begin{aligned}
remit_t^+ &= \sum_{j=1}^{t} \Delta remit_{t-1}^+ = \sum_{j=1}^{t} \max(\Delta remit_j, 0) \\
remit_t^- &= \sum_{j=1}^{t} \Delta remit_{t-1}^- = \sum_{j=1}^{t} \min(\Delta remit_j, 0) \\
gdp_t^+ &= \sum_{j=1}^{t} \Delta gdp_{t-1}^+ = \sum_{j=1}^{t} \max(\Delta gdp_j, 0) \\
gdp_t^- &= \sum_{j=1}^{t} \Delta gdp_{t-1}^- = \sum_{j=1}^{t} \min(\Delta gdp_j, 0) \\
trade_t^+ &= \sum_{j=1}^{t} \Delta trade_{t-1}^+ = \sum_{j=1}^{t} \max(\Delta trade_j, 0) \\
trade_t^- &= \sum_{j=1}^{t} \Delta trade_{t-1}^- = \sum_{j=1}^{t} \min(\Delta trade_j, 0)
\end{aligned} \tag{3}
$$

Eq. (2) can be used to capture the long-run and short-run asymmetric effects.
Long-run asymmetric effects

$$
\begin{aligned}
remit \text{ on } renergy : LR_{remit^+} &= \frac{-\gamma_2^+}{\gamma_1} \quad \text{and} \quad LR_{remit^-} = \frac{-\gamma_2^-}{\gamma_1} \\
gdp \text{ on } renergy : LR_{gdp^+} &= \frac{-\gamma_4^+}{\gamma_1} \quad \text{and} \quad LR_{gdp^-} = \frac{-\gamma_5^-}{\gamma_1} \\
trade \text{ on } renergy : LR_{trade^+} &= \frac{-\gamma_6^+}{\gamma_1} \quad \text{and} \quad LR_{trade^-} = \frac{-\gamma_7^-}{\gamma_1}
\end{aligned} \tag{4}
$$

Short-run asymmetric effects

$$
\begin{aligned}
remit \text{ on } renergy &: \sum_{i=0}^{q} \beta_2^+ \quad \text{and} \quad \sum_{i=0}^{q} \beta_2^- \\
gdp \text{ on } renergy &: \sum_{i=0}^{q} \beta_4^+ \quad \text{and} \quad \sum_{i=0}^{q} \beta_5^- \\
trade \text{ on } renergy &: \sum_{i=0}^{q} \beta_6^+ \quad \text{and} \quad \sum_{i=0}^{q} \beta_7^+
\end{aligned} \tag{5}
$$

Using the Wald test, these long-run coefficients can be tested for possible asymmetric effects of the variables involved. For this, the null hypotheses would be:

$$
\begin{aligned}
remit \text{ on } renergy &: \frac{-\gamma_2^+}{\gamma_1} = \frac{-\gamma_2^-}{\gamma_1} \\
gdp \text{ on } renergy &: \frac{-\gamma_4^+}{\gamma_1} = \frac{-\gamma_5^-}{\gamma_1} \\
trade \text{ on } renergy &: \frac{-\gamma_6^+}{\gamma_1} = \frac{-\gamma_7^-}{\gamma_1}
\end{aligned} \tag{6}
$$

Any diversion from equality concludes the existence of long-run asymmetry. Similarly, the Wald test can also be used for short-run coefficients for testing short-run symmetry. The null hypotheses are:

$$\begin{aligned} remit \text{ on } renergy &: \sum_{i=0}^{q} \beta_2^{+} = \sum_{i=0}^{q} \beta_2^{-} \\ gdp \text{ on } renergy &: \sum_{i=0}^{q} \beta_4^{+} = \sum_{i=0}^{q} \beta_5^{-} \\ trade \text{ on } renergy &: \sum_{i=0}^{q} \beta_6^{+} = \sum_{i=0}^{q} \beta_7^{+} \end{aligned} \tag{7}$$

Similar to the long-run, a rejection of the null hypothesis implies the existence of a short-run asymmetric relationship.

Steps involving NARDL start with testing for stationarity, as the existence of I(2) for any of the variables restricts the applicability of this model [42]. One of the major drawbacks of conventional unit root tests (ADF & PP) is that they do not allow for structural break. Structural break is a very common and significant issue that needs to be addressed while considering time series study. If ignored, it can lead to severe consequences, starting with misspecification of the model and leading to erroneous policy prescriptions. During the period concerned, the Indian economy went through several economic and political changes that profoundly impacted its macroeconomic variables. Hence, any study on India involving this and a larger period should allow the structural break for an impactful policy suggestion. Thus, the study employs a unit root test for unknown structural breaks [43]. The next step involves testing cointegration among the selected variables when asymmetry is considered. The null hypothesis of equality among parameters (γ) is tested against their alternative inequality hypothesis using the bound test [44]. If the estimated F-statistic is beyond the upper bound, we conclude that the series is cointegrated even in the presence of asymmetry. Variable-specific long-run asymmetric effects have been tested using the Wald test. The next step involves applying the nonlinear ARDL method of estimation. This leads to estimating asymmetric dynamic multiplier effects. These result in a dynamic multiplier graph, which shows the adjustment pattern of the dependent variable regarding its new long-run equilibrium as a consequence of a positive or negative unitary shock of the factors involved, e.g., remittances, GDP, and trade. The asymmetric dynamic multiplier effects can be estimated as:

$$
\begin{aligned}
M_h^+(remit) &= \sum_{j=0}^{h} \frac{\delta renergy_{t+j}}{\delta remit_t^+} \\
M_h^-(remit) &= \sum_{j=0}^{h} \frac{\delta renergy_{t+j}}{\delta remit_t^-} \\
M_h^+(gdp) &= \sum_{j=0}^{h} \frac{\delta \text{renergy}_{t+j}}{\delta gdp_t^+} \\
M_h^-(gdp) &= \sum_{j=0}^{h} \frac{\delta renergy_{t+j}}{\delta gdp_t^-} \\
M_h^+(trade) &= \sum_{j=0}^{h} \frac{\delta renergy_{t+j}}{\delta trade_t^+} \\
M_h^-(trade) &= \sum_{j=0}^{h} \frac{\delta renergy_{t+j}}{\delta trade_t^-}
\end{aligned} \tag{8}
$$

If $h \to \infty$, then $M_h^+(remit) \to \frac{-\gamma_2^+}{\gamma_1}$, $M_h^-(remit) \to \frac{-\gamma_2^-}{\gamma_1}$, $M_h^+(gdp) \to \frac{-\gamma_4^+}{\gamma_1}$, $M_h^-(gdp) \to \frac{-\gamma_5^-}{\gamma_1}$, $M_h^+(trade) \to \frac{-\gamma_6^+}{\gamma_1}$, $M_h^-(trade) \to \frac{-\gamma_7^-}{\gamma_1}$ showing asymmetric responses of renewable energy for positive and negative shocks of remittances, GDP, and trade. Based on these results, the dynamic multiplier graphs were plotted. Finally, the study employs a nonlinear stability test in the form of NARDL CUSUM and CUSUM square graphs. Apart from this familiar residual diagnostic test of normality, autocorrelation and heteroscedasticity have also been reported.

5. Results and Discussion

The analysis starts with checking the presence of stationarity in the data through unit root tests. The results of the unit root test are shown in Table 1. The study used ADF [45] and PP [46], the two most conventional unit root tests. The results show that all the variables are non-stationary at a level under the trend and intercept option. But at the first difference, they all become stationary. Conventional unit root approaches don't capture the issue of structural break. To address this issue, this study introduced a unit root test that allows unknown structural break [43]. This test contains a single unknown breakpoint, the results of which have been reported in Table 2. The table shows that while energy, GDP, and trade are stationary at levels, remittances are stationary at the first difference in the presence of a structural break. Here, remittances and trade show structural breaks in 2014, while these are 1998 and 2005 for renewable energy and GDP, respectively. The most important thing is that there is a mix of levels of cointegration (which was absent in the ADF and PP test when we didn't allow structural break). No series is stationary beyond I(1), implying there is enough justification for applying the NARDL method.

The identification of stationarity leads us to cointegration testing to examine whether the associated variables are cointegrated in the long run. This has been done by the bounds F-test following [44]. The results of the bounds test have been given in Table 3.

To apply the asymmetric ARDL (NARDL) model to the data, what follows is testing the existence of a long-term asymmetric relationship of the controlled variables with renewable energy by applying the Wald test. Table 4 reports the long-run asymmetric effect of remittances, GDP, and

Table 1: *Unit root test: trend & intercept (without structural break)*

Variables	ADF (level)	ADF (1st diff.)	PP (level)	PP (1st diff.)	Order
renergy	-0.480	-4.245*	-0.600	-4.243*	I(1)
remit	-2.652	-4.792*	-2.652	-12.304*	I(1)
gdp	-3.313	-5.437*	-3.263	-5.443*	I(1)
trade	-0.608	-4.845*	-0.648	-4.874*	I(1)

Note: * implies 1% level of significance

Table 2: *Zivot and Andrews unit root test (with structural break)*

Variables	ZA	Order	Break year
renergy	-2.449*	I(0)	1998
remit	-2.109**	I(1)	2014
gdp	-4.903*	I(0)	2005
trade	-3.218*	I(0)	2014

Note: * & ** imply 1% & 5% level of significance, respectively

trade on renewable energy. The Wald test shows positive and negative movements of remittances exercise long-run asymmetric impact on renewable energy. But there is no such evidence for GDP and trade.

Once the asymmetric relationship between the two concerned variables is established, one can apply the nonlinear ARDL model to Eq. (2) to estimate the short-run and long-run dynamics among the variables. The results of nonlinear ARDL are represented in Table 5.

Akaike Information Criterion (AIC) was used to select the optimal lag, which came out to be (4,2,2,2,2,2,1). Table 5 has two parts: dynamic asymmetric results in terms of the long-run and short-run coefficients, whereas the lower part represents long-run asymmetric coefficients. These long-run coefficients have already been used for nonlinear bound tests for possible long-run cointegration. The results suggest that while the lagged negative remittance shock has a positive and significant (at 1% level) impact on renewable energy consumption in India, the same can't be said for the lagged positive remittance shock. This implies that in the long run, the impact of remittances on renewable energy is asymmetric as the impact of negative remittances shock is different from that of positive energy shock. The alternative can be seen in the case of gross domestic product (GDP). Here, lagged positive shock has a significant negative effect on renewable energy consumption (at 1% level), whereas its lagged negative shock has an insignificant impact on renewable energy, implying an asymmetric relationship.

The case with trade openness is different from both of the earlier cases. Both the lagged positive and negative shock of trade openness significantly impact renewable energy consumption in India. From the results of long run asymmetric, it is seen that while a positive shock of remittances reduces renewable energy consumption by almost 0.01% (insignificant), a negative shock of remittances (that is, a reduction of remittances) reduces the use of renewable energy by a higher and significant magnitude (almost 0.20%). This implies remittances have long-term asymmetric effects on renewable energy consumption. This justification is, as the use of renewable energy requires higher investment, at least to start with, a continuous and significant flow of remittances is essential to promote the use of renewable energy in a country like India. Support for this can be seen in earlier studies on electricity consumption [15]. Again, since the coefficient of remit- is greater than the coefficient of remit+, the negative shock of remittances has a more dominant impact on renewable energy consumption than its positive counterpart.

Table 3: *Results of nonlinear bound test*

Model	F-statistics	Upper bound	Lower bound
renergy/remit+, remit-, GDP+, GDP-, trade+, trade-	6.08		
Critical values			
10%		1.99	2.94
5%		2.27	3.28
2.5%		2.55	3.61
1%		2.88	3.99

Note: The critical values are based on [47]

Table 4: *Long-run asymmetric effects*

Variables	W-test	p-value
$remit_{LR}$	10.2371*	0.0014
GDP_{LR}	0.1483	0.7002
$trade_{LR}$	2.0966	0.1476

Note: * implies 1% level of significance

On the contrary, while a negative shock of GDP has an insignificant effect on renewable energy consumption, a 1% positive shock reduces renewable energy consumption by almost 0.25%, which is significant at a 1% level. This means economic growth also has an asymmetric effect on the use of renewable energy.

The impact of a positive shock of trade is positive, implying a 1% increase in trade openness increases renewable energy consumption by almost 0.24%, which is significant at a 1% level. In contrast, a negative trade shock reduces renewable energy consumption by 0.21%, which is also significant at 1%. Hence, trade openness also executes a significant asymmetric impact on the use of renewable energy.

In the short run, a reduction in all three variables and their lagged values significantly impacts renewable energy consumption. While a lagged negative shock of remittances reduces renewable energy, its current component has an increasing consequence over renewable energy. The result further highlights that while a 1% positive shock of the current period GDP reduces energy consumption by 0.46%, its lagged value has a positive impact, which is significant at a 1% level. The result also demonstrates both positive and negative shock of trade openness to have a significant positive effect on the use of renewable energy, though varied in dimension, signifying a short-run asymmetric relationship. A significant and negative ECM (-1) term suggests long-run cointegration.

Subsequently, the study has conducted various diagnostic tests to validate the estimated model. The set of diagnostic tests reported in Table 6 comprises a serial correlation test (LM serial correlation Test), a test for heteroscedasticity (Breusch-Pagan-Godfrey test), a test for residual normality (Jarque-Bera test), and a test for model specification (Ramsey RESET test). The results confirm that the model does not suffer from autocorrelation and heteroscedasticity as the p-value of χ^2-statistic for both are 0.9931 and 0.7725, respectively, signifying acceptance of respective null hypotheses. The p-value of the χ^2-statistic of the Jarque-Bera test is 0.2051, resulting in approval of the null hypothesis, implying normality of the residuals. The value of Ramsey RESET comes out to be 0.2825, which is statistically insignificant, indicating the correct specification of the model. Finally, the stability of the model has been tested using both cumulative sum (CUSUM)

Table 5: *NARDL estimation results*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long run				
renergy(-1)	-2.8118*	0.2533	-11.1003	0.0016
remit+(-1)	-0.0230	0.0201	-1.1466	0.3347
remit-(-1)	0.5759*	0.0533	10.8109	0.0017
gdp+(-1)	-0.6910*	0.0822	-8.4042	0.0035
gdp-(-1)	-0.4779	0.3938	-1.2135	0.3118
trade+(-1)	0.6715*	0.0975	6.8873	0.0063
trade-(-1)	0.5793*	0.0558	10.3841	0.0019
Short run				
D(renergy (-1))	0.9140*	0.1817	5.0299	0.0151
D(renergy (-2))	-0.5517*	0.0814	-6.7807	0.0066
D(renergy (-3))	0.2463***	0.0874	2.8167	0.0669
D(remit+)	-0.0067	0.0230	-0.2912	0.7899
D(remit +(-1))	0.0120	0.0140	0.8592	0.4534
D(remit-)	0.1315*	0.0206	6.3906	0.0078
D(remit -(-1))	-0.3158*	0.0325	-9.7194	0.0023
D(gdp+)	-0.4453*	0.0425	-10.4769	0.0019
D(gdp+(-1))	0.4421*	0.0556	7.9570	0.0041
D(gdp-)	8.2142*	0.9095	9.0312	0.0029
D(gdp-(-1))	-1.7892*	0.2253	-7.9430	0.0042
D(trade+)	0.1156**	0.0357	3.2394	0.0479
D(trade+(-1))	-0.0471	0.0309	-1.5235	0.2250
D(trade-)	0.8126*	0.0493	16.4905	0.0005
C	11.2767*	1.0528	10.7109	0.0017
Long run asymmetric coefficients				
remit+	-0.0082	0.0065	-1.2497	0.3000
remit-	0.2048*	0.0120	17.0635	0.0004
gdp+	-0.2457*	0.0118	-20.8838	0.0002
gdp-	-0.1700	0.1435	-1.1846	0.3215
trade+	0.2388*	0.0153	15.6266	0.0006
trade-	0.2060*	0.0077	26.5958	0.0001
C	4.0105*	0.0323	124.0673	0.0000
ECM(-1)	-0.733916*	0.084840	-8.650629	0.0000

Note: *, ** & *** imply 1%, 5% & 10% level of significance respectively

and the cumulative sum of squares (CUSUMQ) tests following [48]. They test for stability of long-run coefficients (Fig. 4). The results show that both these graphs are within the 5% level of critical bound, suggesting the model to be stable parametrically. Fig. 5 provides the asymmetric dynamic multiplier graphs, which are the outcome of the NARDL model. The figure illustrates the asymmetric adjustment of renewable energy consumption to its new long-run equilibrium following positive and negative shocks in remittances, GDP, and trade openness.

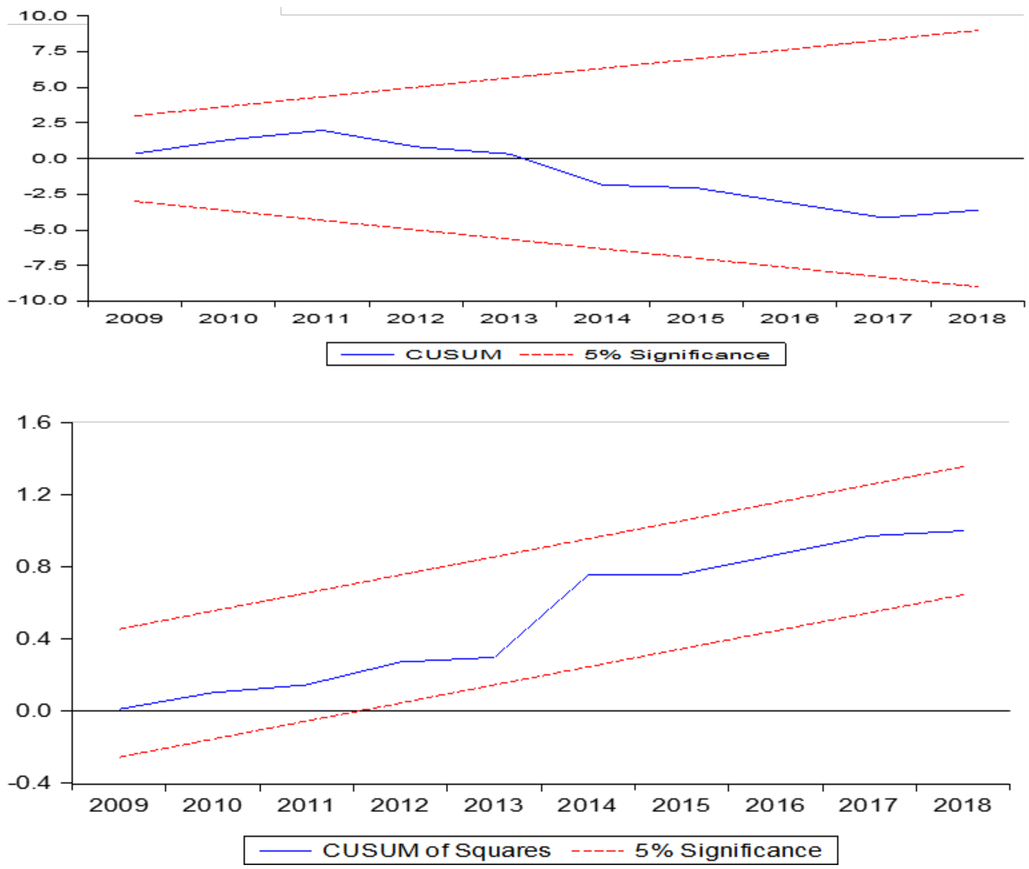

Figure 4: *Test of stability*

Table 6: *Diagnostic analysis*

Diagonstic test	Serial correlation (p-value)	Heteroscedasticity (p-value)	Normality (p-value)	Model specification (p-value)
LM Test	0.9931			
Breusch-Pagan-Godfrey		0.7725		
Jarque-Bera			0.2051	
Ramsey RESET				0.2825

6. Conclusion and Policy Suggestions

Remittances play a significant role in shaping India's macroeconomic status as they are one of the major sources of foreign capital. Energy, on the other hand, is the most dominant component in fuelling economic growth. With the advent of sustainable development, India is moving towards an economic regime with higher use of renewable energy. This will mitigate the adverse effects of growth and lead to a sustainable future. India is one of the largest economies in the world, and its policy formulation in terms of energy use is bound to have a significant impact on the global

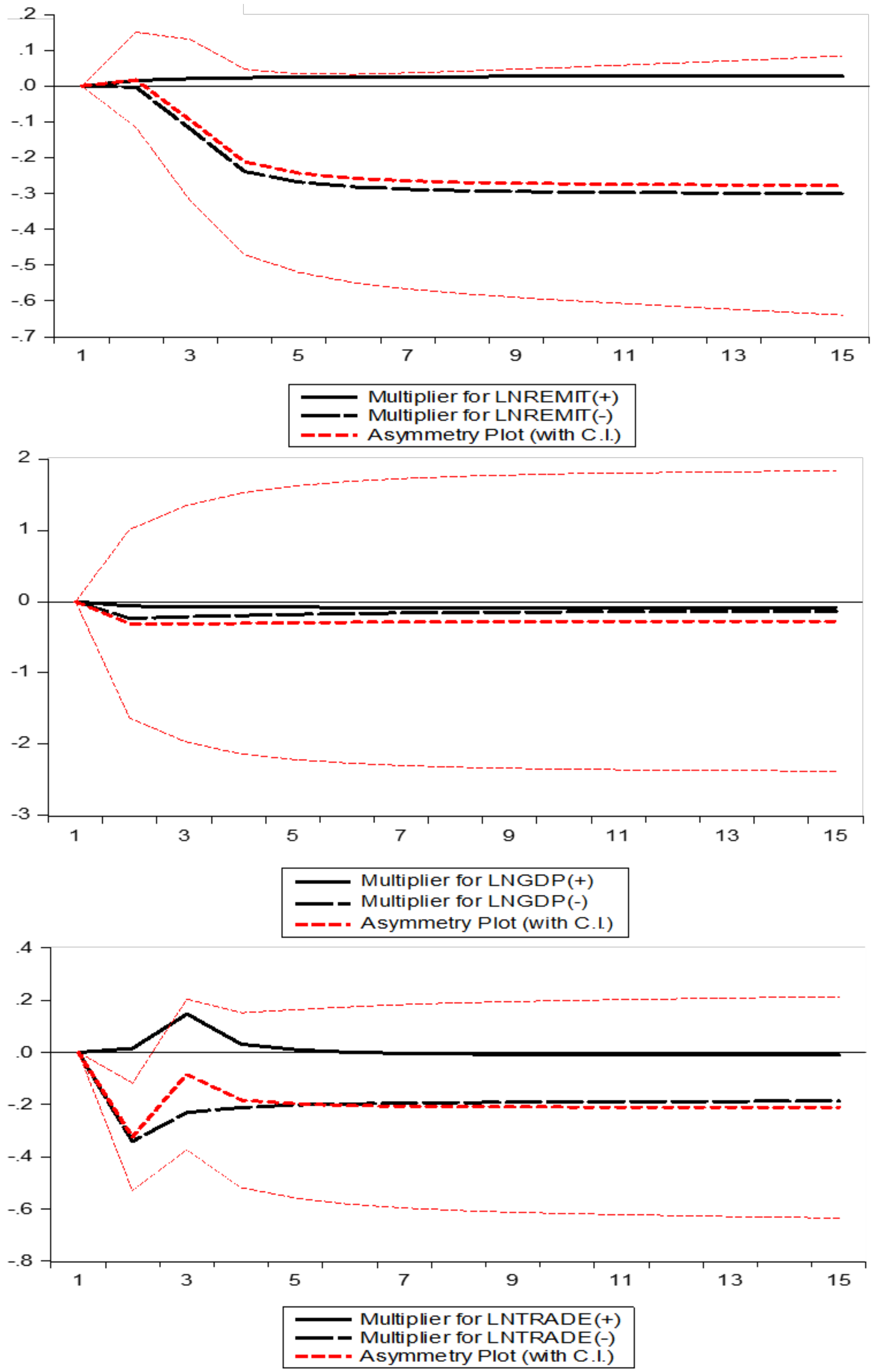

Figure 5: *NARDL multiplier graph*

economy. Looking at these pivotal roles played by both remittances and energy, it is crucial to study their interrelationship for India. The originality of the present study lies in the fact that it is the first attempt to understand this interrelationship, where the focus is to analyze the impact of remittances on renewable energy consumption in India under a time series framework. The study has analyzed this with the help of an asymmetric structure and discussed both short-run and long-run dynamics, which have yet to be dealt with.

The study has applied the nonlinear ARDL (NARDL) model to analyze this impact. Results from the NARDL model suggest that the lagged negative remittances shock positively and significantly impacts renewable energy consumption in India. Here, a 1% increase in remittance inflow results in a 0.13% rise in renewable energy consumption. An insignificant impact of its positive counterpart over renewable energy consumption confirms an asymmetric relationship. Long-run results highlight that while a positive shock of remittances reduces renewable energy consumption by 0.01%, which is insignificant, a negative shock of remittances reduces the use of renewable energy by a higher and more significant magnitude. Again, since the coefficient of the negative shock of remittances is greater than the coefficient of its positive complement, it implies that the negative shock of remittances has a more dominant part in determining its impact on renewable energy consumption than its positive constituent. This indicates remittances have long-term asymmetric effects on renewable energy consumption.

The explanation would be that heavy and costly machinery has to be installed to use renewable energy, which requires massive financial assistance [49, 50]. For a developing country like India, this calls for external financial support as governmental assistance is insufficient. Only through a continuous and significant flow of remittances India can shift its gear from over-exploiting fossil fuels to being the renewable energy hub of the world. Both GDP and trade openness hold an asymmetric relationship with renewable energy, as their lagged positive and negative shocks highlight differentiated results.

Based on these results, India should integrate its foreign and energy policies. As the inflow of remittances promotes renewable energy, policies must be framed to benefit the remittance-sending parties. As a significant share of remittances comes through informal channels, the government should also take all the necessary steps to strengthen the formal money-transferring networks. It requires the overall development of the indigenous banking sector, which may include domestic banks opening overseas branches. Policy must be formulated to reduce the cost of sending remittances as it would increase the inflow of remittances. On the energy front, policy should promote using remittances in renewable energy. Incentive schemes can be launched for domestic remittance-receiving families to promote installing solar panels, using batteries for domestic power consumption, etc [51]. The government could launch renewable remittance bonds to promote investing more in renewable energy by the individuals receiving remittances. This corpus can be used to promote the use of renewable energy in the manufacturing sector. As India is going through a transition phase in energy use, it must integrate its renewable energy use with remittance receipts. This will solve the financial crisis policymakers face and pave the way for sustainable economic growth.

Declaration of interest: None

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