Does renewable energy use enhance exchange rate appreciation and stable rate of inflation?

Abraham Deka 1 · Behiye Cavusoglu 1 · Sindiso Dube 2

Received: 6 July 2021 / Accepted: 23 September 2021 / Published online: 3 October 2021
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract
The current study is aimed at investigating the relationship between the use of renewable energy, the rate of currency exchange, and the rate of inflation with the ARDL model. The findings of the ECM show that in the long run, a bidirectional association between exchange rate and renewable energy exists in Brazil. This shows that the rate of currency exchange affects the use of renewable energy, and the use of renewable energy affects the rate of currency exchange. The inflation rate also affects renewable energy and exchange rate in the long run. The rate of adjustment to equilibrium is also below 50%, indicating that it will take a long time to adjust to long-run equilibrium. In the short run, we ascertain that renewable energy use has a significant negative effect on the rate of currency exchange, showing that a rise in the use of renewable energy significantly causes the exchange rate to appreciate. The long-run results show that renewable energy use negatively impacts exchange rate (appreciation), while the inflation rate and rate of currency exchange significantly affect the use of renewable energy positively. Thus, in addition to lowering carbon dioxide emissions and global warming effects, renewable energy use also facilitates an improvement in the currency’s value. Therefore, the use of renewable energy should be promoted, and nations should shift to the use of renewable energy. This will also promote zero carbon in the future.

Keywords Currency exchange rate · Rate of inflation · Use of renewable energy

Introduction
The use of renewable energy is rising in the world, as nations are attempting to shift from using fossil fuels that are hazardous to the environment. Fossil fuels are recognized to emit carbon dioxide into the environment, which ultimately causes global warming and the greenhouse effect. The United Nations has implemented campaigns to promote the use of renewable energy as a way of reducing greenhouse effects. Thus, nations are working toward achieving zero carbon in the future. Renewable energy sources include hydropower, solar power, wave, wind, and tidal, among many others. Renewable sources of energy are environmentally friendly and are therefore preferred as the best option for assisting with reducing global warming.

The studies by Becker and Fischer (2013), Salim and Rafiq (2012), and Shahbaz et al. (2020) indicated that the change of nations to renewable energy sources is necessary and crucial in order to reduce the effects of global warming around the world. The prices of fossil fuels are also rising, and shocks in the prices of fuel have been experienced in the world, thereby impacting the global economy. Therefore, in addition to causing the greenhouse effect, fossil fuels are finite resources that can be depleted, thereby causing inter-market volatility (Becker and Fischer 2013). Thus, there are many disadvantages of relying on using fossil fuels, and nations should rather adopt the use of renewable energy which is more advantageous compared to fossil fuels.

The environmental Kuznets curve (EKC) was founded as a result of the work of Kuznets (1955), who proposed that there
is an inverted U-shaped relationship between economic growth and income inequality. Kuznets (1955) alluded that as the national income of a country increases, income inequality will first rise and later decline after a turning point is reached. In their studies, Grossman and Krueger (1995), Shafik (1994), Selden and Song (1994), and Stern et al. (1996) postulated that a U-shaped relationship may also apply to the relationship between environmental impacts and economic growth. Many studies have been conducted to ascertain the association, and the results show that the EKC holds (see, for example, Dietz et al. 2012; Filippidis et al. 2021; Ma et al. 2021). Filippidis et al. (2021) identified that economic growth and the use of renewable sources of energy exhibit a U-shaped curve, while the relationship between fossil fuels and economic growth reveals an inverted U-shaped curve. According to Filippidis et al. (2021), increases in the use of renewable sources of energy have the tendency to reduce inequalities in income. Ma et al. (2021) also added that the use of renewable sources of energy reduces emissions of carbon dioxide gasses that are hazardous to the environment. Therefore, renewable energy use plays a crucial role in reducing environmental and economic inequalities in a nation.

It is crucial to ascertain the relationship between renewable energy use and economic indicators to understand the role of renewable energy use in reducing economic inequalities in order to facilitate appropriate policy-making and implementation. Various researches have been conducted in the past to ascertain the association between the use of renewable energy and economic variables such as economic growth, such as Smolović et al. (2020), Shahbaz et al. (2020), Chen et al. (2020), and Ivanovski et al. (2020). The study on the relationship of renewable energy and employment has been partially analyzed (see Ge and Zhi 2016). Researches on the determinants of renewable energy consumption have also been widely conducted (see, for example, Li et al. 2020; Da Silva et al. 2018; Bourcet 2020; Lin and Zhu 2019; Akintanade et al. 2020; Zhao et al. 2020), and different findings have been found. However, no studies have been done to ascertain the impact of renewable energy use on the inflation rate and exchange rate. A high rate of inflation is not good for the economy as this has the impact of eroding the buying power as the currency will depreciate. High inflation is an economic challenge that needs to be controlled in every nation. The work of Fisher (1930) showed that a high rate of inflation causes the exchange rate to rise (currency depreciation). Therefore, there is a gap in the literature since minimal research has focused on examining whether renewable energy stabilizes the inflation rate of nations while also enhancing exchange rate appreciation. The current study is prompted by the work of Deka and Dube (2021), who examined the relationship between inflation, exchange rate, and renewable energy in Mexico. Mexico is a country that is a member of the emerging economies, commonly known as the E7, and the current research seeks to extend their study and ascertain whether other E7 economies produced the same results as Mexico. Due to this reason, in this study, we seek to determine whether renewable energy stabilizes the inflation rate and improves exchange rate appreciation in Brazil, one of the E7 economies. Therefore, the findings of this study can be generalized to other E7 economies with almost the same economic conditions. More work should be done in the future to examine the association in other countries with different economic conditions.

The present research uses the ARDL model developed by Pesaran et al. (1997, 1999, 2001), which is capable of ascertaining the short- and long-run relationships between variables irrespective of whether they are integrated of different orders. This study will help nations to understand how the use of renewable energy can affect the rate of currency exchange, how the rate of currency exchange impacts the use of renewable energy, how the use of renewable energy affects the rate of inflation, and how the inflation rate affects the use of renewable energy in both the short and long run.

**Literature review**

**Environmental Kuznets curves**

The environmental Kuznets curve (EKC) was conceived from the work of Kuznets (1955), which proposes that an inverted U-shaped relationship exists between economic growth and income inequality. According to Kuznets (1955), there is a tendency for income inequality to initially decrease as a nation grows from low to high GDP per capita until it reaches a certain point known as the turning point. Any further increases in national income after the turning point is reached will result in a decline in income inequality. The works of Grossman and Krueger (1995), Shafik (1994), Selden and Song (1994), and Stern et al. (1996) alluded that the proposition made by Kuznets (1955) can also apply to environmental impact. Therefore, the EKC proposition states that the growth in the economy of nations will first tend to degrade the environment up to a certain point, after which, environmental stress will be decreased due to shifts from activities that degrade the environment to more environmentally friendly activities (see Dietz et al. 2012). The shift by nations from fossil fuel usage to the use of renewable sources of energy is another reason behind the shape of the EKC. In the past, nations relied on non-renewable energy sources, but in recent years, nations have started to reject fossil fuels and have shifted to the use of renewable sources of energy. Hence, when nations improve economically through the use of fossil fuels, the EKC will be going up, and when they shift to renewable sources, an increase in GDP is followed by a decline in environmental degradation.
Dietz et al. (2012) argued that if the environment is damaged by economic growth, then nations are faced with a trade-off situation between the two. However, this trade-off situation can be best solved by rejecting fossil fuels and using renewable energy sources that are friendly to the environment to enhance economic growth. For example, the study by Filippidis et al. (2021) alluded that the renewable energy and economic growth relationship exhibits a U-shaped curve. The study identified that using renewable sources of energy tends to reduce inequalities in income. This concurs with the postulations of Ma et al. (2021), who claimed that in France and Germany, the relationship between carbon dioxide emissions and GDP exhibits an inverted U-shape, thus validating the EKC. Ma et al. (2021) further argued that the use of renewable sources of energy decreases emissions of carbon dioxide, thus helping to reduce environmental stress.

Determinants of renewable energy use

Various studies have been undertaken to ascertain the determinants of renewable energy consumption (Akintande et al. 2020; Omri and Nguyen 2014; Lin and Zhu 2019; Papież et al. 2018; Bourcet 2020), while some studies have been conducted to ascertain the link between renewable energy and economic growth (Wang and Wang 2020; Rahman and Velayutham 2020; Eren et al. 2019; Chen et al. 2020; Ivanovski et al. 2020; Chica-Olmo et al. 2020; Smolović et al. 2020), and other researches have been done to analyze the link between employment and the use of renewable energy (Ge and Zhi 2016).

According to Akintande et al. (2020), there is a significant positive impact of human capital, population growth, and urban population on renewable energy use. The results of the research indicated that increases in the population growth, urban population, and human capital of a nation have the tendency to promote renewable energy use. This implies that nations with high populations and high human capital have greater chances of increasing renewable energy use. Bourcet (2020) concurred with Akintande et al. (2020) that demographic factors are the major determinants of renewable energy. In addition to demographic factors, Bourcet (2020) added regulatory and political factors as major determinants of renewable energy. This implies that the regulatory system of a nation significantly affects renewable energy consumption. Other studies like Saidi and Omri (2020) alluded that carbon dioxide emissions and trade openness significantly impact renewable energy use.

In the OECD, renewable energy consumption was found to have a positive impact on economic growth (see, for example, Wang and Wang 2020; Chen et al. 2020). Therefore, renewable energy should be promoted in the OECD countries since it helps to improve economic growth in these nations. In Europe, renewable energy is also observed to improve economic growth (Chica-Olmo et al. 2020; Smolović et al. 2020). Thus, in addition to reducing global warming effects, renewable energy significantly improves the economic growth of nations. As a result, if nations shift from fossil fuels to renewable energy sources, they will create a carbon-free environment while also improving the nation’s economic growth.

Relative purchasing power parity

The association between the rate of currency exchange and the rate of inflation was first examined in the Relative Purchasing Power Parity theory by Fisher (1930). The Relative Purchasing Power Parity theory is an extension of the Purchasing Power Parity theory proposed by Fisher (1930), which alludes that a positive association exists between the inflation rate and exchange rate. Thus, a high rate of inflation in a nation has the effect of increasing the exchange rate (currency depreciation). Therefore, a high inflation rate is not good for the economy because it reduces the value of the nation’s currency, thereby reducing its buying power. For this reason, any factors that raise inflation and depreciate the currency in a nation are always shunned, and thus, this research seeks to determine whether renewable energy stabilizes the inflation of nations while also promoting the currency value.

At this juncture, we have found out that renewable energy affects various economic factors such as economic growth and employment, among others, while renewable energy is determined by various factors including economic, political, demographic, and regulatory factors. However, few research have been carried out to directly ascertain the association between the use of renewable sources of energy and exchange rate on the one hand and the association between the use of renewable energy and the rate of inflation on the other. It is evident from the literature discussed above that a relationship may exist between these variables since economic factors significantly determine renewable energy use and this will be ascertained in this study.

Method and data

In this study, we aim to identify the relationship between the rate of currency exchange, the use of renewable energy, as well as the rate of inflation of Brazil for the period from 1990 to 2019. The use of renewable energy refers to the sources of energy that are not harmful or hazardous to the environment. They are environmentally friendly and have the capability of being used over and over again, and hence cannot be depleted, unlike fossil fuels that are hazardous to the environment and can be depleted. Sources of renewable energy include water, wind, tidal, waves, and solar, among many others. The rate of exchange is the price at which one currency is sold against another currency in the foreign exchange market.
In this study, the exchange rate employed is expressed as Brazilian real per one United States dollar (real/dollar), and a rise in the rate of currency exchange indicates a depreciation in the Brazilian real, whereas a drop in the currency shows an appreciation. The inflation rate is referred to as a general rise in the price of goods and services, and in this study, the consumer price indicator (CPI) of Brazil is used to proxy the inflation rate.

In order to analyze the relationship between the use of renewable energy, rate of inflation, and rate of currency exchange of Brazil, the dynamic autoregressive distributive lag (ARDL) model is employed. The ARDL approach was pioneered by Pesaran et al. (1997, 1999, 2001). Before, it was not possible to run levels relationship with variables that are integrated of different orders, and rather variables were supposed to be stationary to be specified in the traditional ordinary least square (OLS) model or to be integrated of the same order one, I(1), in order to be specified in cointegration regressions such as fully modified ordinary least square (FMOLS) or dynamic ordinary least square (DOLS) or in a vector error correction mechanism (VECM)(Pesaran et al. 2001; Keele and DeBoef 2008). However, the ARDL approach allows for variables that are integrated of different orders, I(0) and I(1), or that are not mutually cointegrated to be specified in a levels’ relationship (Pesaran et al. 2001; Keele and DeBoef 2008). It follows that, although I (0) and I (1) variables cannot be specified by employing the ARDL method, I (2) variables cannot be specified; hence, a unit root test should be employed to check if all variables are I (0) or I (1) (Pesaran et al. 2001; Smolović et al. 2020; Salim and Rafiq 2012). Thus, in this paper, we test for stationarity by employing the augmented Dickey–Fuller(ADF) test, which was pioneered by Dickey and Fuller (1979), and the Phillips–Peron(PP) test, which was pioneered by Phillips and Perron (1988). Various studies have recommended the ADF and PP tests of the unit root as the best and most appropriate methods (see Granger 1986).

The ARDL model is a univariate method that is based on F-statistics and t-statistics to test for the existence of levels relationship of variables irrespective of whether they are I (0), I (1)(Pesaran et al. 2001). The null hypothesis of the model is that there is no levels relationship irrespective of the fact that the regressions are I (0), I (1)(Pesaran et al. 2001). When the F-statistics and t-statistics values of the ARDL bounds test approach are greater than the I (0) and I (1) bounds, then a levels relationship exists and we can specify the short-run ARDL model and the equilibrium correction mechanism (ECM)(Pesaran et al. 2001). The ECM examines the long-run association and equilibrium among the variables and the rate of adjustment to a long-run equilibrium (see, for example, Granger 1986; Engle and Granger 1987; Pesaran et al. 2001). When the F-statistics and t-statistics values are less than the I(1) and I(0), then we can only specify the short-run ARDL model (Pesaran et al. 2001). However, when the F-statistics and t-statistics lie in between the I (0) and I (1) bounds, then the inference is inconclusive and the problem can be overcome by examining the integration order and cointegration of the variables (Pesaran et al. 2001).

Equations (1), (2), and (3) below are the statistical representation of the short-run ARDL model when exchange rate, inflation, and renewable energy use are the explained variables, respectively, while Equations (4), (5), and 6 are the statistical representation of the long-run ARDL model when exchange rate, inflation, and renewable energy use are the explained variables, respectively (see, for example, Pesaran et al. 1999; Pesaran et al. 1997; Pesaran et al. 2001). The long-run ARDL model contains the error correction term (ECT) of the ECM model plus the short-run coefficients of the regressors. The ARDL model in this study is employed in such a way that all variables are employed as dependent variables in turn in order to examine how each variable is impacted by the other variables (Pesaran et al. 2001). \(\beta_0\), \(\beta_1\), \(\beta_2\), and \(\beta_3\) are the coefficients of the short- and long-run ARDL model, and \(\beta_4\) is the ECT’s coefficient, whereas \(\epsilon t\) is the error term.

**Short-run ARDL model statistical representation**

\[
\Delta ER_t = \beta_0 + \sum_{i=1}^{p} \beta_1 iER_{t-i} + \sum_{i=0}^{q} \beta_2 iLnRE_{t-i} + \sum_{i=0}^{q} \beta_3 iINF_{t-i} + \epsilon_t
\]  

(1)

\[
\Delta INF_t = \beta_0 + \sum_{i=1}^{p} \beta_1 iER_{t-i} + \sum_{i=0}^{q} \beta_2 iLnRE_{t-i} + \sum_{i=1}^{q} \beta_3 iINF_{t-i} + \epsilon_t
\]  

(2)

\[
\Delta LnRE_t = \beta_0 + \sum_{i=0}^{p} \beta_1 iER_{t-i} + \sum_{i=1}^{q} \beta_2 iLnRE_{t-i} + \sum_{i=0}^{q} \beta_3 iINF_{t-i} + \epsilon_t
\]  

(3)

### Table 1 Results of descriptive statistics

| Variable | ER  | INF | lnRE |
|----------|-----|-----|------|
| Mean     | 1.9224 | 59.574 | 3.7489 |
| Median   | 1.9501 | 6.6 | 3.7541 |
| Maximum  | 3.9445 | 952 | 3.8439 |
| Minimum  | 0.00003 | 3.2 | 3.6187 |
| Std. Dev.| 1.1249 | 196.45 | 0.0594 |
| Sum      | 57.674 | 1608.5 | 112.47 |
| Obs      | 30 | 30 | 30 |

© Springer
Long-run ARDL model statistical representation

\[ \Delta ER_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta ER_{t-i} + \sum_{i=0}^{q} \beta_{2i} \Delta \ln RE_{t-i} \\
= \sum_{i=0}^{q} \beta_{3i} \Delta \ln RE_{t-i} + \beta_4 \text{ECT}_{t-1} + \epsilon_t \]

\[ \Delta \ln RE_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta ER_{t-i} + \sum_{i=0}^{q} \beta_{2i} \Delta \ln RE_{t-i} \\
= \sum_{i=0}^{q} \beta_{3i} \Delta \ln RE_{t-i} + \beta_4 \text{ECT}_{t-1} + \epsilon_t \]

Data analysis and results

Descriptive statistics

The descriptive statistics results in this study are provided in Table 1 below, and we ascertain that this study uses 30 observations for each variable (use of renewable energy, rate of currency exchange, rate of inflation). For the rate of currency exchange, the mean value is 1.9224 Brazilian real per dollar for the period between 1990 and 2019, while the standard deviation is 1.1249. The mean values of the rate of inflation and use of renewable energy are 59.57% and 3.7489, respectively, and their standard deviations are 196.45 and 0.0594, respectively. We observed that the inflation rate of Brazil deviates significantly from the mean value, meaning it is not stable.

Unit root test

The results of the unit root tests of the variables under study are provided in Table 2 below. Pre-testing of the variables is not compulsory (Pesaran et al. 2001) since we employ the ARDL approach which can be employed irrespective of whether the variables are I (0), I (1) or are not cointegrated. However, since I (2) variables cannot be specified in an

Table 2  Unit root test results

| Variable | ADF test | PP test |
|----------|----------|---------|
|          | Level t-statistic P-value First difference t-statistic P-value | Level t-statistic P-value First difference t-statistic P-value |
| ER       | -0.6889  0.8343 -3.8525 0.0284** | -0.8330  0.7945 -3.8154 0.0307** |
| lnRE     | -2.4389  0.1408 -3.3224 0.0234** | -2.0154  0.2789 -3.3224 0.0234** |
| INF      | 19.458   1.0000 -14.2717 0.0000*** | 18.072   1.0000 -37.6856 0.0000*** |

*It represents a 5% level of significance  
**It represents a 1% level of significance

Table 3  ARDL bounds test results

| Dependent variable | F-statistic Signif. | I(0) | I(1) | t-statistic Signif. | I(0) | I(1) |
|--------------------|--------------------|------|------|--------------------|------|------|
| ER                 | 7.8030*** 10% 4.19 5.06 -5.0634*** 10% -3.13 -3.63 |
|                    | 5% 4.87 5.85 5% -3.41 -3.95 |
|                    | 1% 6.34 7.52 1% -3.96 -4.53 |
| lnRE               | 7.2268*** 10% 2.17 3.19 -4.8463*** 10% -1.62 -2.68 |
|                    | 5% 2.72 3.83 5% -1.95 -3.02 |
|                    | 1% 3.88 5.3 1% -2.58 -3.66 |
| INF                | 124.75*** 10% 2.17 3.19 20.3386*** 10% -1.62 -2.68 |
|                    | 5% 2.72 3.83 5% -1.95 -3.02 |
|                    | 1% 3.88 5.3 1% -2.58 -3.66 |

***It represents a 1% level of significance  
Schwarz information criterion is used to automatically select a lag length.
It represents a 1% level of significance

It represents a 5% level of significance

*It represents a 10% level of significance

Adjusted

-RTrend 0.0281*
Constant 13.849***

INF −ER −Long-run relationship

Short-run relationship

Δ(F) 0.348*** 1.249*** −0.0163***
Δ(INF(−1)) −1.5905 1.249*** 6.2705*
Δ(INF) 3.759* 1.249***
Δ(DIF(−1)) −3.6028*** −9.2607 −0.0163***
Δ(F) 13.849***
Trend 0.0281***
R-squared 0.5521 0.9503 0.4746
Adjusted R-squared 0.4937 0.9432 0.4746

ARDL model, we conduct the unit root test to verify that no variable is I (2). By employing the ADF and PP unit root tests, we ascertain in this study that the variables rate of currency exchange, rate of inflation, as well as the use of renewable energy are all integrated of order one, I (1). Therefore, in this study, we specify variables that are stationary at first difference; however, we specify them in an ARDL model at a level without converting them to the first difference since the ARDL model will automatically convert them to the first difference where necessary.

ARDL test results

The F- and t-statistics results of the ARDL bounds test in Table 3 show that when the rate of currency exchange, the rate of inflation, and the use of renewable energy are specified in an ARDL model as the explained variables in turn, there is significant levels relationship among the variables irrespective of whether they are I (1), I (0) or are not mutually cointegrated (Pesaran et al. 2001; Narayan 2005). Therefore, we ascertain that we can specify both the ECM and the short-term ARDL model (Pesaran et al. 2001). Moreover, in this study, the Schwarz information criterion is used to automatically select the lag length, and lag 1 is selected for all variables, thereby making it an ARDL(1;1;1) model.

We also provide the ECM findings in Table 4 below. When the rate of currency exchange and the use of renewable energy are specified as explained variables, respectively, the error correction term (ECT) is negative and significant at 1% level, implying that a long-run effect running from the rate of inflation and use of renewable energy to rate of currency exchange exists in addition to a long-run effect running from the rate of inflation and rate of currency exchange to the use of renewable energy (Pesaran et al. 2001; Pesaran et al. 1999; Granger 1986; Engle and Granger 1987). Therefore, in the long term, the use of renewable energy and the rate of inflation significantly impact the rate of currency exchange, while the rate of currency exchange and rate of inflation also significantly impact the use of renewable energy. Thus, a bidirectional causal effect on the rate of currency exchange and the use of renewable energy in the long run is ascertained. If the rate of inflation is given as the explained variable in the ECM, its ECT is found to be positive, as shown in Table 4 below, indicating that divergence will occur in the long run, thereby making it impossible for a long-run equilibrium to occur. The ECT also gives the adjustment rate to equilibrium (Granger 1986), where the ECT when the rate of currency exchange is the explained variable is 34.79%, while when the use of renewable energy is the explained variable, it is 1.63%. The ECT values are very low at below 50%, showing that the adjustment rate to a long-run equilibrium is very low (Granger 1986).

The long-run results of the ARDL model are given in Table 4 below, and the findings show that in the long run, a negative association exists between the rate of foreign exchange as the explained variable and inflation rate and renewable energy use as the explanatory variables. This shows that a rise in renewable energy by 1 unit will significantly reduce the rate of foreign exchange (currency appreciation) by 10.65 units. Therefore, in the same way that it reduces economic inequalities and environmental stress, renewable energy is also capable of reducing currency depreciation in the long run. The research found no significant long-term relationship between the rate of inflation and the exchange rate and use of renewable energy. A significant long-term impact of the rate of currency exchange and inflation rate on renewable energy is also ascertained, as shown in Table 4 below.

Moreover, in Table 4 below, the findings of the short-run ARDL model when the rate of currency exchange, rate of inflation, and use of renewable energy are the explained variables are given. The findings show that in the short run, renewable energy has a significant negative impact on the exchange rate in Brazil. The results are significant, implying that a rise in the use of renewable energy in Brazil has the effect of reducing the foreign exchange rate (currency appreciation), ceteris paribus. In the short run, the inflation rate is found to have no significant effect on the rate of currency exchange in Brazil, ceteris paribus. The lag value of the rate of exchange significantly affects the current rate of currency exchange negatively, indicating that if the exchange rate was high in the past in Brazil, it will fall in the future and vice versa. Therefore, we
propose that in addition to reducing the effects of global warming, the use of renewable energy is vital in ensuring high currency value in a country, and thus, Brazil should invest in renewable energy. Our findings support the findings of Smolović et al. (2020) and Shahbaz et al. (2020).

The findings also show that the rate of currency exchange significantly impacts the use of renewable energy positively in the short run. This shows that a rise in the foreign exchange rate has the effect of promoting the use of renewable energy, ceteris paribus. In other words, undervaluation of the Brazilian real will improve renewable energy use in the nation. The effect of the inflation rate is positive and significant, indicating that a high rate of inflation in Brazil will cause the use of renewable energy supply to rise. The lag value of renewable energy significantly impacts the current value negatively. However, the results show that the use of renewable energy and the rate of currency exchange in Brazil do not significantly impact the rate of inflation. It is only the lag value of the inflation rate that positively affects the inflation rate.

The Schwarz information criterion is used to automatically select the lag length.

### Residual diagnostic and stability test results

The Breusch–Godfrey serial correlation test is used to test whether the residuals in the models are serially correlated or not. Also, the Jarque–Bera normality test and the Breusch–Pagan–Godfrey test of heteroskedasticity are employed in this research. The results indicate that the residuals of the models have no serial correlation problems, and that they are homogeneous. When the rate of currency exchange and use of renewable energy are the explained variables, the residuals are normally distributed, but when the rate of inflation is the explained variable, the residuals are not normally distributed. Therefore, we ascertain that the models’ residuals have no serial correlation problems, are homogeneous, and are normally distributed; thus, the robustness, reliability, and validity of the findings in this study have been confirmed. The findings of the residual diagnostic tests indicate that a correct functional form of the model has been employed (Table 5).

The Schwarz information criterion is used to automatically select the lag length.

In Figs. 1, 2, and 3 below, we provide the results of the CUSUM stability test results. The CUSUM graphs in all three figures lie within the 5% significance bounds, indicating that the ARDL models employed in this study are stable, and the results are therefore robust.

Moreover, Figs. 4, 5, and 6 below provide the results of the CUSUM of square stability results to check the omitted variable bias in the models. The CUSUM of the square graph in all three figures lies within the 5% significance bounds.

| Table 5 | Residual diagnostic test results |
|---------|---------------------------------|
|         | Breusch–Godfrey serial correlation LM test | Jarque–Beranormality test | Heteroskedasticity test: Breusch–Pagan–Godfrey |
|         | $F$-statistic | $P$-value | Statistic | $P$-value | $F$-statistic | $P$-value |
| ER      | 1.6869        | 0.2131    | 0.8617    | 0.6499    | 0.6118        | 0.718     |
| lnRE    | 0.1928        | 0.826     | 1.5776    | 0.4544    | 0.7708        | 0.5222    |
| INF     | 0.1377        | 0.8723    | 207.33    | 0.0000*** | 0.6512        | 0.689     |

* ***It represents significance at 1% level

**Fig. 1** CUSUM stability test (exchange rate is the dependent variable)

**Fig. 2** CUSUM stability test (renewable energy is the dependent variable)
indicating that the ARDL models employed in this study are stable, and hence, modeling and variable selection are correct.

**Conclusion**

In short, the research findings show that when the rate of currency exchange, use of renewable energy, and rate of inflation are specified as the explained variables in an ECM model, a long-run effect on renewable energy and inflation rate to the rate of currency exchange is observed; the long-run effect of the rate of currency exchange and rate of inflation on the use of renewable energy exists because the ECT is negative and significant (Pesaran et al. 2001; Granger 1986; Engle and Granger 1987). This implies that in the long run, the use of renewable energy and the rate of inflation of Brazil significantly impact the nation’s rate of currency exchange and that in the long run, the rate of currency exchange and the rate of inflation significantly impact the use of renewable energy (Granger 1986). Therefore, in the long run, a bidirectional relationship between the rate of currency exchange and the use of renewable energy in Brazil is observed. The ECT when the rate of inflation is the explained variable is positive and significant, indicating that the variables will not converge but rather diverge. The speed of adjustment to the equilibrium of the ECM models is very low, below 50%, showing that it will take a long time for the rate of currency exchange, use of renewable energy, and the rate of inflation of Brazil to adjust to the long-run equilibrium (Granger 1986; Engle and Granger 1987).

We also ascertain that renewable energy use significantly affects the rate of currency exchange negatively in the short run. This implies that a rise in the use of renewable energy in Brazil will have the effect of improving the value of the Brazilian real. This is in line with the findings of Deka and Dube (2021). Therefore, in addition to reducing the emissions of carbon dioxide and the effects of global warming (Smolović et al. 2020; Shahbaz et al. 2020), the use of renewable energy in Brazil leads to an improvement in the value of the nation’s currency. The long-run results that are used for policy-making in this research study show that renewable energy use significantly affects the exchange rate in a negative
way, while exchange rate and inflation affect renewable energy use positively in the long run. Therefore, renewable energy use encourages exchange rate appreciation.

Therefore, like in all other nations that have shifted from the use of non-renewable energy sources to the use of renewable energy sources, nations are encouraged to increase the use of renewable energy sources and this move will help achieve zero carbon in the future and also correct some economic and environmental stress (Filippidis et al. 2021; Ma et al. 2021). The limitations of the research study are that it only employs three variables and omits other determinants of the exchange rate, renewable energy use, and those of inflation rate which could produce biased results. However, the model used in this study, the ARDL model, includes the lag values of the explained variable and those of the explanatory variables, which increases the number of regressors in the model, and therefore, the results are robust. These results can be generalized to other emerging economies that have similar conditions to Brazil, and more studies in the future should be conducted to examine how the rate of currency exchange is impacted by the use of renewable energy in developing and developed countries.

Availability of data and materials The data used in this paper is secondary data and were retrieved from the Organization for Economic Cooperation and Development (OECD) website, www.oecd.org.

Author contribution AD: conceptualization, methodology, writing – original draft, software. BC: data curation, writing – review and editing, supervision. SD: visualization, investigation.

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication The authors guarantee that this manuscript has not been previously published in other journals and is not under consideration by other journals. The authors also guarantee that this manuscript is original and is their own work.

Competing interests The authors declare no competing interests.

References

Akintande OJ, Olubusoye OE, Ademkinju AF, Olanrewaju BT (2020) Modeling the determinants of renewable energy consumption: evidence from the five most populous nations in Africa. Energy 206: 117992

Becker B, Fischer D (2013) Promoting renewable electricity generation in emerging economies. Energy Policy 56:446–455

Bourcet C (2020) Empirical determinants of renewable energy deployment: a systematic literature review. Energy Econ 85:104563

Chen C, Pinar M, Stengos T (2020) Renewable energy consumption and economic growth nexus: evidence from a threshold model. Energy Policy 139:111295

Chica-Olmo J, Sari-Hassoun S, Moya-Fernández P (2020) Spatial relationship between economic growth and renewable energy consumption in 26 European countries. Energy Econ 92:104962

Da Silva PP, Cerqueira PA, Ogbe W (2018) Determinants of renewable energy growth in Sub-Saharan Africa: evidence from panel ARDL. Energy 156:45–54

Deka A, Dube S (2021) Analyzing the causal relationship between exchange rate, renewable energy and inflation of Mexico (1990–2019) with ARDL bounds test approach. Renew Energy Focus 37:78–83. https://doi.org/10.1016/j.renef.2021.04.001

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74(366a):427–431

Dietz T, Rosa EA, York R (2012) Environmentally efficient well-being: is there a Kuznets curve? Appl Geogr 32(1):21–28

Engle RF, Granger CW (1987) Co-integration and error correction: representation, estimation, and testing. Econometrica 55:251–276

Eren BM, Taspinar N, Gokmenoglu KK (2019) The impact of financial development and economic growth on renewable energy consumption: empirical analysis of India. Sci Total Environ 663:189–197

Filippidis M, Tzouvanas P, Chatziantoniou I (2021) Energy poverty through the lens of the energy-environmental Kuznets curve hypothesis. Energy Econ 105328:105328

Fisher I (1930) Theory of interest: as determined by impatience to spend income and opportunity to invest it. Augustus Kelly Publishers, Clifton

Ge Y, Zhi Q (2016) Literature review: the green economy, clean energy policy and employment. Energy Procedia 88:257–264

Granger CW (1986) Developments in the study of cointegrated economic variables. In: Oxford Bulletin of economics and statistics

Grossman G, Krueger A (1995) Economic growth and the environment. Q J Econ 110:353–377

Ivanovski K, Hailemariam A, Smyth R (2020) The effect of renewable and non-renewable energy consumption on economic growth: non-parametric evidence. J Clean Prod 286:124956

Keele L, DeBoef S (2008) Taking time seriously: dynamic regression. Am J Polit Sci 52(1):184–200

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45(1):1–28

Li J, Zhang X, Ali S, Khan Z (2020) Eco-innovation and energy productivity: new determinants of renewable energy consumption. J Environ Manag 271:111021

Lin B, Zhu J (2019) Determinants of renewable energy technological innovation in China under CO2 emissions constraints. J Environ Manag 247:662–671

Ma X, Ahmad N, Oei PY (2021) Environmental Kuznets curve in France and Germany: role of renewable and nonrenewable energy. Renew Energy 172:88–99

Narayan PK (2005) The saving and investment nexus for China: evidence from cointegration tests. Appl Econ 37(17):1979–1990

Omri A, Nguyen DK (2014) On the determinants of renewable energy consumption: international evidence. Energy 72:554–560

Papić M, Śmiech S, Frodyma K (2018) Determinants of renewable energy development in the EU countries. A 20-year perspective. Renew Sust Energ Rev 91:918–934

Pesaran, M. H., Shin, Y., & Smith, R. P. (1997). Pooled estimation of dynamic heterogeneous panels. J Environ Econ Manag 27:111021

Pesaran MH, Y Hussain SF, Smith RP (1999) Pooled mean group estimation of dynamic heterogeneous panels. J Am Stat Assoc 94(446):621–634

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16(3):289–326

Phillips PC, Perron P (1988) Testing for a unit root in time series regressions. Biometrika 75(2):335–346
Rahman MM, Velayutham E (2020) Renewable and non-renewable energy consumption-economic growth nexus: new evidence from South Asia. Renew Energy 147:399–408
Salim RA, Rafiq S (2012) Why do some emerging economies proactively accelerate the adoption of renewable energy? Energy Econ 34(4): 1051–1057
Selden TM, Song D (1994) Environmental quality and development: is there a Kuznets curve for air pollution emissions? J Environ Econ Manag 27:147–162
Shafik N (1994) Economic development and environmental quality: an econometric analysis. In: Oxford economic papers, pp 757–773
Shahbaz M, Raghutla C, Chittedi KR, Jiao Z, Vo XV (2020) The effect of renewable energy consumption on economic growth: evidence from the renewable energy country attractive index. Energy 207:118162
Smolović JC, Muhadinović M, Radonjić M, Đurašković J (2020) How does renewable energy consumption affect economic growth in the traditional and new member states of the European Union? Energy Rep 6:505–513
Stern DI, Common MS, Babbier EB (1996) Economic growth and environmental degradation. World Dev 24:1151–1160
Wang Q, Wang L (2020) Renewable energy consumption and economic growth in OECD countries: A nonlinear panel data analysis. Energy 207:118200
Zhao P, Lu Z, Fang J, Paramati SR, Jiang K (2020) Determinants of renewable and non-renewable energy demand in China. Struct Chang Econ Dyn 54:202–209
Saidi K, Omri A (2020) The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. Environ Res 186:109567

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.