Monetary and Energy Policy interlinkages:
The case of renewable energy in the US

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Highlights

•Knowledge of all factors driving renewable energy adoption assists policymakers.

•Monetary policy instruments may affect renewable energy consumption.

•Expansionary monetary policy promotes renewable energy consumption.

•Interest rates affect future changes in renewable energy and need to be considered.

Abstract

The rising threats of environmental deterioration propel the use of renewable energy (RE). However, the proportion of RE compared to non-renewables is still limited due to various socioeconomic factors. Investigating the drivers of renewable energy consumption (REC) remains the field's main focus, which interestingly disregards the investigation of monetary policy (MP) as a driver of REC. So, we probe whether MP affects REC in the US. The findings document that expansionary monetary policy (EMP) promotes REC during the long-run (LR) and short-run (SR), and vice versa. Further, the impact of MP is relatively strong in the SR. Based on the findings, we propose to introduce/adopt an EMP that will escalate REC. Moreover, during the episodes of contractionary monetary policy, special incentives (e.g., tax cuts on renewable energy products, etc.) should be provided to offset the detrimental impact of contractionary monetary policy. Finally, the role of MP in the choice of RE as the preferred energy type directs energy policymakers not to underrate policy instruments such as interest rates in anticipating future changes and reacting accordingly.

Keywords: monetary policy; REC; sharp and smooth structural breaks unit root test; Fourier augmented ARDL; US

Abbreviations:

- Monetary policy MP
- Contractionary monetary policy CMP
- Expansionary monetary policy EMP
- Economic growth EG
- Renewable energy RE
- Renewable energy consumption REC
- GDP per capita GDPP
- Oil prices OIL
- Carbon dioxide CO2
- Short-run SR
- Long-run LR
- Sharp and smooth structural break unit root test SOR test
- Fourier augmented ARDL FA-ARDL

1. Introduction

In the academic literature and policy debate, the adoption of RE and its higher role in the supply mix internationally are among the main proposed approaches to curve the increasing trend of greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions (Sarfraz et al., 2022; Wei et al., 2022). Particularly after the COVID-19 pandemic, economies struggle to pick up their productivity, and hence, policies are sensitive to avoid any negative consequences to economic growth (EG) and development. However, the advantages of REC for energy security and environmental conditions are well-reported in the literature. At the same time, the impact of RE adoption on economic welfare is generally positive (Inglesi-Lotz, 2016; Mohsin et al., 2022).

The overall energy transition from fossil fuels to RE has been accelerated in recent years but not necessarily at the expected speed considering renewable energy's documented benefits. This was historically attributed to low Research and Development in the field, well-established fossil fuel dominance, and most importantly, renewable energy's high installation and maintenance costs. Considering these hurdles, the literature examining what determines RE adoption focused on EG

(Li et al., 2022), oil prices (Sadorsky, 2009), and financial development (Lahiani et al., 2021), among others.

Even though the investment requirements of RE technologies have been considered high, the impact of MP[1], proxied by interest rates, did not receive the necessary attention in the literature. For instance, Ziaei (2018) shows that MP affects energy consumption through portfolio balancing and signalling channels. The portfolio balancing channel expounds that EMP[2] escalates the consumption of goods, including REC. Similarly, the signalling channel explains that successive interest rate cuts (as a result of EMP) transmit the signal in the market that the interest rate will remain low in the future. As a result, demand for goods in all markets (i.e. goods market, energy markets, factors market, etc.) will surge. Likewise, the demand channel argues that EMP leads to higher EG, propelling consumers to use RE products. Qingquan et al. (2020) expound that EMP exerts pressure on producers to produce more output to meet the higher demand. As a result, non-renewable energy (NRE) consumption escalates while REC will witness a plunge. Similarly, export-based firms use cheap energy sources (i.e., NRE) to produce more at a lower cost. As a result, NRE and REC increase and decrease, respectively.

Parallel to this, EMP upsurges consumers' disposable income, raising the demand for a clean environment, and hence there will be a rise in REC (Egli et al., 2018). The increase in the real interest rate (i.e., contractionary MP[3]) leads to exchange rate depreciation. This depreciation in the

[1] Monetary policy is generally defined as the actions by the central bank (i.e., Federal Reserves in our case) to manage money circulation and interest rate to achieve economic stability.
[2] Expansionary monetary policy is refered as an increase in money circulation and/or decrease in interest rate in the economy.
[3] Actions related to plunging the money circulation and/or escalating interest rate are refered as contractionary monetary policy.

exchange rate discourages the imports of RE products, and hence REC witnessed a plunge in the economy.

Based on the discussion above, it can be deduced that MP can either escalate or plunge REC. Therefore, it is crucial to investigate how MP affects REC to understand the relationship and anticipate the impact. Comprehending that MP can potentially be a hurdle to the transition to RE may explain the slow adoption of RE. Hence, this study examines whether and how MP affects REC in the US from 1960 to 2020.

The motivation to choose the US for this study lies in the fact that it is the largest economy globally, whereas it is the second-largest carbon emitter. According to a report by the Energy Information Administration[4], petroleum and natural gas are the leading-consumed energy sources, but RE is the fastest-growing energy source in the US. Further, according to section 203 of the Energy Policy Act of 2005, renewable electricity use should be at least 7.5% of total electricity use in the US. RE directly provides jobs to almost 0.4 million citizens from an economic perspective. The US gives several financial incentives to the RE sector, such as rebates, performance-based incentives, grants, loan programs, loan guarantees, leases, renewable energy certificates, and feed-in tariffs. On the other hand, the US develops renewable portfolio standards, which are set of standards at the federal and state level to encourage RE. In the presence of all the incentives above, REC is still about 12.6% of the total energy consumption in the US[4]. On top of this, the Annual Energy Outlook of

[4] Center, B. P. (2020). Annual energy outlook 2020. Energy Information Administration, Washington, DC, 12, 1672-1679.

2021 claims economic policies as critical drivers of REC in the US. Therefore, the US seems an appropriate case study for our analysis.

The study's contribution to the literature is two-fold. The study contributes to the understanding of how MP decisions affect the transition to RE, notably in the US. To study the LR and SR effects of MP on REC, we methodologically use econometric tools including i) Shahbaz et al. (2018) unit root test (SOR), which accounts for both smooth and sharp structural breaks, and (ii) the Fourier Augmented Autoregressive Distributed Lag model (FA-ARDL). Additionally, the FA-ARDL model makes use of Fourier terms to account for the structural discontinuities in the dataset and produce results that are solid and trustworthy (Solarin, 2019). Finally, the robustness and sensitivity analysis is based on various model specifications (i.e., incorporating CO_2 emissions as a control variable and using per capita REC as a dependent variable) to examine how robust the baseline findings are with the choice of the empirical model.

It will become more important to guide future energy policies in accordance with the idea that monetary policy tools affect consumers' consumption decisions and patterns of renewable energy. The findings can help energy policies anticipate changes in REC patterns and use current or anticipated interest rate changes to supplement incentives and subsidies to encourage the use of RE and hasten the energy transition.

2. Literature review

We consolidate the literature on the impact factors of REC. Bourcet (2020) separates the drivers of REC into five broad categories: 1) economic determinants; 2) environmental determinants; 3) demographic determinants; 4) political/institutional determinants; 5) energy-related determinants.

The existing literature notes that institutional quality has a direct and indirect impact on REC. Uzar (2020a) investigates whether institutional quality enhances REC in selected 38 countries by using the PMG-ARDL model. The author concludes that improved institutional quality upsurges REC. Chen et al. (2021) argue that institutional quality performs a key role in REC. The authors note that, in countries with improved/high institutional quality, EG and trade escalate REC. Contrarily, EG and trade plunge REC in countries having low-quality institutions. In the case of Bangaldesh, Islam et al. (2022) adopt the dynamic ARDL model to discern the dynamic effect of institutional quality and urbanization in REC development. The outcomes from the study expound that institutional quality upsurges REC whilst urbanization exerts a detrimental impact on REC. Alsagr and Hemmen (2021) noted that geopolitical risk interestingly escalates REC. For selected emerging economies, Rahman and Sultana (2022) investigate whether the institutional quality is a hindrance to REC. The outcomes conclude that institutional quality positively affects REC.

Related to demographic determinants of REC, Willis et al. (2011) probed the impact of aging on REC. The study describes that the old-age population is not inclined towards new technology adoption and hence they avoid REC. Yang et al. (2016) attempt to probe the impact of urbanization on REC. The abovementioned study concludes that urbanization and REC have a positive relationship with each other. Atif et al. (2021) stated that female directors (in the US) upsurge REC at the firm level. Likewise, Salim and Shafiei (2014) examine the role of the population in REC for OECD countries. The outcomes of the study show that population is a critical driver of REC in OECD countries. For selected African countries, Akintande et al. (2020) investigate whether urbanization, population, and EG plummet REC. The outcomes expound that urbanization, population, and EG escalate REC.

There is a plethora of literature on the environmental drivers of REC. The prior literature mostly adopts CO2 emissions to represent environmental degradation, and discerns whether environmental degradation influences REC. The literature often describes that CO2 emissions promote REC. Omri and Nguyen (2014) probe whether CO2 emissions, trade, and oil affect REC in selected 64 countries. The findings from the GMM model claim that trade and emissions escalate REC. Similarly, Chen (2018) investigates whether CO2, EG, and trade upsurge REC in China. The author notes heterogeneous findings, i.e., emissions escalate REC in several provinces whereas it plunges REC in other provinces. Alola et al. (2019) probe whether CO2 emissions, housing policy, and EG aggravate REC. The outcomes highlight that CO2 emissions, housing policy, and EG enhance REC in the LR. Contrarily, there exist various studies which claim that CO2 emissions either plunge or exert no impact on REC (Marques and Fuinhas, 2011).

On the economic and energy-related determinants of REC, it is a well-documented point that EG is a key driver of REC. The higher EG allows economic agents (i.e., consumers and producers) to convert from non-renewables to REC. Therefore, empirical studies validate that EG escalates REC (Omri et al., 2015; Li and Leung, 2021). Fiscal decentralization and eco-innovations can also influence REC. For instance, Li et al. (2020) noted that human capital, energy prices, EG, and eco-innovations escalate REC in OECD countries. Su et al. (2021) confirm that fiscal decentralization, political stability, and eco-innovation related to RE promote REC in several OECD countries. Financial development is also found to be a key determinant of REC. To report this, Eren et al. (2019) conclude that financial development and EG upsurge REC in India. Likewise, Anton and Nucu (2020) validate that financial development upsurges REC in selected European Union (EU) member countries. Similar outcomes are reported by Mukhtarov et al. (2022) for Turkey. Lahiani et al. (2021) noted that financial development exerts an asymmetric impact on REC. Shahbaz et al. (2022) also highlighted that financial development and foreign direct investment (FDI) enhance REC. Fan and Hao (2020) report that FDI improves REC in China. Uzar (2020b) proposes a new driver of REC, i.e., income inequality. The author investigates the impact of income inequality on REC. The findings claim that income inequality discourages REC. Likewise, Asongu and Odhiambo (2021) conclude that income inequality affects REC in African countries.

The current section reports the drivers of REC wherein economic determinants are the most critical. While reviewing the economic determinants of REC, we notice that there does not exist any empirical work that links monetary policy and REC. Therefore, we attempt to explore whether MP affects REC in the US.

3. Theoretical framework, empirical model, and data

We use the neoclassical demand function to model the impact of MP on REC, which describes that the quantity demanded of a good depends on the level of income and relative prices. It is worth mentioning that various empirical studies also adopt the neoclassical demand function to model the drivers of REC (Li et al., 2022; Mukhtarov et al., 2020; Sadorsky, 2009). It is worth noting that an upsurge in income escalates purchasing power of individuals which propels them to use environment-friendly products (e.g., renewables) and hence REC witnessed an increase over time. Next, oil prices are negatively associated with non-renewable energy. Therefore, high oil prices plunge the non-renewable energy consumption. Since REC and non-renewable energy are substitutes, a decrease in non-renewable energy will escalate REC. Thus, high oil prices may promote REC. Next, MP could be the potential influencer of REC. As we mentioned in the introduction section, MP may affect REC through the portfolio and signalling channel. After incorporating MP as a key independent variable in the demand function, the final model is expressed as follows:

$$REC = f\,(GDPP, OIL, MP) \qquad (1)$$

Where REC denotes REC, GDPP is gross domestic product per capita, OIL represents crude oil prices, and MP is monetary policy (proxied by real interest rate). REC is measured in British thermal units; GDPP is measured in 2015$, OIL is measured via the West Texas Index, and MP denotes monetary policy proxied by the real interest rate from 1960 to 2020. The GDPP, OIL, and MP data are derived from Federal Reserve Economic Data (FRED) (https://fred.stlouisfed.org/), while data on REC is downloaded from Energy Information Administration (EIA) (https://www.eia.gov/). The variables are converted into a natural logarithmic form in the modelling exercise.

The descriptive statistics of the entire dataset are reported in Table 1, which delineates that the entire dataset is normally distributed.

Table 1: Descriptive statistics

Statistic	Mean	Standard Deviation	Skewness	Kurtosis	Jarque-Bera
GDPP	10.52	0.34	-0.3	1.87	(0.12)
MP	1.13	0.64	-0.47	2.72	(0.29)
OIL	2.90	1.11	-0.44	2.12	(0.13)
REC	8.66	0.35	0.02	2.55	(0.77)

Note:(.) denotes p-value. *** represents the level of significance at 1%.

4. Econometric methodology

4.1. ***SOR unit root test***

Unit root testing is indispensable in time series datasets to evade spurious outcomes. Several unit root tests exist in the literature, such as the ADF test, Zivot and Andrew test, Enders and Lee (2012) test, etc. However, these tests have a few drawbacks. For instance, the ADF test does not cover structural breaks, while Zivot and Andrew's test captures one break. It is worth mentioning that different dynamics of time series datasets exist, such as state-dependent nonlinearity, smooth breaks, sharp breaks, and/or a combination of them. Conventional unit root tests cover one dynamic of datasets at a time. ignoring the presence of breaks and nonlinearity may provide unreliable results. Therefore, Shahbaz et al. (2018) proposed a sharp and smooth structural breaks unit root test (SOR) that covers nonlinearity in consort with the sharp and smooth breaks and generates reliable results. Particularly, SOR test is based on a two-step procedure, wherein the following models/equations are estimated in the first step:

Model-A1: $$\hat{\varepsilon}_t = y_t - \hat{\alpha}_1 - \hat{\alpha}_2 F_t\,(\hat{\gamma}, \hat{\tau}) \tag{2}$$

Model-A2: $$\hat{\varepsilon}_t = y_t - \hat{\alpha}_1 - \hat{\beta}_1 t - \hat{\alpha}_2 F_t\,(\hat{\gamma}, \hat{\tau}) \tag{3}$$

Model-A3: $$\hat{\varepsilon}_t = y_t - \hat{\alpha}_1 - \hat{\beta}_1 t - \hat{\alpha}_2 F_t\,(\hat{\gamma}, \hat{\tau}) - \widehat{\beta_2} F_t\,(\hat{\gamma}, \hat{\tau}) t \tag{4}$$

In step 2, we compute the t ratio affiliated with $\hat{\varphi}$, which is Enders and Lee (2012) test statistic, in the following OLS regression:

$$\hat{\varepsilon}_t = d(t) + \varphi_1 \hat{\varepsilon}_{t-1} + \varepsilon_t \tag{5}$$

In Equation (5), d(t) represents a deterministic function of t, while ε_t is a stationary error term. The null hypothesis of the SOR test expressed that a unit root exists in the data, whilst the alternate reports that there does not exist a unit root in the dataset. To save space, we do not present the detailed methodology of the SOR test, therefore, readers are advised to refer to Shahbaz et al. (2018).

4.2. ***Fourier augmented ARDL***

To scrutinize whether MP affects REC, we employ the novel FA-ARDL approach. This section initially explains the methodology of augmented ARDL, while the latter expounds on how we transform the augmented ARDL model into the FA-ARDL model.

Pesaran et al. (2001) provide the ARDL bounds test to investigate the cointegration across variables. In the ARDL specification, Eq. (1) can be expressed as:

$$\Delta \mathrm{REC}_t = \alpha + \sum_{i=1}^{y} \varphi_i \Delta REC_{t-i} + \sum_{i=0}^{p} \beta_i \Delta GDPP_{t-i} + \sum_{i=0}^{q} \gamma_i \Delta OIL_{t-i} + \sum_{i=0}^{m} \omega_i \Delta MP_{t-i} + \pi_1 REC_{t-1} + \pi_2 GDPP_{t-1} + \pi_3 OIL_{t-1} + \pi_4 MP_{t-1} + v_t \quad (6)$$

In Equation (6), α displays the intercept, while φ_i, β_i, γ_i, and ω_i are SR coefficients. π_i (i=1, 2, 3, 4) shows the LR estimates. Also, y, p, q, and m symbolize the lag order whilst v_t shows the disturbance term. The ARDL bounds test contains an assumption, i.e., the dependent variable has no impact on the independent variable(s). This indicates that the variables are (weakly) exogenous, however, this assumption merely holds. Wherefore, the invalidity of the weak exogeneity assumption makes the assumption (i.e., related to the distribution) of the ARDL bounds test invalid (McNown et al., 2018).

For probing the cointegration, Pesaran et al. (2001) provide two tests: the F-test (H_0: $\pi_1 = \pi_2 = \pi_3 = \pi_4 = 0$) on all lagged level variables (i.e., all LR estimates); and the t-test (H_0: $\pi_1 = 0$) on the lagged level dependent variable. Whereas McNown et al. (2018) and Sam et al. (2019) propose a new F-test on the lagged level independent variables (Ho : $\pi_2 = \pi_3 = \pi_4 = 0$) in the augmented ARDL approach, which complements the mentioned F- and t-tests by Pesaran et al.

(2001). McNown et al. (2018) and Sam et al. (2019) claim that these three tests should be employed to split cointegration, non-cointegration, and degenerate cases. Pesaran et al. (2001) argued that two degenerate cases (i.e., degenerate case-I and case-II) exist in ARDL modelling, and both claim the invalidity of cointegration. The degenerate case-I is noticed if the lagged level independent variable(s) are statistically insignificant in the ARDL model. It is also worth mentioning that the critical values for the degenerate case-I (i.e., whether the lagged level independent variable(s) is(are) significant) are not provided. To evade the degenerate case-I, the dependent variable needs to be stationary (I(1)). Nonetheless, it is now well known that unit root tests have low power, inferring that the results from the unit root test could be deceptive. Thus, the augmented ARDL test handles this concern by rendering an additional F-test on lagged level independent variables. Hence, the augmented ARDL method concludes that cointegration will be scrutinized based on all three tests reported as follows:

- F-test (1): which is applied on all lagged level variables;
- t-test: which is applied on lagged level dependent variable;
- F-test (2): which is applied on lagged level independent variables.

Additionally, cointegration occurs only if the null hypothesis of these tests is rejected. Hence, the augmented ARDL approach outperforms conventional ARDL bounds tests since it expounds a complete picture of cointegration and rules out any inconclusive findings.

The augmented ARDL approach cannot cover the sharp and smooth structural breaks, while disregarding them may lead to weak inferences (Enders and Lee, 2012). Thus, the analysis uses the Fourier approximation because it can handle the presence of sharp and smooth breaks (Gallant,1981). It is worth noting that the Fourier approximation does not require any prior information about the nature, frequency, and date/time of structural breaks. Moreover, unlike structural break dummies, the Fourier approximation does not require several parameters and provides good size and power properties (Enders and Lee, 2012). Based on the above arguments, the analysis employs the augmented ARDL model with the Fourier approximation (i.e., the Fourier augmented ARDL approach) to explore the impact of MP on REC. The final expression of the Fourier augmented ARDL model yields:

$$\Delta \mathrm{REC}_t = \alpha + \sum_{i=1}^{y} \varphi_i \Delta REC_{t-i} + \sum_{i=0}^{p} \beta_i \Delta GDPP_{t-i} + \sum_{i=0}^{q} \gamma_i \Delta OIL_{t-i} + \sum_{i=0}^{m} \omega_i \Delta MP_{t-i} + \pi_1 REC_{t-1} + \pi_2 GDPP_{t-1} + \pi_3 OIL_{t-1} + \pi_4 MP_{t-1} + \Psi_1 \sin\left(\frac{2\pi kt}{T}\right) + \Psi_2 \cos\left(\frac{2\pi kt}{T}\right) + v_t \quad (7)$$

Where Ψ_1 and Ψ_2 respectively, represent the amplitude and displacement of the frequency component. Next, $\pi = 3.14$, k denotes the frequency of Fourier, t denotes trend, and T represents the sample size. For further details related to the Fourier approximation in ARDL modelling, the reader is advised to see the study of Solarin (2019).

Regarding the motivation for employing the novel SOR test and FA-ARDL modeling, it is worth noting that economic indicators (e.g., EG, OIL, REC, etc.) witness several structural breaks over time. For instance, the oil crisis of the 1970s, the global financial crisis, and the COVID-19 pandemic are perceived as the most critical structural breaks that have significantly affected the global economy. Further, ignoring structural breaks while testing the unit root property and/or investigating the dynamic relationship between variables may yield unreliable inferences (Nawaz et al., 2019). Therefore, covering the issue of structural breaks is imperative while handling time series datasets. Based on this, we employ the SOR test and the novel FA-ARDL model that can account for the multiple structural breaks. On top of this, unlike other models (e.g., linear and nonlinear ARDL, FMOLS, DOLS, etc.) FA-ARDL modelling has an additional advantage that it incorporates three tests to validate the cointegration. Hence, the FA-ARDL has two advantages: 1) it comes up with the whole situation/scenario of cointegration; 2) it covers breaks/nonlinearity.

5. Empirical results

We report the empirical findings in this section. Firstly, we report the findings from the novel SOR test in Table 2.

Table 2: SOR test results

Indicator	**Level**			**1st difference**		
	Model-A1	**Model-A2**	**Model-A3**	**Model-A1**	**Model-A2**	**Model-A3**
GDPP	-3.814	-4.16	-4.47	-4.79**	-4.99**	-5.68**
OIL	-3.02	-3.11	-3.14	-6.53**	-6.25**	-6.72**
MP	-3.90	-5.60**	-5.67**	-6.78**	-	-
REC	-1.54	-3.64	-4.51**	-5.53**	-5.88**	-

Note: ** represents p-value <0.05. Also, k=5. For critical values, see Shahbaz et al. (2018).

As depicted in Table 2, the null hypothesis for GDPP and OIL at the level (I (0)) across all models (i.e., Model-A1, Model-A2, Model-A3) could not be rejected, indicating that GDPP and OIL contain unit root at the level. Whereas the null hypothesis for GDPP and OIL at the first difference in all models could be rejected, suggesting that these variables are integrated at I (1). In the case of MP, we can reject the null hypothesis at the level for Model-A2 and Model-A3. Therefore, it could be concluded that MP is integrated at the level (I (0)). Next, the null hypothesis for REC at the level in Model-A1 and Model-A2 could not be rejected, indicating that there exists the unit root at I (0). However, we can reject the null hypothesis for REC at I(1) in Model-A1 and Model-A2. This implies that REC is integrated at I(1). we can apply the novel FA-ARDL approach to discern the impact of MP on REC as our dataset is integrated at I(0)/I(1).

In the next step, we test for cointegration through the novel FA-ARDL bounds test. The outcomes are reported in Table 3. Since the calculated values of F-test (1), t-test, and F-test (2) are greater than the upper bound values, we can reject the null hypothesis of no cointegration. Hence, it could be concluded that cointegration holds in our case.

Table 3: Testing cointegration

Test	Calculated value	Lower bound	Upper bound
F-test (1)	7.14***	4.29	5.61
t-test	-5.28***	-3.43	-4.37
F-test (2)	9.49***	3.83	6.33

Note: The critical values for F-test (2) are gathered from Sam et al. (2019). *** shows p-value<0.01.

After that, the impact of MP on REC is investigated through the novel FA-ARDL. The findings from the novel FA-ARDL model are expressed in Table 4. The LR estimates are reported in section-1, the SR results are reported in section-2, and the diagnostics in consort with other statistics are highlighted in section-3. As shown in Table 4, the MP, GDPP, and OIL coefficients are statistically significant at 1% in the LR and SR. This indicates that MP, GDPP, and OIL significantly impact REC. The value of MP is -0.13 and -0.17 in the LR and SR, respectively. This implies that a 1% increase in real interest rate (i.e., CMP) plunges the REC by 0.13% and 0.17% in the LR and SR, respectively. Finally, section-3 reports diagnostics, which are found to be satisfactory.

Table 4: Findings from the novel FA-ARDL model

Variable	Coefficient	p-value
Section-1 (LR findings)		
MP	-0.13***	0.00
GDPP	0.33***	0.00
OIL	0.13***	0.00
Section-2 (SR findings)		
MP	-0.17***	0.00
GDPP	0.42***	0.00
OIL	0.16***	0.00
Section-3 (diagnostics & other statistics)		
Adjusted R-square	0.62	
ECT	-0.72***	0.00
LM test	-	0.65
ARCH test	-	0.13
Ψ_1	-0.15	0.20
Ψ_2	-0.00	0.48
CUSUM	Stable	
CUSUM-square	Stable	

Note: *** denotes p-value<0.01. We do not report the SR coefficients at higher lags. ECT represents the error correction term.

Next, we incorporate per capita REC (RECP), REC/total population, as a dependent variable to perform sensitivity analysis. The findings while using RECP are reported in Table 5. As can be seen from section-4 (Table 5), the calculated values of F-test (1), t-test, and F-test (2) are larger than the upper bound values. Therefore, we can reject the null hypothesis and conclude the existence of cointegration. Further, the GDPP, OIL, and MP coefficients are statistically significant at 1% in the LR and SR, implying that these variables above significantly impact RECP. The coefficient of MP is negative in both the LR and SR, indicating that a rise in the real interest rate (i.e., CMP) impedes RECP. A positive coefficient for OIL and GDPP expounds that these variables above contribute to higher RECP. It is worth noting that these findings are similar to our baseline findings (i.e., Table 4). Therefore, we can conclude that we provide robust outcomes.

Table 5: Sensitivity analysis using RECP in the novel FA-ARDL model

Variable	Coefficient	p-value
Dependent variable = RECP		
Section-1 (LR findings)		
MP	-0.006***	0.00
GDPP	0.055***	0.00
OIL	0.007***	0.00
Section-2 (SR findings)		
MP	-0.007***	0.00
GDPP	0.056***	0.00
OIL	0.006***	0.00
Section-3 (diagnostics & other statistics)		
Adjusted R-square	0.57	
ECT	-0.61***	0.00
LM test	-	0.15
ARCH test	-	0.15
Ψ_1	-0.10	0.13
Ψ_2	-0.14	0.17
CUSUM	Stable	
CUSUM-square	Stable	
Section-4 (cointegration)		
Test	**Calculated value**	**Upper bound**
F-test (1)	5.58***	4.84
t-test	-3.80***	-3.33
F-test (2)	7.32***	5.93

Note: *** denotes p-value<0.01, whereas ** represents p-value<0.05. We do not report the lag coefficients in the SR. ECT represents the error correction term.

For the second sensitivity analysis, we employ CO_2 emissions as an additional control variable to discern whether our main findings are sensitive to the choice of the empirical model. The results are depicted in Table 6. Section-4 of Table 6 delineates the cointegration summary. The calculated values for F-test (1), t-test, and F-test (2) are greater than the upper bound values, suggesting that cointegration holds in this case. Further, the coefficient of MP is statistically significant. It contains a negative sign in both the LR and SR, indicating that an increase in the real interest rate (i.e., CMP) plunges the REC.

Table 6: Sensitivity analysis using CO_2 emissions in the novel FA-ARDL model

Variable	Coefficient	p-value
Dependent variable = REC		
Section-1 (LR findings)		
MP	-0.17***	0.00
GDPP	0.68***	0.00
OIL	0.10***	0.00
CO_2	-0.90**	0.03
Section-2 (SR findings)		
MP	-0.20***	0.00
GDPP	0.81***	0.00
OIL	0.11***	0.00
CO_2	-1.07**	0.03
Section-3 (diagnostics & other statistics)		
Adjusted R-square	0.58	
ECT	-0.91***	0.00
LM test	-	0.17
ARCH test	-	0.13
Ψ_1	5.10	0.11
Ψ_2	1.02	0.51
CUSUM	Stable	
CUSUM-square	Stable	
Section-4 (cointegration)		
Test	**Calculated value**	**Upper bound**
F-test (1)	4.85***	4.44
t-test	-4.65***	-4.23
F-test (2)	6.07***	5.35

Note: *** denotes p-value<0.01, whereas ** represents p-value<0.05. We do not report the lag coefficients in the SR. ECT represents the error correction term.

6. Conclusion and Discussion

6.1.Summary of findings

The international energy transition is undoubtedly on its way but not as fast as expected to mitigate the negative consequences of climate change. The literature discusses a variety of factors that affect the speed, particularly from technological and economic perspectives, as well as with regard to energy policy design and implementation. Understanding possible hurdles or boosters for RE adoption will assist the industry and policymakers in the future. Still, the impact of MP on REC remains understudied in the literature. For this reason, the direction and magnitude of the impact are not confirmed. Therefore, this study investigates the impact of MP on REC specifically in the

US. Our findings revealed that CMP (i.e., an increase in the real interest rate) discourages REC in the SR and LR, and vice versa. Next, the impact of MP on REC is relatively profound in the SR. Besides, two sensitivity analyses were introduced to probe whether the findings are robust to the choice of model and/or variables. The findings from the sensitivity analysis were found to be in line with our main results.

6.2.Results discussion

The potential reasons for these findings are as follows. First, the portfolio balancing channel expounds that an upsurge in the real interest rate (i.e., CMP) discourages demand for goods and services. This decline in demand for goods and services plunges REC directly and indirectly (i.e., derived demand). Second, the signalling channel notes that a consecutive surge in interest rate transmits a signal in the market that interest rate will remain high in the future. As a result, individuals decrease the demand for goods and services, including REC. Third, an increase in the real interest rate (i.e., CMP) impedes the income of the individuals. This decline in income level propels them not to demand a clean environment since environment-friendly goods and services are relatively expensive. Consequently, the demand for renewables impedes. The rise in the real interest rate (i.e., CMP) leads to exchange rate depreciation. This depreciation in the exchange rate discourages the imports of RE products, and hence REC witnessed a plunge in the economy. Next, the results show that both GDPP and OIL escalate REC. These results are backed by the conclusion of Sadorsky (2009). Higher GDPP improves the level of income, which, in turn, compels them to demand a clean environment, and hence REC will eventually increase. Parallel to this, higher oil prices impede the demand for non-renewables. As a result, REC raises since it is a substitute for non-renewables.

6.3.Policy implications

The study's findings provide policy insight from both monetary and energy policy perspectives. From this study's results, policymakers are advised to take into account the impact of MP on REC while modeling or designing MP based on the impact of MP on REC. Therefore, thorough research is necessary (in this area) to ascertain how MP transmits shocks in the renewable energy market. The next step is for policymakers to implement EMP to boost RE use in the US. This suggests that interest rates in the US should be kept low, as doing so encourages EG and strengthens REC. In order to prevent distortions or shocks in the market for renewable energy, the interest rate in the US should remain steady.

Being aware of this effect, energy regulators can predict how changes in interest rates would affect the REC and take preventive measures. The intake of RE will drop during CMP events. In order to counteract the adverse effects of CMP on REC, energy planners need to take further steps, such as lowering import tariffs on renewable energy goods or introducing a renewable energy subsidy.

Subsidized loans should be given to producers of RE products. There is a dire need for financing in the renewable energy market at a lower interest rate. Therefore, energy policies should be formulated to provide credit to consumers and producers of renewables at the lowest cost. Economic policy (i.e., MP in our case) should align with the energy policy to achieve a common objective. The divergence between the goals of these policies described above might cause issues while formulating these policies, and it can also impede the effectiveness of these policies.

Finally, monetary policy should be sustainable, implying that its objective should be to achieve economic stability without deteriorating environmental quality. Hence, this study proposes a coordinated approach to monetary and energy policymaking, appreciating the interlinkages of the two and the systemic interactions.

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