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RESEARCH ARTICLE

Renewable energy and non-renewable energy consumption: assessing the asymmetric role of monetary policy uncertainty in energy consumption

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Abstract

Previous infant literature has assessed the symmetric impact of monetary policy uncertainty on a few macro variables. Our study has considered asymmetric monetary policy uncertainty impacts on energy consumption. Our key concern in this study is to regulate whether US monetary policy uncertainty has an asymmetric impact on energy consumption. We employ the symmetric and asymmetric autoregressive distributed lag (ARDL) estimation methods, and we found that monetary policy uncertainty has short- and long-run negative effects on renewable energy consumption in the linear model, while decreased monetary policy uncertainty has a significant negative influence on renewable energy consumption in the USA in the non-linear model. However, in the short and long run, the measure of monetary policy uncertainty has an insignificant impact on non-renewable energy consumption, while increased monetary policy uncertainty in the USA has negative effects and decreased monetary policy uncertainty has positive effects on non-renewable energy consumption in the short and long run in the non-linear model. The effects are asymmetric in direction and magnitude. The study results call for vital changes in renewable and non-renewable energy policies to accommodate monetary policy uncertainties.

Keywords Monetary policy uncertainty · Renewable energy consumption · Non-renewable energy consumption · Non-linear ARDL

Introduction

The world economy is witnessing turnout events in recent decades, which give rise to climate change and political and economic uncertainties. Accordingly, the research scholars are trying to analyze these contemporary concerns for the betterment and substance of the global economy. Energy is a vital input to support basic human needs and achieve economic growth and development objectives. The literature on energy and economic performance is growing in recent years. However, the literate related to energy and economic policies is still in its initial stages. Particularly, the studies related to economic policy uncertainty (EPU) and energy consumption nexus are limited.

The EPU is referred to as an uncertain economic environment caused by government regulatory, monetary, and fascial policy management decisions, which modify economic consequences and the environment for economic interactions. With greater policy uncertainty, economic agents including firms revise their economic decision. For example, firms postpone their investment plans and such disclosure with other

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economic agents also delay their consumption, saving, and investment decisions. In an uncertain economic environment, policies related to public and financial sectors become weaker (Halkos and Tzeremes 2013; Aastveit et al. 2017) and it is likely that environmental issues are postponed because consumption pressure is alleviated. Besides, with high policy uncertainty, firms are likely to deploy conventional cheap energy sources for the production process to compensate for the low turnover in such an environment. On the flip side, the firms are likely to deploy clean energy sources when their net income increases, which will improve environmental quality (Majeed and Luni 2019).

The literature on policy uncertainty and environment nexus suggests both positive and negative effects in an open economy. Wang et al. (2020) argued that an open economy has a high level of energy-intensive product consumption and energy investment. They assert that policy uncertainty adversely affects energy investment and consumption, which they refer to as "consumption effect." Consequently, emissions decline, and environmental quality improves. Contrary to this, they also propose that policy uncertainty can negatively affect investment in green projects and renewable sources and emissions will increase. They refer to it as "investment effect (substitution effect)." Thus, it remains an empirical query to understand that which effect dominates in an economy.

In a recent study, Pirgaip and Dinçergök (2020) explored the dynamic associations among EPU uncertainty, energy consumption, and CO_2 emissions for G7 economies over the period 1998–2018 employing a panel Granger causality analysis. They found unidirectional causality from EPU to energy consumption for Japan, the USA, Germany, and Canada. In the case of Italy, they found bidirectional causality from EPU to energy consumption. Based on findings, the authors strongly suggest that G7 economies need to consider the negative impacts of EPU on energy preservation and to switch for clean energy sources.

The literature offers different links of policy uncertainty with the energy market. A high EPU deepens the "financing friction" in the capital market, escalates the debt defaulting risks, and increases the equity financing costs (Pástor and Veronesi 2013). These all adversely influence enterprise investment. Since investment in the renewable energy sector requires a large initial investment and returns are reaped over a longer period (Majeed and Luni 2019), it is riskier as compared to the conventional energy sector. Reuter et al. (2012) argued that the policy uncertainties feed-in-tariffs, subsidies, taxes, portfolio need, and certification system are the important concerns for investment in renewable energy sector. Some recent studies such as He et al. (2018a, b) and Ragosa and Warren (2019) provide evidence that investment in renewable energy sector internalizes the risks costly associated with electricity price uncertainty.

Contrary to this, the literature also offers the mechanism through which policy uncertainty effects on energy market are alleviated. For instance, future growth prospects can mitigate the negative effects of policy uncertainty on energy sector investment and consumption. The growing energy market represents high prospects for future profits. In such a situation, firms can afford high risks and high capital costs to harness future potential benefits (Gennaioli et al. 2016). Particularly such effects are more prominent in the case of renewable energy sector (Liu et al. 2020).

Financing constraints also play a significant role in influencing energy market (Ozturk and Acaravci 2010; Ozturk and Acaravci 2013; He et al. 2018a, b; Majeed and Mazhar 2019; Hafeez et al. 2019a, b; Yang et al. 2020). There are certain friction factors like information asymmetries and agency costs which increase external financing costs than that of the internal financing costs and create financing constraints (Modigliani and Miller 1958). In such a situation, EPU increasingly increases the chances of default, therefore causing negative effects on energy production and consumption. This effect can be more dominant for the renewable energy industry than for the non-renewable energy industry because renewable sector's development is still going through its early stage of development and largely depends upon external financing. With the increasing financing limitations, the high costs related to the external financing will have a more negative effect on the renewable energy sector.

External demand also plays a conducive role in explaining energy sector dynamics. According to "sales' acceleration" theory, revenues from sales impact capital spending (Fazzari and Hubbard 1988). Carruth et al. (2000) provided evidence to consolidate the view that policy uncertainty discourages investment by increasing the cost of capital. Besides, Bloom et al. (2018) also link policy uncertainty with sales uncertainty and investment spending. They view policy uncertainty as to the inhibiting force. However, in the presence of greater external demand, the negative impact of policy uncertainty can be diminished as energy sector will grow to reap the future prospective profits. In the context of non-renewable and renewable energy sectors, the external demand may change more rapidly because of complex external business setup (Gu et al. 2019). Besides, Liu et al. (2020) argued that this effect is more significant for renewable energy enterprises.

Ownership concentration also reflects the short- and long-run dynamics of energy sector. In this regard, the implications of the "principal-agent" theory provide relevant insights. With greater policy uncertainty, the management authorities focus on short-term benefits and put aggressive decisions to maintain their own position. Consequently, ownership is concentrated in an uncertain policy environment. That is, few shareholders control the business enterprise and reduce the investment level to manage it effectively under an uncertain policy environment (Li and Yang 2015). In the case of renewable energy sector, the development stage is still at its initial stages and management and shareholders overlap and the management gives more weight to the preferences of the shareholders. Hence, a higher concentration of enterprise equity augments the negative effect of policy uncertainty and this effect is more dominant in the case of renewable energy sector (Li et al. 2019; Liu et al. 2020).

In a recent study, Liu et al. (2020) explored the dynamic associations of renewable energy and non-renewable energy for China over the period 2007Q1–2017Q4. Their analysis showed the differential impact of policy uncertainty on renewable energy and non-renewable energy investment demand. Policy uncertainty significantly impedes investment in conventional energy sources whereas this effect is not significant in the case of renewable energy investment. In particular, the results showed that policy uncertainty inhibits investment in coal and petroleum sectors. In contrast, policy uncertainty boosts investment in solar, geothermal, and renewable energy sources. Besides, their findings suggest that future growth prospects for energy demand can offset policy uncertainty effects. With greater financing constraints, policy uncertainty boosts conventional energy sectors and has an insignificant impact on renewable energy demand. Furthermore, policy uncertainty effect is intensified with ownership concentration, but this effect is insignificant for the conventional energy sector. Thus, the policy uncertainty effect significantly varies across renewable energy and non-renewable energy industries.

A small number of studies have explored the effects of EPU on environmental variables. Jiang et al. (2019) investigated the dynamic associations between EPU and CO_2 emissions using sectoral-level data. Their results validate significant relationships between the growth rate of carbon emissions in industrial, residential, and transport sectors with EPU. However, the direction of the relationship is not conclusive. Adedoyin and Zakari (2020) investigated the causal associations between carbon emission, EPU, and energy consumption for the UK from 1985 to 2017. The results suggest that EPU decreases emissions only in the short run while no significant effect is found in the long run. Ulucak and Khan (2020) explored the dynamic effects of energy intensity on carbon emissions under policy uncertainty. The findings of their study suggest that EPU escalates the positive effect of energy intensity on carbon emissions.

One strand of the literature has focused on policy uncertainty and carbon emissions nexus for the United States (US) economy. For example, Wang et al. (2020) explore the dynamic association between EPU on CO_2 emissions for the USA over the period 1960–2016 using the "autoregressive distributed lag (ARDL) model". Their findings suggest that the world uncertainty index is positively associated with carbon emissions in the long run. This study, however, assumes symmetric effects of policy uncertainty on carbon emissions. Further, the dynamic and non-linear effects of monetary policy uncertainty (MPU) are not analyzed. The aforementioned literature suggests that the research in this field is relatively scarce and the extant studies employ conventional estimation approaches such as ARDL, Granger causality tests, FMOLS, and DOLS. These studies mainly focus on the association between EPU and environmental pollution ignoring the dynamic effects on different energy sectors.

Besides, the available research provides conflicting results. One likely reason for conflicting results can be the approach of estimation that assumes symmetric associations between the selected variables. In contrast, the non-linear estimation approach can counter counterfeit impacts of explanatory variables on explained variables and discourses the hitches of behavior and interpretation of symmetric estimation approaches. Besides, dynamic associations between time series variables depend upon various factors such as socioeconomic, political, and world economic conditions, considering just symmetric relationships can produce misleading implications. Hence, it is important to isolate the effects of positive and negative components of the dynamic indicators to trace their heterogeneous impacts on different forms of energy market. In this milieu, we complement the existing literature by considering the positive and negative elements of monetary policy uncertainty on renewable energy and non-renewable energy consumption. In this manner, we employ the "Shin et al. (2014) non-linear ARDL approach and Hatemi-j (2012) asymmetric causality test" to improve the extant literature on policy uncertainty and energy sector nexus.

To explore the dynamic symmetric and asymmetric effects of the MPU, we focus on the US economy. The main motivation for selecting the USA for the empirical analysis is that it has the biggest economy in the world, and its experiences provide beneficial insights for the rest of global economies. According to the World Bank (2019), it comprises a US$17.3 trillion GDP. Besides, it is also ranked as the second highest in greenhouse gas emissions all over the world. Similarly, the US economy is also ranked as the second-largest economy in installed renewable energy capacity worldwide. In the US economy, energy-related emissions declined 12% over the period 2007–2016, whereas the US GDP increased by 19% over the same period (Wang et al. 2019). Empirical findings on energy, environment, and policy uncertainty in the USA offer a solid implication that can be useful for many other countries in shaping energy market security and a smooth transition from conventional energy sources to clean energy industry. At present, EPU has soared in the USA, and it is argued that policy uncertainty and environmental deterioration follow a relatively consistent and steady dynamic path (Jiang et al. 2019; Hafeez et al. 2020).

In this milieu, this study examines the asymmetric role of MPU on renewable energy and non-renewable energy consumption. This study extends the empirical literature on energy and policy uncertainty nexus in a number of ways. First, to the best of the authors' knowledge, this is the first study of its kind that examines the asymmetric role of MPU on renewable energy and non-renewable energy consumption. The MPU may offset market distortions initiated by the negative externalities of carbon emissions. The policy uncertainty may distract focus on energy market failures and environmental regulations that are overlooked by the US government in recent years. Second, prior research does not untangle the asymmetric effects of monetary policy uncertainty on energy consumption.

To the best of our knowledge, the available studies on environmental indicators and policy uncertainty have mainly focused on CO_2 emissions and have overlooked the effects on energy sectors. There are few studies that have explored the role of EPU for CO_2 emissions for the USA, and no study has focused on energy sectors. Besides, these studies did not consider the asymmetric effects of policy uncertainties. The present study attempts to fill this research lacuna by employing a symmetric and asymmetric ADRL estimation approach to estimate the non-linear hidden relationships between monetary policy uncertainty and energy consumption for the large economy of the USA using annual time series data from 1985 to 2019. The findings of the study are useful for managing environmental sustainability in an uncertain policy environment. This study also enriches the literature of environmental economics.

Besides, our study represents leading studies in the USA across the globe that establishes asymmetric associations between monetary policy uncertainty and energy consumption and provides the basis for a unique framework of the analysis in environmental and energy economics. The empirical results of this research are helpful for diverse stakeholders in the arena of energy and environmental economics like energy enterprises, academic scholars, energy experts, public institutes, central bank officials, international organizations, and policymakers. Our study provides new insights into monetary policy uncertainty and energy industry nexus to energy economists, central bankers, and policy managers to opt for suitable strategies to promote the use of clean energies and to manage sustainable development goals. The results of this study are useful for other large economies of the world with similar characteristics. Further, the analysis is useful for the economies which are seeking effective management of the energy market and environmental performance.

In the next section, we have provided a brief discussion on the model and methods with data. The empirical findings and their interpretation are discussed in "Results and discussion." Finally, "Conclusion and policy implications" concludes the study and suggest appropriate policy implications.

Data, model, and methodology

Data

The frequency of data used in this study is annual, i.e., from 1985 to 2019. We have used non-renewable energy (NRE) and renewable energy (RE) consumption as the dependent variables. Non-renewable energy (NRE) is the energy that comes from various sources like coal, petrol, and natural gas, while renewable energy is an aggregate of solar energy, wind energy, biofuel energy, and nuclear energy. Both the energy sources are measured in quad BTU and the source of the data is Energy Information Administration (EIA). Our main independent variable is the monetary policy uncertainty (MPU) index which is a volatility measure of discount rate in the USA, and data is retrieved from "www.policyuncertainty.com." Three control variables are also included: (1) Real Gross Domestic Product (GDP) per capita measured in US$ and gathered from Word Development Indicators (WDI); (2) Consumer Price Index (CPI) is used as a proxy of energy prices, and data on this variable is generated from the International Financial Statistics (IFS); (3) government expenditures (GE) as a percentage of GDP used as a proxy for all government spending and once again the data source is WDI. Descriptive statistics are also given in Table 1.

Model and methods

Two models, with the help of previous studies, are constructed, to see the influence of monetary policy uncertainty on non-renewable and renewable energy consumption.

$$\mathrm{LnNRE}_t = \alpha_0 + \alpha_1 \mathrm{LnMPU}_t + \alpha_2 \mathrm{LnGDP}_t + \alpha_3 \mathrm{LnCPI}_t + \alpha_4 \mathrm{LnGE}_t + \mu_t \quad (1)$$

$$\mathrm{LnRE}_t = \beta_0 + \beta_1 \mathrm{LnMPU}_t + \beta_2 \mathrm{LnGDP}_t + \beta_3 \mathrm{LnCPI}_t + \beta_4 \mathrm{LnGE}_t + \epsilon_t \quad (2)$$

Equations (1) and (2) give us long-run estimates that determine the impact of monetary policy uncertainty on energy

Table 1 Descriptive statistics

	LNRE	LNNRE	LNMPU	LNGE	LNGDP	LNCPI
Observations	35	35	35	35	35	35
Mean	2.645	4.366	4.454	3.069	10.682	4.394
Median	2.650	4.388	4.527	3.064	10.716	4.412
Maximum	2.965	4.459	5.127	3.264	10.926	4.764
Minimum	2.325	4.191	3.676	2.886	10.377	3.898
Std. Dev.	0.161	0.073	0.357	0.088	0.1630	0.260

consumption by using the OLS. We incorporate the short-run effects and follow Pesaran et al. (2001) and convert Eqs. (1) and (2) to an error-correction form as in Eqs. (3) and (4):

$$\begin{aligned}\Delta \mathrm{LnNRE}_t = \gamma &+ \sum_{p=1}^{n1} \gamma_{1p} \Delta \mathrm{LnNRE}_{t-p} \\ &+ \sum_{P=0}^{n2} \gamma_{2p} \Delta \mathrm{LnMPU}_{t-p} + \sum_{p=0}^{n3} \gamma_{3p} \Delta \mathrm{LnGDP}_{t-p} \\ &+ \sum_{p=0}^{n4} \gamma_{4p} \Delta \mathrm{LnCPI}_{t-p} + \sum_{p=0}^{n5} \gamma_{5p} \Delta \mathrm{LnGE}_{t-p} \\ &+ \pi_1 \mathrm{LnNRE}_{2,t-1} + \pi_2 \mathrm{LnMPU}_{t-1} \\ &+ \pi_3 \mathrm{LnGDP}_{t-1} + \pi_4 \mathrm{LnCPI}_{t-1} \\ &+ \pi_5 \mathrm{LnGE}_{t-1} + \mu_t \end{aligned} \tag{3}$$

$$\begin{aligned}\Delta \mathrm{LnRE}_t = \delta &+ \sum_{p=1}^{n1} \delta_{1p} \Delta \mathrm{LnRE}_{t-p} + \sum_{P=0}^{n2} \delta_{2p} \Delta \mathrm{LnMPU}_{t-p} \\ &+ \sum_{p=0}^{n3} \delta_{3p} \Delta \mathrm{LnGDP}_{t-p} + \sum_{p=0}^{n4} \delta_{4p} \Delta \mathrm{LnCPI}_{t-p} \\ &+ \sum_{p=0}^{n5} \delta_{5p} \Delta \mathrm{LnGE}_{t-p} + \varphi_1 \mathrm{LnRE}_{2,t-1} \\ &+ \varphi_2 \mathrm{LnMPU}_{t-1} + \varphi_3 \mathrm{LnGDP}_{t-1} \\ &+ \varphi_4 \mathrm{LnCPI}_{t-1} + \varphi_5 \mathrm{LnGE}_{t-1}\ \epsilon_t \end{aligned} \tag{4}$$

Equations (3) and (4) reported by the error-correction model estimate the long- and short-run effects of monetary policy uncertainty on energy consumption. To assess the cointegration, Pesaran et al. (2001) recommend two tests: the first is the *F* test and the second is an ECM or *t* test. Cointegration is established if the *F* test is significant and $\mathrm{ECM}_{t\text{-}1}$ carries a negative significant coefficient, while Pesaran et al. (2001) provide new critical values for *F* tests. One main assumption behind Eqs. (3) and (4) is that energy consumption responds to changes in monetary policy uncertainty in a symmetric manner. However, in fact, increased monetary policy uncertainty could affect energy consumption at different rates compared to decreased monetary policy uncertainty, hence an asymmetric effects. To assess the asymmetric impacts of monetary policy uncertainty on energy consumption, we follow Shin et al.'s (2014) methodology which contains positive changes that reflect an increase in the monetary policy uncertainty and negative changes that reflect declines. Based on this information, we create two new time series variables as drawn by Eqs. (5) and (6).

$$\mathrm{MPU\_POS}_t = \sum_{m=1}^{t} \Delta \mathrm{LnMPU}_t^{+} = \sum_{k=1}^{t} \max(\Delta \mathrm{LnMPU}_m, 0) \tag{5}$$

$$\mathrm{MPU\_NEG}_t = \sum_{m=1}^{t} \Delta \mathrm{LnMPU}_t^{-} = \sum_{k=1}^{t} \min(\Delta \mathrm{LnMPU}_m, 0) \tag{6}$$

In the above specifications, MPU_POS represents a positive change that reflects an increase in monetary policy uncertainty measure and MPU_POS demonstrates a negative change that reflects a decrease in monetary policy uncertainty in the variable. Therefore, we move back to Eqs. (3) and (4) and replace LnMPU with the two new variables to attain at Eqs. (7) and (8):

$$\begin{aligned}\Delta \mathrm{LnNRE}_t = \gamma &+ \sum_{p=1}^{n1} \gamma_{1p} \Delta \mathrm{LnNRE}_{t-p} \\ &+ \sum_{P=0}^{n2} \gamma_{2p} \Delta \mathrm{LnMPU\_POS}_{t-p} \\ &+ \sum_{p=0}^{n3} \gamma_{3p} \Delta \mathrm{LnMPU\_NEG}_{t-p} \\ &+ \sum_{p=0}^{n4} \gamma_{4p} \Delta \mathrm{LnGDP}_{t-p} + \sum_{p=0}^{n5} \gamma_{5p} \Delta \mathrm{LnCPI}_{t-p} \\ &+ \sum_{p=0}^{n6} \gamma_{6p} \Delta \mathrm{LnGE}_{t-p} + \pi_1 \mathrm{LnNRE}_{t-1} \\ &+ \pi_2 \mathrm{LnMPU\_POS}_{t-1} + \pi_3 \mathrm{LnMPU\_NEG}_{t-1} \\ &+ \pi_4 \mathrm{LnGDP}_{t-1} + \pi_5 \mathrm{LnCPI}_{t-1} \\ &+ \pi_6 \mathrm{LnGE}_{t-1} + \mu_t \end{aligned} \tag{7}$$

$$\begin{aligned}\Delta \mathrm{LnRE}_t = \delta &+ \sum_{p=1}^{n1} \delta_{1p} \Delta \mathrm{LnRE}_{t-p} \\ &+ \sum_{P=0}^{n2} \delta_{2p} \Delta \mathrm{LnMPU\_POS}_{t-p} \\ &+ \sum_{p=0}^{n3} \delta_{3p} \Delta \mathrm{LnMPU\_NEG}_{t-p} \\ &+ \sum_{p=0}^{n4} \delta_{4\mathrm{p}} \Delta \mathrm{LnGDP}_{t-p} + \sum_{p=0}^{n5} \delta_{5p} \Delta \mathrm{LnCPI}_{t-p} \\ &+ \sum_{p=0}^{n5} \delta_{5p} \Delta \mathrm{LnGE}_{t-p} + \varphi_1 \mathrm{LnRE}_{t-1} \\ &+ \varphi_2 \mathrm{LnMPU\_POS}_{t-1} + \varphi_3 \mathrm{LnMPU\_NEG}_{t-1} \\ &+ \varphi_4 \mathrm{LnGDP}_{t-1} + \varphi_5 \mathrm{LnCPI}_{t-1} + \varphi_6 \mathrm{LnGE}_{t-1} \\ &+ \mu_t \end{aligned} \tag{8}$$

Equations (7) and (8) are new error-correction models that could be used to assess the dynamic effects of monetary policy uncertainty on energy consumption. Such models are also labeled as non-linear or asymmetric ARDL models. However, Shin et al. (2014) establish a similar diagnostic approach in NARDL and applies the *F* as well ECM tests to establish cointegration. They even recommend a few additional diagnostic statistics for asymmetry; the Wald test is applied in the short and long runs. In the short run, if estimates of

$\sum\gamma_{2p} = \sum\gamma_{3p}$ and $\sum\delta_{2p} = \sum\delta_{3p}$ are dissimilar at the similar lag order and two partial sum series take different lag order, it will support the short-run asymmetry. Finally, the long-run asymmetry is confirmed if the null hypothesis of $\frac{\pi_2}{-\pi_1} = \frac{\pi_3}{-\pi_1}$ and $\frac{\varphi_2}{-\varphi_1} = \frac{\varphi_3}{-\varphi_1}$ is rejected by the Wald test (for more on the application of these non-linear ARDL econometric methods, see Ullah et al. 2020a, b and Usman et al. 2020).

Results and discussion

The first step in the analysis is to make sure that all variables are eligible to be added to the ARDL model. To that end, we check the stationary of the time series included in the analysis by applying two unit root tests, i.e., augmented Dickey-Fuller (ADF) and Phillips-Perron (PP), and confirmed that no variable among the chosen variables is $I(2)$. This fulfills the precondition of applying the ARDL model. The results of the unit root tests are provided in Table 2. Then, we also have to pick the number of lags before the formal analysis. As our data is annual and observations are 35, we have only applied maximum to lags. Akaike's information criterion (AIC) is used to select a suitable number of lags.

We have provided the estimated coefficient of both the RE and NRE models in Table 3. The linear estimate of the ΔMPU in the RE model is significant and positive at previous lags and significant and negative in the current year. This confirms that, over time, the increased marginal policy uncertainty will hurt renewable energy consumption in the USA. However, the size of the estimates is very small in the short run which depicts the weak impact of ΔMPU on renewable energy consumption. The estimated coefficients of the other three variables are exerting a positive effect on renewable energy consumption in the USA. Hence, the increased government expenditures, GDP per capita, and energy prices in the USA augment renewable energy consumption. As far as the effect of ΔMPU on non-renewable energy consumption is concerned, the effect is insignificant in the short run. However, the effects of government expenditures are significant and positive on the consumption of non-renewable energy in the USA, suggesting that the government has kept an eye on the sustainable development goal and hence invested more in renewable energy consumption as compared to non-renewable energy consumption. On the contrary, increased GDP per capita and energy prices have benefited the use of non-renewable energy consumption in the USA.

From panel B, we see that the long-run linear estimate of the MPU variable is significant and positive in the RE energy model, whereas it is insignificant in the case of the NRE model. From these estimates, we confer that increased uncertainty with regard to monetary policy rates proves detrimental for renewable energy consumption in the USA. Moreover, the long-run results are continuity of the results provided by our short-run estimates that over time increased risk attached to monetary policy will induce the government and private people to invest less in the renewable energy projects which in turn affect renewable energy consumption negatively. Hence, monetary policy stability is very essential for the sustainable development goal in the USA. As the increased renewable energy consumption will reduce the CO_2 emissions in the environment which will help achieve the sustainable development aim (Ozturk 2010; Hafeez et al. 2019a, b; Usman et al. 2020). However, the fiscal instrument, i.e., government expenditures, does not have any significant impact on renewable energy consumption in the USA, while it proves harmful for non-renewable energy consumption. In order to achieve sustainable development, the government of the USA might be shifting its focus from non-renewable energy to renewable energy projects, but the long-run effects are yet to appear. According to Ullah et al. (2020a, b), government expenditures show an important role in curbing environmental pollution which helps in achieving sustainable economic growth. On the other hand, as the per-capita income in the USA increases, people consume more non-renewable energy and decrease the consumption of renewable energy. The implied reason could be the high initial cost of renewable energy and the easy availability of non-renewable energy. Surprisingly, the estimated coefficient of LnCPI, in the long-run, in both the energy models is positively significant implying that the increased energy prices in the USA drive up the consumption of both

Table 2 Unite root tests

	ADF			PP		
Variables	Level	First difference	Decision	Level	First difference	Decision
LNRE	− 0.55	− 6.29***	$I(1)$	− 0.51	− 6.34***	$I(1)$
LNNRE	− 2.61	− 5.44***	$I(1)$	− 2.64	− 5.44***	$I(0)$
LNMPU	− 3.72***		$I(0)$	− 3.73***		$I(0)$
LNGE	− 2.21	− 3.29***	$I(1)$	− 1.22	− 2.91**	$I(1)$
LNGDP	− 1.06	− 3.63***	$I(1)$	− 1.43	− 3.46***	$I(1)$
LNCPI	− 4.14***		$I(0)$	− 4.73	− 3.14**	$I(0)$

*, **, and *** indicate significance levels at 10%, 5%, and 1% respectively

Table 3 ARDL and NARDL estimates of RE and NRE models

	ARDL-RE		NARDL-RE		ARDL-NRE		NARDL-NRE	
Variable	Coefficient	*t* Stat	Coefficient	*t* Stat	Coefficient	*t* Stat	Coefficient	*t* Stat
Short-run estimates								
D(LNMPU)	− 0.02**	2.28			− 0.00	0.29		
D(LNMPU(-1))	0.07**	3.76						
D(LNMPU_POS)			− 0.01	0.44			− 0.02**	2.71
D(LNMPU_POS(-1))							− 0.02**	1.93
D(LNMPU_NEG)			− 0.05**	2.31			0.05**	4.47
D(LNMPU_NEG(-1))			0.07**	2.74			0.01	1.59
D(LNGE)	0.56**	2.79	− 0.09	0.44	− 0.25**	2.73	0.47**	4.93
D(LNGE(-1))							0.55**	3.71
D(LNGDP)	1.78**	3.09	− 0.66	1.04	1.67**	6.85	2.44**	8.95
D(LNGDP(-1))							1.51**	3.45
D(LNCPI)	0.69**	2.40	0.67	1.36	0.74**	4.22	0.82**	5.69
D(LNCPI(-1))			− 1.04**	2.51				
Long-run estimates								
LNMPU	− 0.16**	2.64			0.05	1.25		
LNMPU_POS			− 0.04	0.72			− 0.00	0.00
LNMPU_NEG			− 0.24**	3.07			0.11**	8.11
LNGE	0.34	1.29	− 0.21	0.85	− 0.35**	2.21	− 0.14**	2.60
LNGDP	− 1.04*	1.94	− 1.48**	2.53	− 0.77	1.30	0.34**	2.01
LNCPI	1.11**	3.09	0.15	0.29	0.75**	1.90	0.76**	6.91
C	8.52*	1.94	17.97**	3.19	10.01**	2.11	− 2.01	1.25
Diagnostic tests								
ECM_{t-1}	− 0.46**	4.22	− 0.48**	4.49	− 0.25**	6.36	− 1.04**	6.73
Adj R^2	0.97		0.97		0.95		0.96	
F test	2.45		2.61		5.50		2.92	
LM	2.09		1.15		1.63		1.93	
RESET	2.37		0.01		0.10		1.79	
CUSUM	S		S		S		S	
$CUSUM^2$	S		S		US		S	
Wald-SR			1.69				3.84**	
Wald-LR			10.26**				65.47**	

renewable and non-renewable energies. This means that the demand for energy in the USA is highly inelastic. From panel C, we got an idea that these long-run results are meaningful in both the models as cointegration among the long-run estimates is confirmed through bounds *F* test or alternative ECM_{t-1} test of cointegration.

The coefficient estimate values of *t* test are 1.64 at 10% (*) and 1.96 at 5% (**) significance level, respectively. The critical values of Wald, LM, and RESET at the 10% level of significance indicate (*) at 2.70 and 5% level of significance indicate (**) at 3.84

The next thing we want to see is how energy consumption responds to positive and negative shocks in the monetary policy rate uncertainty. In the short run, the positive shock of D(MPU) is insignificant, whereas the negative shock of D(MPU) is significant and positive in the renewable energy model. Inversely, the positive change in D(MPU) is exerting a negative impact on the consumption of non-renewable energy, while the negative change in D(MPU) is exerting a positive impact on the consumption of non-renewable energy. In general, these findings suggest that both the increased and decreased uncertainty in the monetary policy rates reduced the overall energy consumption in the USA. Moreover, the opposite signs attached to positive and negative shocks of monetary policy uncertainty variable hint at its asymmetric impacts on the non-renewable energy consumption which is also confirmed by the short-run WALD statistics. Other short-run estimates are interpreted in the same way as we have already explained in the linear model.

Just like the linear model, we also want to see in the non-linear model whether short-run effects survive in the long run or not. The estimated coefficient of LnMPU_POS is insignificant in both the renewable energy and the non-renewable energy models. However, the coefficient estimate attached to LnMPU_NEG is significantly negative in the renewable energy models and significantly positive in the non-renewable energy model. In other words, we can say that the negative shock in LnMPU increases the consumption of renewable energy and decreases the non-renewable energy consumption. Moreover, we can say that the stability in monetary policy rates is necessary for sustainable economic growth through the increased use of renewable energy consumption. Once again, these long-run results are false if we fail to establish cointegration among them. To that end, to confirm the long-run asymmetric impact on the positive and negative changes in LnMPU variable in both the models, we turn our attention to panel C, in which the WALD-LR statistic is significant in both the models. Once again, we do not need to explain other long-run variables as they performed in the same way as in the linear model.

In panel C, some of the diagnostic tests are reported which confirm the reliability of our results. To check the first-order serial correlation, the Lagrange Multiplier (LM) test is used which confirms that our models are free from autocorrelation. Then, Ramsey's RESET test is used to detect the misspecification in the model which confirms that our models are correctly specified. Next, the CUSUM and CUSUMSQ confirm the parameter stability where "S" represents the stability and "US" is a symbol of unstable parameters. Lastly, the goodness of fit of our model is confirmed through the estimates of adjusted R^2.

Conclusion and policy implications

One common factor that affects the energy market is monetary policy uncertainty. The significance of uncertainty in monetary policies linked to economic decisions is higher than ever before in today's unified world. Overall, monetary policy uncertainty has also a significant influence on energy policies as well as on climate changes. Uncertainty could arise due to financial crises, economic situation, political instability, and the international community. The fact is the larger the economy in which uncertainty creates, the larger the impact; it means the USA has larger effects. Our basic aim of this study is to assess the asymmetric impacts of MPU on renewable and non-renewable energy consumption. We employ annual US data from 1985 to 2019. There are no past studies, which effort on the influences of monetary policy–related uncertainty on renewable and non-renewable energy consumption. Based on the literature, our results are novel and fill the gap of infant existing literature in this research area.

Using the linear and non-linear ARDL approaches, it was found that monetary policy uncertainty of the USA has short-run negative effects on renewable energy consumption, while the short-run effect is also maintained in the long run. While short- and long-run symmetric effects are also maintained into asymmetric. Therefore, positive and negative changes in monetary policy uncertainty have negative impacts on renewable energy consumption in the long and short term. Similarly, monetary policy uncertainty does not affect energy consumption of non-renewable in the short and long run in linear ARDL. While the positive changes in monetary policy uncertainty have a negative effect on non-renewable energy consumption, negative changes in monetary policy uncertainty have adverse effects, and it is negative in the short run. Moreover, positive shock in monetary policy uncertainty carries a positive insignificant coefficient and negative shock in monetary policy uncertainty carries a positive significant coefficient in non-renewable energy in the long run. However, short-run non-linear effects are also translated into significant long-run non-linear effects in the USA. Besides, negative changes to monetary policy uncertainty have relatively larger effects on non-renewable energy consumption than do positive changes to monetary policy uncertainty in the short and long run. Our findings for the MPU effects across linear and non-linear models are too different in direction and magnitude. These findings are also country-specific.

These outcomes are significant for policymakers in the energy and carbon market. This study recommends that the USA should sustain the stability of monetary policies based on the full consideration of renewable energy and the environment. The reason lies in that the adjustment of monetary policies will bring new renewable energy consumption opportunities, which can promote clean energy consumption. Maintaining stable monetary policies, authorities could promote its realization of carbon reduction targets by increasing renewable energy consumption. Understanding the influence of the time horizon on the impact of monetary policy uncertainty on renewable energy consumption is valuable for environmental management. Future work can analyze the heterogeneous effects of fiscal policies and tax policies on energy consumption policies, and we leave these possibilities for future studies. A similar study can also further extend the political fragile economies. Finally, future empirical research should pay attention to scrutinizing the numerous forms of uncertainty in terms of the risk, misspecification, and ambiguity and quantifying them properly in differential effects, if any, to offer evidence-informed energy consumption and climate policy. This study which focuses on the USA only is constrained by data that is one of the limitations.

Authors' contributions This idea was given by Muhammad Tayyab Sohail. Muhammad Tayyab Sohail, Ahmed Usman, Yu Xiuyuan, Sana Ullah, and Muhammad Tariq Majeed analyzed the data and wrote the complete paper, while Ahmed Usman and Sana Ullah read and approved the final version.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval Not applicable

Consent to participate I am free to contact any of the people involved in the research to seek further clarification and information.

Consent for publication Not applicable

Competing interests The authors declare no conflict of interest.

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