The Role of Economic Policy Uncertainty in Renewable Energy-Growth Nexus: Evidence from the Rossi-Wang Causality Test

Zhou **Lu**
Zhou Lu, School of Economics
Tianjin University of Commerce, Tianjin, China
Email: luzhou59@tjcu.edu.cn

Linchuang **Zhu**
School of Economics, Tianjin University of Commerce
Tianjin, China.

Chi Keung Marco **Lau**
(Corresponding Author)
Teesside University Business School
Teesside University, the UK
Email: c.lau@tees.ac.uk

Aliyu Buhari **Isah**
Huddersfield Business School
University of Huddersfield, the UK
Email: aliyu.isah@hud.ac.uk

Xiaoxian **Zhu**
Teesside University Business School
Teesside University, the UK
Email: x.zhu@tees.ac.uk

Zhou Lu: Methodology, Writing-Original Draft Preparation, Supervision

Linchuang Zhu: Writing-Revision Draft Preparation.

Aliyu Buhari Isah: Data Curation, Writing-Original Draft Preparation

Chi Keung Marco Lau: Investigation, Software, Visualization, Writing-Original Draft Preparation

Xiaoxian Zhu: Supervision, Editing, Writing-Original Draft Preparation

Abstract: This paper examines the causal relationship between renewable energy consumption and economic growth in four countries: Brazil, Germany, Japan, and the United States. Unlike previous papers, we control economic policy uncertainty's effects to capture the role of capabilities on the renewable energy-growth nexus. The recent Vector Autoregression (VAR)-based Granger-causality test of Rossi-Wang shows a bidirectional causal relationship between renewable energy and the economic growth in Brazil and Germany. There is also a significant causality from renewables to economic growth in the United States.

Keywords: renewable energy consumption; economic growth; renewable energy-growth nexus; economic policy uncertainty; Granger-causality test; the presence of instabilities

1. Introduction

Both developing and developed economies have increased their renewable energy use and production since the 1980s. There are four aspects to the emergence of renewable energy. The first is technological advancement, which has reduced the cost of investing in renewable energy installations (Apergis and Payne, 2010a; 2010b, Luqman, Ahmad, & Bakhsh, 2019). The second aspect relates to governments regulations which provided supportive policy implications for renewable energy investments such as the establishment of credit easing and tax deductions for green energy by most governments, which in turn, has increased certificate and portfolio standards in renewable energy investments (Apergis and Payne, 2012; Asiedu, Hassan, & Bein, 2021). The third point has to do with climate change issues. It is argued that increased use of renewable energy reduces CO2 emissions, allowing renewable energy to mitigate the harmful effects of climate change (Bowden and Payne, 2009; Payne, 2009, Ali, 2021). Finally, the increase in the price of fossil fuels has encouraged the use of renewable energy (Gozgor, 2018). With these four factors in mind, renewable energy has the potential to bring long-term economic growth.

The role of renewable energy in bringing long-tern economic growth seems to be challenged, recently, by policy uncertainties and instabilities currently facing the global economy. One of such emerging uncertainties/instabilities is the economic policy uncertainty (EPU). The EPU is policy uncertainty associated with changes in government policy direction (e.g., monetary, or fiscal policy changes, tax regulations, etc.), which tends to cause delays in spending and investment by individuals and businesses until such uncertainty is resolved.

Policy changes and uncertainty relating to energy consumptions have been argued to affect the concerned country's overall economic growth (Aizenman and Marion, 1993; Gulen and Ion, 2016; Tiwari, 2011). For example, uncertainty about energy prices can force profit-optimizing firms to either suspend or quit investment decisions, which ultimately causes a decline in the aggregate output (Bernanke, 1983; Elder and Serletis, 2010). The empirical evidence further suggests that policy uncertainty about energy use, such as reducing CO_2 emissions and fossil fuels, is harmful to investment in renewable energy, which can slow down the pace of economic growth (Adedoyin and Zakari, 2020).

Although the effect of the EPU on the number of variables has been widely explored in the literature (see, e.g., Bhattacharya et al., 2016; Pao and Fu, 2013; Solarin and Ozturk, 2015); however, there are very few papers for analyzing the effect of the EPU on energy indications, the only exceptions being Adedoyin & Zakari (2020) and Ulucak and Khan (2020). For instance, Adedoyin and Zakari (2020) attempt to provide evidence on the role of the EPU in the United Kingdom's energy consumption. By applying the Autoregressive Distributed Lag (ARDL) bound and Granger Causality tests, they show that the EPU matters to the United Kingdom most in the short run for two reasons. First, it reduces the growth of CO_2 emissions. Second, with the prolonged use of the EPU, there will be a continuous rise in CO_2 emissions. Using the same methodology (i.e., the ARDL bound test) for the case of the United States, Ulucak and Khan (2020) show that higher energy intensity contributes to pollution and that the EPU does not only adversely affects environmental quality but also strengthens the detrimental effect of energy intensity on CO_2 emissions.

One major takeaway from these studies is their limited application to either the United Kingdom (Adedoyin and Zakari, 2020) or the United States (Ulucak and Khan, 2020). Besides, neither of these studies captures the effect of the EPU in the growth model. A broader understanding of how the EPU affects energy use across countries will provide a clearer insight

into the global policy focus regarding uncertainty and energy use. Therefore, differing from existing studies, our paper examines the causal relationship between renewable energy consumption and economic growth in four countries: Brazil, Germany, Japan, and the United States by controlling for the effects of the EPU to capture the role of capabilities on renewable energy-growth nexus.

At this stage, we implement the recent Vector Autoregression (VAR)-based Granger-causality test of Rossi and Wang (2019). The authors argue that the traditional Granger causality test that assumes stationarity of variables is not reliable in modelling relationship between variables with high uncertainty/instabilities as it can lead to misleading inferences. They extend Rossi's (2005) methodology and include robust versions of the Mean and Exponential Wald, Nyblom, and Andrew's Quasi-Likelihood Ratio tests. Rossi and Wang (2019) illustrate how to test the Granger causality to produce robust results in the presence of instabilities.

Our paper focuses on the cases of Brazil, Germany, Japan, and the United States because they have one of the world's major renewable energy matrices, with high renewable energy generation and use. A study by the International Renewable Energy Agency (IRENA) (2016) estimated that, by 2030, renewable energy would contribute to the overall global economic growth by values between 0.6% and 1.1%, amounting to $706 billion to $1.3 trillion. A further study estimate that renewable energy will be worth $ T2 trillion in 2050, with the United States, Germany, Japan, and Brazil, among other nations, experiencing the most of these increases (IRENA, 2018).

On the other hand, the United States is the biggest economy globally and one of the largest renewable energy consumers. Of the world's total primary energy consumption, the United States is the largest energy consumer country with a share of 16.2% annual growth rate

and CO_2 emission of 14.5% as of 2019.[1] Japan, Germany, and Brazil had a share of 3.2%, 2.3%, and 2.1%, and the CO_2 emission rate of 3.3%, 2% and 1.3%, respectively (British Petroleum (BP), 2020). While the electric power sector accounted for 56% of total renewable energy consumption in the United States in 2019, about 17% of the country's electricity generation was from renewable energy sources (U.S. Energy Information Administration (EIA), 2021). EIA (2021) estimates that renewable energy consumption will continue to rise in the country up to 2050.

Being a technology giant country, Japan has recently put forward new legislation in 2017 with plans to increase its reliance on and use renewable energy to 24% of its energy mix, representing more than double of its current production. In 2019, it was reported that Japan needs to import 90% of its energy. Due to the Fukushima disaster in 2011, the country's share from nuclear sources plummeted significantly from 30% to a production target of just 20% by 2030 (Casey, 2017). Consequently, Japan is now turning to other energy sources, including wind, solar, and tidal power, to reduce its reliance on foreign sources and further enhance innovation in its domestic energy sector.

In Germany, renewable energy is mainly based on solar, wind, and biomass. The country has one of the world's largest photovoltaic installed capacities, making it the world's major renewable energy economy with a powerful wind power capacity. German's share of renewable electricity reached 10% in 2005 from just 3.4% in 1990, and by 2019, it recorded 42.1% of gross electricity consumption (EIA, 2020). Recently, the German government is focusing particularly on the offshore wind farm, following the European Union (EU)'s mandatory energy plan requirement of reducing CO_2 emission by 20% before the end of 2020 and consumption of renewable energies of 20% of the total EU consumption.

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[1] Primary energy here is composed of commercially traded fuels and modern renewables that are used to generate electricity (BP, 2020: 8).

Brazil is also another country with a solid renewable energy matrix. A large chunk of Brazil's renewable energy is from hydroelectric power plants. With the recently introducing public policies (e.g., the 10-year Energy Expansion Plan 2026) that aim to promote other non-traditional renewables (e.g., ethanol, made from sugarcane), the share of Brazil's renewable energy is now rising reasonably. Renewable sources supplied about 44% of the Brazilian energy consumption as of 2016 and 79.3% in 2018 (IEA Bioenergy, 2018).

To the best of our knowledge, this study is the first research in the empirical literature to examine the causal relationship between renewable energy and economic growth by controlling the role of economic policy uncertainty. For this purpose, we utilize the recent VAR-based Granger-causality test of Rossi and Wang (2019) in instabilities, which is another novelty of the study. We observe a bidirectional causal relationship between renewable energy and economic growth in Germany. There is also a significant causality from renewables to economic growth in Brazil and the United States. However, there is no significant causality between renewable energy and economic growth in Japan.

The remainder of the study is organized as follows. Section 2 provides a literature review of the renewable energy-growth nexus. Section 3 defines the data, sets the empirical model, and explains the Granger-causality test. Section 4 discusses the empirical findings. Section 5 concludes.

2. Literature Review

There are four views to explain the causality between economic growth and renewable energy. First, the "growth hypothesis" indicates that renewable consumption causes economic growth. Second, the "conservation hypothesis" states that economic growth causes renewable energy. Third, the "feedback hypothesis" suggests a bidirectional causal relationship between renewable energy and economic growth. Finally, the "neutrality hypothesis" proposes no causality between renewable energy and economic growth (Tiba and Omri, 2017).

There are previous papers to examine these hypotheses. For instance, Sadorsky (2009a) argues that energy use in all forms (such as industrial and residential, among others) is a primary determinant of economic growth and prosperity. As countries prosper, energy demand also increases. Sadorsky (2009b) also models the relationship between energy consumption and income for a panel of 18 emerging market economies from 1994 to 2003. The panel estimates confirm, yet again, that income per capita exert a statistically significant positive impact on per capita renewable energy consumption, thus providing evidence in support of the *conservation hypothesis.*

Using the panel dataset of 20 OECD countries, Apergis and Payne (2010a) investigate the causal link between renewable energy consumption and economic growth within a multivariate framework over 1985–2005. The Granger-causality test results show a two-way causal relationship between renewable energy consumption and economic growth in both the short-run and the long run. However, considering Eurasia's dependency on fossil fuels, Apergis and Payne (2010b) further extend their analyses to examine the validity of the feedback hypothesis for the panel of 13 countries within Eurasia, this time using a short data set covering the period of 1992–2007 within a multivariate framework. The heterogeneous panel cointegration test suggests a long-run equilibrium relationship between real GDP and renewable energy consumption, among other variables. Similarly, for a panel of six Central American countries over the period 1980–2006, Apergis and Payne (2011) find evidence of a bidirectional causal relationship between renewable energy consumption and economic growth in both the short-run and long run. A unidirectional causality from economic growth to renewable energy use is also found by Rahman and Velayutham (2020). Similar results also hold for the panel of 80 countries throughout 1999–2004 are obtained by Apergis and Payne (2012); thus, reiterating the validity of the feedback hypothesis that renewable energy consumption and economic growth are interdependently related.

Motivated by the role of renewable and non-renewable energy in Brazil's economic growth and how, in turn, economic growth experienced in Brazil played a crucial role the growth and development as well as the recent massive investment in the country's renewable energy sector, Pao and Fu (2013) attempted to obtain if there was evidence for the "feedback hypothesis" in Brazil throughout 1980–2010 by exploring the causal relationship between economic growth (real GDP) and four types of energy consumption: non-hydroelectric renewable energy consumption, total renewable energy consumption (TREC), non-renewable energy consumption, and the total primary energy consumption. Their study's long-run relationship indicates that a 1% increase in the TREC increases real GDP by 0.20%. An error correction model application further indicates a bidirectional causal relationship between the TREC and economic growth, among other findings. However, this outcome is fascinating because recently, development suggests that Brazil could change dramatically from a large oil importer to a self-sufficient energy economy. The pioneer works of Bhattacharya et al. (2016), Carmona et al. (2017), and Inglesi-Lotz (2016) also find support for the "feedback hypothesis". Similar results are obtained by Solarin and Ozturk (2015) for a panel of Latin American countries.

To conclude the literature review, various studies have analyzed the relationship between renewable energy consumption and economic growth in developing and developed countries. Even the most recent studies exist (e.g., Aydin, 2019; Ajmi and Inglesi-Lotz, 2020; Gao and Zhang, 2021) merely examine the causal relationship between renewable energy consumption and economic growth of some number of countries. None of these studies capture the effect of economic policy uncertainty in a growth model. Therefore, our paper contributes to this literature by introducing a new growth model that includes economic policy uncertainty on economic growth.

3. Data, Model, and Methodology

Our sample covers the annual data in Brazil (1970-2019), Germany (1971-2019), Japan (1970-2019), and the United States (1965-2019). The begging date of the sample is based on the data availability. We use renewable energy consumption (mtoe), and the data is obtained from British Petroleum Statistical Review. We also consider economic growth, based on logarithmic changes of per capita gross domestic product with the constant 2010 $ prices. We also use the World Uncertainty Index (WUI) to capture the role of economic policy uncertainty, and the data are obtained from https://worlduncertaintyindex.com/. A greater value of the WUI means that there is a greater level of economic policy uncertainty. At this stage, we test the following causal relationships:

$$\text{GROWTH}_t = \alpha_0 + \alpha_1 RENEWABLES_{t-k} + \alpha_2 \text{WUI}_{t-k} + \varepsilon_{t1} \tag{1}$$

$$RENEWABLES_t = \beta_0 + \beta_1 \text{GROWTH}_{t-k} + \beta_2 \text{WUI}_{t-k} + \varepsilon_{t2} \tag{2}$$

In Eq. (1) and Eq. (2), GROWTH_t is economic growth, $RENEWABLES_t$ is renewable energy consumption, and WUI_{t-k} is the World Uncertainty Index. At this stage, we obtain four alternative test statistics: Exponential Wald (ExpW), Mean Wald (MeanW), Nyblom (Nybolm), and Quandt Likelihood Ratio (SupLR) to estimate the causal relationships. The lag selection is based on the Akaike Information Criterion (AIC). The VAR model is estimated with one lag. Here, all four test statistics must exceed the critical values of these tests and then we can conclude that there is a statistically significant causality between the related variables. Otherwise, there is no significant causal relationship. For details, refer to Rossi (2005), Rossi and Wang (2019) and *gcrobustvar* Stata command.

4. Empirical Results

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Following Gozgor (2016), we implement various unit root tests and confirm the renewable energy, growth, and the EPU series are stationary. Figure 1 shows the renewable energy consumption for four countries. USA consumes the most of renewable energy among four countries. Table one shows the results for traditional Granger Causality test of Granger (1969), and it indicates that no Causality relationships found between renewable energy consumption and economic growth for all countries at the 5% significant level.

[Insert Table 1 around here]

Then we implement the Rossi-Wang causality test and report the results in Table 2. Regarding the causality from renewables to growth, we find that all test statistics (ExpW, MeanW, Nyblom, and SupLR) are statistically significant at the 1% level in Brazil, Germany, and the United States.

[Insert Table 2 around here]

Regarding the causality from growth to renewables, we observe that all test statistics (ExpW, MeanW, Nyblom, and SupLR) are statistically significant at the 1% level in Brazil and Germany.

Therefore, we conclude a bidirectional causal relationship between renewable energy and the economic growth in Brazil and Germany. There is also a significant causality from renewables to economic growth in the United States. However, there is no significant causal relationship in Japan.

We check the robustness of the results. Specifically, we exclude outlier observations and rerun the causality analyses. The results align with the benchmark results, but we do not report them to save space.

5. Conclusion

This paper examines the causal relationship between renewable energy consumption and economic growth in four countries: Brazil, Germany, Japan, and the United States. We control the impact of economic policy uncertainty on renewable energy-growth nexus. The findings from the VAR-based Granger-causality test of Rossi and Wang (2019) show a bidirectional causal relationship between renewable energy and economic growth in Brazil and Germany. There is also a significant causality from renewables to economic growth in the United States. However, there is no robust causality between renewable energy and economic growth in Japan.

This paper's novelty is to implement the causality test of Rossi and Wang (2019). Future studies can use Rossi and Wang's (2019) test for examining the relationship between different macroeconomic indicators and energy variables in other developed and developing economies. Finally, future studies can use disaggregated level renewable energy data (e.g., biomass, solar, and wind) by implementing Rossi and Wang's (2019) test.

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Table 1. Traditional Granger Causality Test

Renewables → Growth	F-Statistics	P-Value
Brazil	1.7565	0.1916
Germany	1.2371	0.2719
Japan	2.7058	0.1068
USA	0.4187	0.5205
Growth →Renewables		
Brazil	0.0304	0.8623
Germany	0.3461	0.5593
Japan	0.0241	0.8774
USA	2.2196	0.1424

Renewables → Growth	ExpW	MeanW	Nyblom	SupLR
Brazil	77.3306***	67.2236***	26.3675***	161.6903***
Germany	163.4795***	92.2268***	11.0431***	333.9459***
Japan	118.1134***	79.4802***	0.6625	243.2561***
United States	30.9121***	14.8006***	4.88341***	69.0515***
Growth →Renewables	**ExpW**	**MeanW**	**Nyblom**	**SupLR**
Brazil	31.6875***	4.76007	9.7408***	70.404***
Germany	27.9398***	17.0675***	12.6300***	62.8645***
Japan	39.8567***	27.8097***	2.7757	86.7362***
United States	86.5835***	26.2080***	5.1459	179.8434***

Notes: Four test statistics are reported: Exponential Wald (ExpW), Mean Wald (MeanW), Nyblom (Nybolm) and Quandt Likelihood Ratio (SupLR) tests. Lag selection is based on the AIC. The VAR model is estimated with one lag. *** $p<0.01$.

Table 2: Results of Rossi-Wang Causality Test

Figure 1. Renewable energy consumption