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Incentives for Sustainability: Relationship Between Renewable Energy Use and Carbon Emissions for Germany and Finland

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Abstract: Green energy, a hot topic of recent energy studies, is any type of energy created using renewable resources, such as sunlight, wind, or water. Despite several variations between it and renewable energy, green energy typically comes from renewable energy sources. The use of these energy sources should not damage the environment by means like emitting greenhouse gases into the atmosphere. Producing power with minimal carbon footprint is a huge step toward a future that is more environmentally friendly. The global energy system has been moving away from fossil fuels towards carbon-free energy sources. The International Renewable Energy Agency (IRENA) estimates that energy efficiency and renewable energy policies have the potential to reduce carbon emissions by 90 percent. Our research focuses on the usage of renewable energy, and assesses how it affects carbon emissions in Germany and Finland. The recent panel causality test of Yilanci and Kilci was performed to examine the causality relationships between variables in 1990-2020. This study offers important insights into how using renewable energy affects carbon emissions for the two countries.

Keywords: Renewable energy use; Carbon emission; Sustainability; Green energy

1. Introduction

Energy is very important as a driver of a country's progress. Particularly, the use of fossil fuel energy has become widespread on a global scale. However, the expansion of energy-consuming activities in both developed and developing nations, as well as waste in wealthy nations like the Gulf states, leads to two main problems: The depletion of the most accessible energy sources, like oil, and the problem of global warming as a result of the rapidly expanding emissions of greenhouse gases, including carbon dioxide and methane. These two problems are linked together and might have a significant impact on how the world develops. The need for effective management of renewable energy resources is critical given the global breadth of the energy issues (Sebri & Ben-Salha, 2014).

The production of energy, specifically the burning of fossil fuels to generate electricity and heat, is a significant contributor to the greenhouse gas emissions that blanket the Earth and trap solar heat. Burning fossil fuels, such as coal, oil, and gas, is the main cause of greenhouse gas emissions, accounting for more than 75% of global emissions and almost 90% of carbon dioxide emissions. If emissions are reduced by roughly half by 2030 and reach net zero by 2050, the catastrophic effects of climate change might be avoided. Countries must abandon fossil fuels and switch to renewable energy sources, which are better for the environment, the economy, and the stability of our electricity system. Renewable energy sources have almost little carbon emissions and do not cause global warming (United Nations, Climate Action, 2022).

The creation of a sustainable environment has been a worldwide priority in recent years. Researchers and politicians are motivated to invest a lot of time and attention into studying the connection between energy use, emissions, and economic growth. For example, Antonakakis et al. (2017), Apergis & Payne (2009), Koondhar et al. (2021), Menyah & Wolde-Rufael (2010), Sebri & Ben-Salha (2014), Shafiei & Salim (2014), Wang & Yang (2015), Wang et al. (2012), and Zhang & Cheng (2009) studied the relationship among renewable and non-renewable energy use, carbon emissions, and economic growth, although this is a relatively new field of research.

Sebri & Ben-Salha (2014) employed a multivariate approach to investigate the relationship between renewable energy utilization and BRICS economic progress between 1971 and 2010. They supported the empirical evidence that the variables are in a long-run equilibrium with their ARDL estimations. Furthermore, their findings demonstrate the bidirectional Granger causation between economic growth and the utilization of renewable energy, supporting the feedback theory, which explains how renewable energy drives economic development in the BRICS countries.

Similar to this, Antonakakis et al. (2017) utilized panel vector autoregression to examine data on real GDP, energy consumption, carbon dioxide emissions, and four socioeconomic groups in 106 countries between 1971 and 2011. Their goal was to better understand the dynamic relationship between output, energy use, and the environment. They discovered that each country has varied effects of energy use on carbon emissions and economic growth. The feedback hypothesis supports their findings, which point to a bidirectional causality between economic development and energy use. Koondhar et al. (2021) attempted to analyze the relationships between the use of renewable energy sources, carbon emissions, forestry, and agricultural value added per capita, focusing on China for the years 1998 to 2018. Their results prove that using renewable energy sources reduced carbon emissions in the short term.

The relationship between energy use and carbon emissions has been the focus of countless studies, carried out in a variety of countries with radically disparate outcomes, but these studies have not led to a conclusive result. To add to the body of knowledge, this study investigates how switching to renewable energy affects carbon emissions in two Eurozone nations. Our research contributes in a number of significant ways:

We concentrated on Finland and Germany, two nations that play significant roles in promoting the use of renewable energy. Finland is at the forefront of developing and implementing policies to increase the use of renewable energy. The main objectives of Finland's renewable energy plan are to transition away from an energy system based on fossil fuels and to reduce greenhouse gas emissions. The National Energy and Climate Strategy for 2030 seeks to boost the share of renewable energy in energy use to over 50% by 2030 from the current level of over 40%. The use of renewable energy is impacted by Finland's own energy and climate policies as well as obligations and policy choices under European Union energy and climate legislation, which have the EU committed to achieve carbon neutrality by 2050 (International Trade Administration, 2022).

Germany used 49% renewable sources of electricity in the first half of 2022, rising 6% from the same period the previous year, according to Reuters (2022). 139 billion kWh, or 13.5% more than the previous year, were produced from renewable energy sources as wind, sun, hydro, biomass, waste, and geothermal energy.

To the best of our knowledge, this study is one of the few to compare the use of renewable energy sources and carbon emissions across European nations. Furthermore, we employed a recent panel causality test proposed by Yilanci & Kilci (2021). Using the Fourier functions, this test, which is based on the methodology created by Enders & Jones (2016), permits structural modifications.

The rest of this paper is organized as follows: Section 2 explains the details of our methodology; Section 3 introduces the research data; Section 4 summarizes the analysis results; Section 5 concludes the paper by giving some policy implications.

2. Methodology

In our analysis focusing on the relationship between renewable energy use and carbon emissions, we use the method presented by Bahmani-Oskooee et al. (2015). Bahmani-Oskooee et al. (2015) designed the panel stationary test, which incorporates Fourier functions into the CBL test that detects structural shifts using dummy variables. To simulate the mean reversion features of renewable energy use and carbon emissions for Germany and Finland, Y, we employ the following specification, on which Bahmani-Oskooee et al. (2015) depend;

$$y_t = \alpha + \sum_{l=1}^{m+1} \theta_t DU_{l,t} + \sum_{k=1}^{n} \gamma_{l,k} sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2,k} cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad (1)$$

where, t stands for time, T for sample size, and m for the optimal number of shifts. We can state the remaining regressors as follows;

$$DU_{k,t} = \begin{pmatrix} 1 & if \quad TB_{k-1} < t < TB_k \\ 0 & otherwise \end{pmatrix} \quad (2)$$

The model involves the term DU so that we can detect sudden shifts. $\sum_{k=1}^{n} \gamma_{l,k} sin\left(\frac{2\pi kt}{T}\right)$ and $\sum_{k=1}^{n} \gamma_{2,k} cos\left(\frac{2\pi kt}{T}\right)$ are inserted to capture a smooth break in the Fourier estimation. Both n and k, which stand for the total number of frequencies, are included in the approximation. Bahmani-Oskooee et al. (2015) argue that it is reasonable to assume n = 1, because the null hypothesis of time invariance is rejected. Then, Bahmani-Oskooee et al. (2015) might reduce Eq. (1) to;

$$y_t = \alpha + \sum_{l=1}^{m+1} \theta_t DU_{l,t} + \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \tag{3}$$

There is a two-stage estimate procedure that Bahmani-Oskooee et al. (2015) propose for Eq. (3). First, they determine the ideal frequency (k) and breakpoint (m). After reporting the sum of squared residuals (SSR) Bahmani-Oskooee et al. (2015) use the F statistic in the following way to check for the no-presence of the nonlinear component in Eq. (3);

$$F(k^*) = \frac{(SSR_{unresticred} - SSR_{resticred}(k^*))/2}{SSR_{resticred}(k^*)/T - q} \tag{4}$$

Monte Carlo simulation is used to determine critical values for the proposed test since it does not follow a normal distribution.

After confirming that the panel is stationary and the series become stationary at the same level, we use a panel causality test recently suggested by Yilanci & Kilci (2021). Granger (1969) was the first to introduce the concept of causal analysis to the academic literature. This method is used to see whether one variable can be used to predict the value of another. Enders & Jones (2016) and Nazlioglu et al. (2016) introduced causality tests that account for the VAR model's structural breaks. Because not only can structural breaks affect the results of unit root and cointegration tests, but they might also affect the results of causality tests. In this context, Enders & Jones (2016) and Nazlioglu et al. (2016) use the Fourier functions. By using the Fourier approximation, it is not needed to anticipate the number, date, and type of the breaks in the analysis, since just a few low-frequency components may adequately capture the structural changes. Yilanci & Kilci (2021) introduce a new panel causality test by extending the causality test proposed by Enders & Jones (2016) and Nazlioglu et al. (2016). For this panel causality test, they determine the following regression;

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \delta_i \sin\left(\frac{2\pi kt}{T}\right) + \theta_i \cos\left(\frac{2\pi kt}{T}\right) \varepsilon_{i,t} \tag{5}$$

They use the following steps to develop null and alternative hypotheses;

$$\begin{aligned} &H_0 = \beta_i = 0 && \forall i = 1,\ldots,N \\ &H_1 = \beta_i = 0 && \forall i = 1,\ldots,N_1 && 0 \le N_1 / N < 1 \\ &\quad\;\; \beta_i \ne 0 && \forall i = N_1 + 1,\ldots,N \end{aligned} \tag{6}$$

Specifically, they use the following test statistic to determine whether or not the null hypothesis holds;

$$W_{N,T}^{Hnc} = \frac{1}{N} \sum_{i=1}^{N} W_{i,T} \tag{7}$$

The critical values are derived through bootstrap simulations.

3. Data

We utilize the data on Germany's and Finland's renewable energy use and carbon emissions. Annual data from 1990 through 2020 are included in our analysis. Both countries have made substantial investments in renewable energy technology in recent years, therefore we are focusing on these in our research by using the data from The World Bank (2022). While renewable energy use is the percentage of the total energy used that originates from renewable resources, total carbon dioxide (CO_2) emissions are reported in metric tons per capita. As seen in Figure 1 and Figure 2, while renewable energy use increases in the two countries, the carbon emissions gradually decrease over the period 1990-2020.

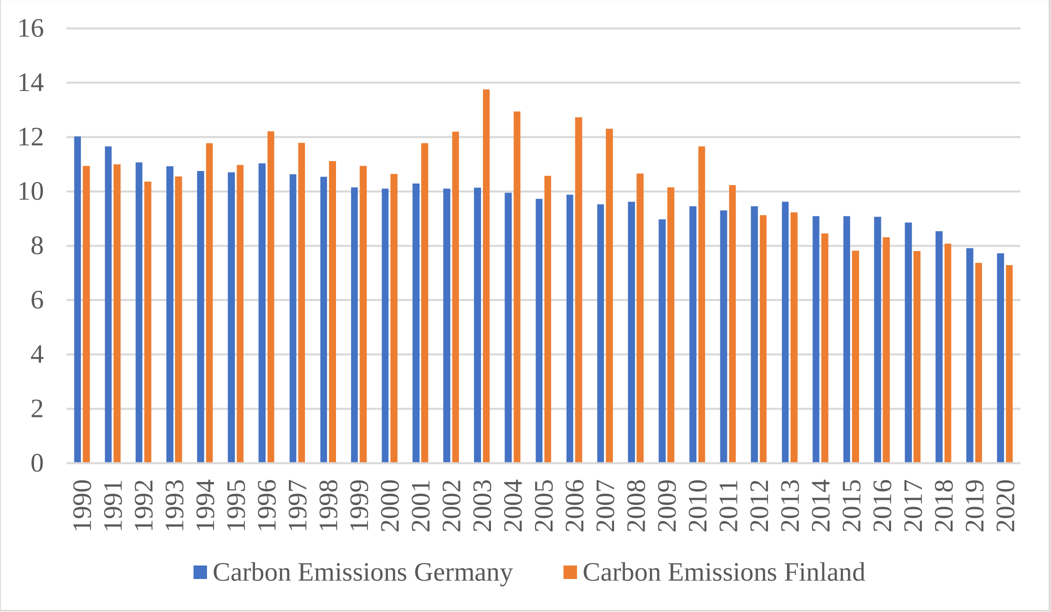

Figure 1. Carbon emissions in Germany and Finland: 1990-2020
Source: The World Bank (2022)

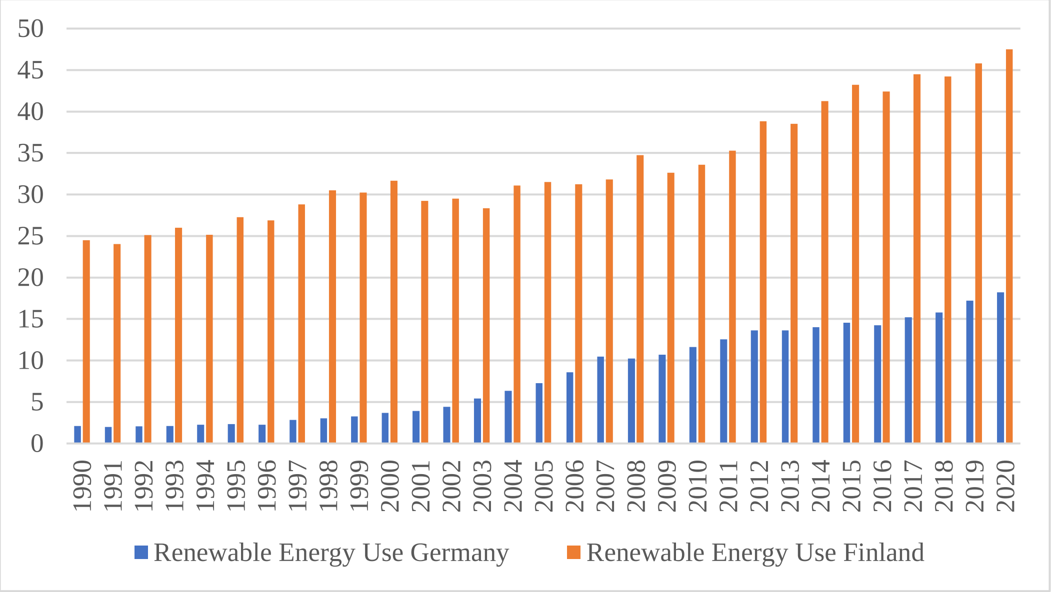

Figure 2. Renewable energy use in Germany and Finland: 1990-2020
Source: The World Bank (2022)

Table 1 gives brief information about the variables which we use in the empirical analysis.

Table 1. Definition of the variables

	Variables	Abbreviation	Type	Source
Dependent Variable	Carbon emissions	CO_2	Annually	World Bank
Independent Variable	Renewable energy use	RE	Annually	World Bank

4. Results and Discussion

We begin by using a panel stationary test with sharp shifts and smooth breaks proposed by Bahmani-Oskooee et al. (2015) to examine whether or not the panel and variables exhibit stationary behavior. Table 2 and Table 3 detail the results of our empirical analysis. For both countries, using both homogeneous long-run variance and heterogeneous long-run variance, we can't reject the null hypothesis of stationarity according to our panel stationary unit root test. The results in Table 2 and Table 3 indicate that the panel is stationary and the series individually do have unit root.

Table 2. Panel unit root test results for carbon emissions

Panel A: Panel Unit Root Test						
Pesaran (2004) cross-sectional dependence test	Test statistic	p-value				
	3.587	0.000				
Panel unit root test	Test statistic	Critical values				
		90	95	97,5	99	p-value
Homogeneous long-run variance	0.725	3.12	3.62	4.07	4.59	0.234
Heterogeneous long-run variance	0.801	3.96	5.89	7.92	11.34	0.211
Panel B: Univariate Unit Root Test						
Country	**Bartlett**	**95%**				
Germany	0.106	0.089				
Finland	0.192	0.121				

Table 3. Panel unit root test results for renewable energy use

Panel A: Panel Unit Root Test						
Pesaran (2004) cross-sectional dependence test	Test statistic	p-value				
	5.278	0.000				
Panel unit root test	Test statistic	Critical values				
		90	95	97,5	99	p-value
Homogenous long-run variance	-0.2132	0.54	0.99	1.50	2.36	0.584
Heterogeneous long-run variance	0.1051	1.46	2.79	4.05	5.99	0.458
Panel B: Univariate Unit Root Test						
Country	**Bartlett**	**95%**				
Germany	0.178	0.134				
Finland	0.116	0.078				

Note: A Monte Carlo simulation with 10.000 replications was used to calculate the finite sample critical values; the maximum number was set at 2 for breaks and frequencies.

Table 4 and Table 5 report the optimum frequency and break dates. When we check the F statistics in Table 4 and Table 5, we can see that the calculated F-statistics values are greater than critical values, so we confirm that the test results are meaningful.

Table 4. Estimation findings for the mean reverting function in Eq. (3)

Panel A: The Findings for Optimum Frequency and the F-Statistic and Its Critical Values						
Country	**Optimum Frequency**	**F statistic**	**90%**	**95%**	**97,5%**	**99%**
Germany	2	8.73	2.48	3.32	4.19	5.72
Finland	1	68.62	2.48	3.40	4.20	5.37
Panel B: The Findings for Sharp Breaks in Eq. (3)						
Country	**Break Dates**					
Germany	1997	2013				
Finland	1997	-				

Table 5. Estimation findings for the mean reverting function in Eq. (3)

Panel A: The Findings for Optimum Frequency and the F-Statistic and Its Critical Values						
Country	**Optimum Frequency**	**F statistic**	**90%**	**95%**	**97,5%**	**99%**
Germany	2	13.64	2.52	3.37	4.33	5.56
Finland	1	3.70	2.55	3.41	4.28	5.53
Panel B: The Findings for Sharp Breaks in Eq. (3)						
Country	**Break Dates**					
Germany	2005	2009				
Finland	1996	2011				

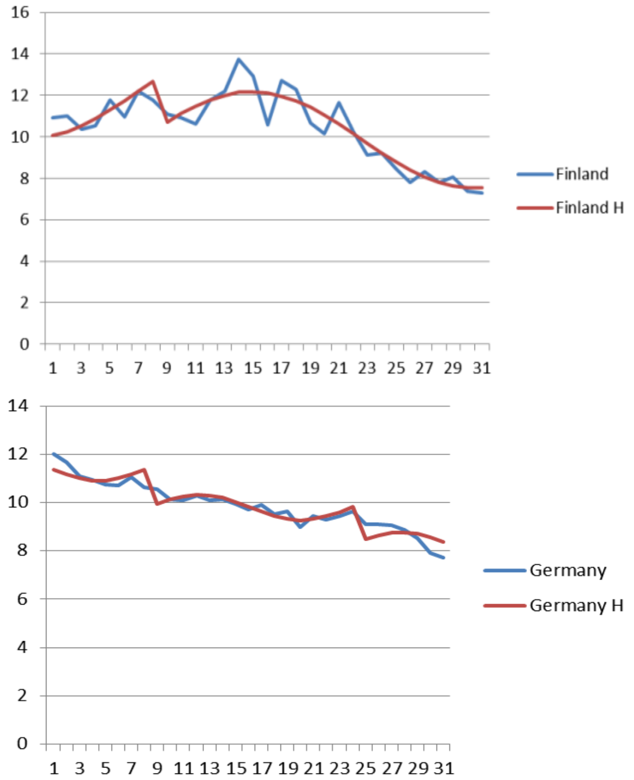

Figure 3. Time series plot of carbon emissions for Germany and Finland and the fitted nonlinear flexible intercept with sharp shifts and smooth breaks

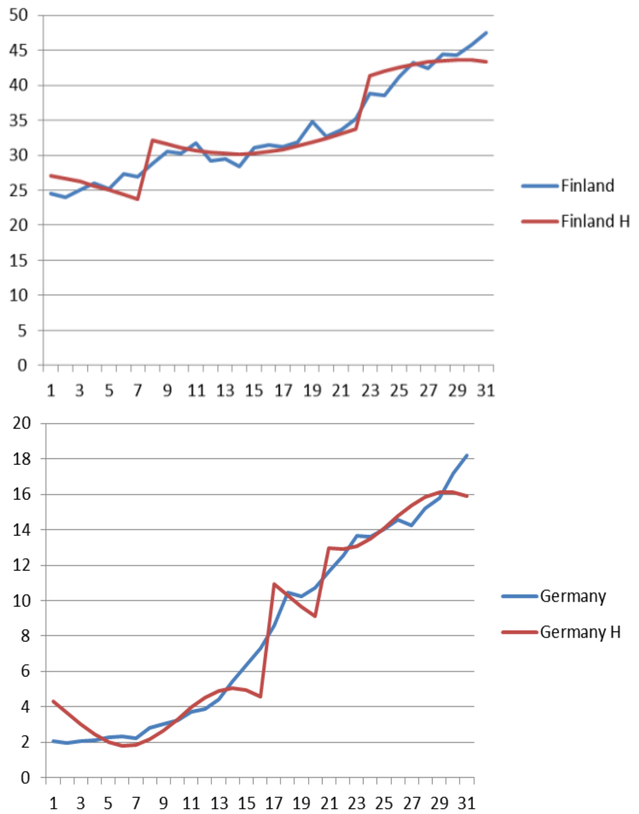

Figure 4. Time series plot of renewable energy use for Germany and Finland and the fitted nonlinear flexible intercept with sharp shifts and smooth breaks

The data exhibits structural breaks, as seen in Figure 3 and Figure 4, which enables testing for a unit root that incorporates both major shifts and smooth transitions. The predicted time paths of the time-varying intercept are also shown in Figure 3 and Figure 4.

In the second stage, we employ the panel causality test proposed by Yilanci & Kilci (2021) to test the relationship between carbon emissions and renewable energy use. Table 6 presents the findings of the panel causality test.

Table 6. Panel causality test results

Country	H0: RE → CO_2		
	Test statistic	Frequency	p value
Germany	5.485	1	0.019**
Finland	8.070	1	0.018**
Panel	4.309		0.000*
Country	H0: CO_2 → RE		
	Test statistic	Frequency	p value
Germany	4.883	1	0.027*
Finland	0.886	1	0.642
Panel	1.131		0.258

Note: * and ** shows the statistical significance 1 and 5 percent. We run 5.000 simulations to obtain the critical values.

We cannot reject the null of no-causality between the variables since the p-value is 0.000 for the panel. Therefore, we can imply that there is a unidirectional causality run from renewable energy use to carbon emissions confirming that renewable energy use does have an impact on carbon emissions in both Germany and Finland. In addition, we note that there is a bidirectional causality relationship between renewable energy use and carbon emissions in Germany while there is a unidirectional causality run from renewable energy use to carbon emissions in Finland.

Interest in renewable energy sources has increased in the Euro-Area countries in recent years as a means to address climate change and to ensure and diversify the supply of energy mix. Numerous government incentive schemes, like feed-in tariffs, subsidies for renewable technology, tax rebates, and so on, have contributed to this rising interest. Therefore, in 2020, most countries in the Euro-Area saw a percentage of renewables in total electricity production that was more than 15% and this share is gradually increasing. As a result, carbon emissions in a decreasing trend in the Euro-Area. Finland and Germany are two examples. Over the years, while the share of renewable energy use has increased, carbon emissions are declining in a significant way. Furthermore, if Finland's government follows through on its aggressive climate ambitions, it would become the first European nation to achieve net zero by the year 2022, as reported by Euronews (2022). To go even further in its environmental efforts, Finland aspires to become net negative by 2040, meaning that it will absorb more CO_2 than it emits. This puts Finland ahead of the European Union's 2050 aim for carbon neutrality, making it a frontrunner in the global effort to reduce emissions. Using the same metric, it is determined that the European Union and Germany must achieve net zero greenhouse emissions by the early 2030s to meet the requirements of the Paris Agreement and the principles of climate justice.

5. Conclusions

To reduce emissions of greenhouse gases, especially carbon dioxide (CO_2), which makes up more than 60% of the total, renewable energy sources must be used extensively. If the long-term mean global temperature increase is to be confined to between 2 and 2.4°C, the International Energy Agency asserts that a worldwide 50% reduction goal in CO_2 emissions by 2050 is essential (Sebri & Ben-Salha, 2014). Given that renewable energy has a key role in reducing carbon emissions, in this paper, we attempt to examine the causality relationship between renewable energy and carbon emissions in two European countries as Germany and Finland. Employing the panel causality test proposed by Yilanci & Kilci (2021) with the annual data covering the period 1990-2020, we find a unidirectional causality from renewable energy use to carbon emissions supporting the evidence that renewable energy use does have an impact on carbon emissions in Germany and Finland. In other words, we can say that one efficient strategy for lowering carbon emissions is cutting down on non-renewable energy use, particularly fossil fuel usage as stated by Zhang & Cheng (2009). In this context, fossil fuel dependence might be lowered with the help of energy diversification policies. It is imperative that countries take proactive actions to expand the use of greener energy sources. While it is concerning that major countries like India and China have not committed to reducing their emissions of greenhouse gases, it is encouraging that these nations have prioritized the development of renewable energy as a means to cut carbon emissions. Renewable energy is a viable solution to climate change since it may lessen reliance on fossil fuel imports while simultaneously increasing the generation of reliable sources of energy. On the contrary to the countries which have not committed to reducing carbon emissions, Finland and Germany have been pioneers in the movement to promote the use of renewable energy via the creation and implementation of laws that encourage its widespread adoption. Both Finland and Germany have made reducing greenhouse gas emissions and transitioning away from an energy system based on fossil fuels central tenets of their national renewable energy strategies.

When put into effect throughout the Euro-Area, the supporting policies for renewable energy use have the potential to greatly boost job creation, enhance health, and provide platforms for innovations. On the other hand, Shafiei & Salim (2014) emphasize that it is important for governments and policymakers in industrialized and developing economies to remember that there is a cost associated with introducing renewables as a supplement or alternative to non-renewable energy sources for a clean and sustainable environment. There are a number of policy measures that might help advance renewable energy, and researchers such as Antonakakis et al. (2017) and Koondhar et al. (2021) highlight the importance of things like tax rebates for using renewable energy and introducing renewable energy portfolio principles. In this sense, our study is in line with the studies in the academic literature which coincide with the European Union's newly enacted and revised energy policies by further advocating for rapid adoption of the recent directives by the European Union. In addition, Apergis & Payne (2009) indicate that carbon dioxide emissions from the burning of fossil fuels vary widely across nations, even after controlling for factors like the size of the economy and population. Hence, this study might be extended in the future by taking into consideration such variations and policy revisions in the countries.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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