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CAUSAL MECHANISM OF RENEWABLE ENERGY, AIR QUALITY AND ECONOMIC GROWTH

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Abstract

In recent years, the threat of environmental pollution, particularly to human health, has highlighted the importance of air quality in environmental sustainability processes and the role of renewable energy in these processes. In this respect, the impact of renewable energy use on emission reduction policies is attracting increasing global attention. Identifying appropriate energy sources that are environmentally friendly has become a critical challenge for countries to support economic growth. Therefore, this study aims to investigate the causal relationship between air quality, economic growth and the use of renewable energy sources. To this end, a panel causality analysis was conducted for 38 OECD countries over the period 1990-2020. The availability of variables was taken into account when defining the dataset. The results of the analysis showed that GDP per capita, which is a growth variable, is the cause of the $PM_{2.5}$ air quality variable, that renewable energy consumption is the cause of the $PM_{2.5}$ variable, and that there is a two-way causality between renewable energy consumption and the GDP per capita variable.

Keywords: Economic Growth, Environmental Sustainability, Panel Data Econometrics

JEL Codes: C23, O13, S56

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INTRODUCTION

Human activities, which form the basis of sustainability, are essential for the smooth functioning of environmental resources for present and future generations. Therefore, the main condition for sustainability is the idea that humans and nature complement each other. Humans, who initially did not accept this basic idea, have continuously exploited the environment for their own benefit. As a result, the environment and its resources have undergone a very rapid process of consumption and pollution. On the other hand, the destruction of the environment and the uncontrolled and unplanned consumption of resources make it difficult to protect and plan natural resources in a sustainable way. Particularly sensitive ecosystems such as soil, water and air, which are among the physical elements of the natural environment, are polluted by humans without them being aware of it. This means that soil, water and air, whose natural cycles are disrupted, cannot perform as they used to. As a result, air pollution caused by air degradation is an important factor in sustainability. It is a global problem that has major implications for human health as well as global warming. According to the World Bank and the Institute for Health Metrics and Evaluation, air pollution prevents about 92% of the world's people from breathing clean air (World Bank Group, 2016). Long-term exposure to air pollutants can cause cancer and death (Pope et al., 2002, p.6). In particular, fine particulates damage the human respiratory tract, and some of these particles accumulate in cells and the blood after inhalation, leading to serious health effects (Manisalidis et al., 2020, p.2) Accordingly, air pollution, as represented by $PM_{2.5}$ concentrations, has a negative impact on ecosystem health, climate change and air quality. The number of premature deaths is one of the most devastating effects of $PM_{2.5}$ concentrations. In 2019, outdoor air pollution associated with $PM_{2.5}$ concentrations was responsible for 4.20 million premature deaths worldwide (WHO, 2022). Air quality therefore has a direct impact on the health of the urban population. On the other hand, health problems caused by the effects of particulate matter lead to lost work days. This reduces productivity and threatens economic sustainability. Furthermore, unhealthy societies are less likely to participate in environmental protection and sustainability efforts, making it more difficult to achieve long-term environmental goals. As a result, air quality has become a major challenge for the sustainability of the environment (Chen et al., 2024, p.1).

The review of the literature indicates that the increasing level of harmful emissions and the potential for severe adverse effects on environmental sustainability are of global concern for policymakers. Maintaining intergenerational equity is a dilemma because of global consumption patterns, energy-driven growth and the rapid depletion of natural resources (Xue et al., 2002, p. 899). This is undermining the foundations of sustainable development. To address this global concern, the United Nations has put forward the Sustainable Development Goals (SDGs). By the end of 2030, nations around the world will have to adhere to 17 development agendas. The aim of the SDGs is to restore global balance through a reorientation of the current trajectory of economic growth. SDG 13, which deals with climate action, is one of the 17 development goals that deserves special attention. The increase in industrial activity in the country and the rapid growth of the population are also increasing the demand for energy. In this regard, fossil fuels play an important role as the dominant source of commercial fuels. This type of fuel is known to cause serious air pollution and has a negative impact on global climate change (see; Balsalobre-Lorente 2021; Cheng et al. 2021). Therefore, SDG 13 plays an important role in the realisation of SDG 7 in terms of clean and affordable energy solutions. Thus, the development and research of clean energy solutions is necessary to address the ongoing climate challenges. On the other hand, since it is known that air pollution differs according to the degree of industrialisation or structural change in the economy, many studies in the literature (Grossman and Krueger 1995; McConnell 1997; Sun et al. 2008; Qui et al. 2019; Jiang et al. 2020; Zhang et al. 2022; Yi et al. 2024; Lohwasser et al. 2025) have examined how air pollution is related to the stages of economic growth. In most of the studies in the literature, there is an emphasis on the fact that economic growth should be sufficient to be a solution to air pollution problems. In addition, it has been recognised that energy consumption is an important driver of air pollution (Xie et al. 2021, p.2). Whereas earlier research focused mainly on the impact of fossil fuels on air pollution, renewable energy sources are now the focus of research because of their environmental benefits and, as mentioned earlier, as a potential source of energy for sustainable development (Sebestyén 2021; Adebayo 2022; Chien 2022; Miao et al. 2022; Dilanchiev et al 2024; Bashir et al. 2025). The positive impact of renewable energy on the environment has been extensively studied in the literature. Many studies have confirmed that the transition to renewable energy improves environmental quality and reduces harmful emissions (See: Özdemir and Koç 2020; Bilgili et.al. 2016; Doğan and Özturk 2017; Mirziyoyeva and Salahodjaev 2022, Raihan and Mainul Bari 2024. On the other hand, energy is the most important driver of economic growth in both the developed and the developing world (Cai et.al., 2018, p.1001). As there are limitations within literature regarding renewable energy consumption, air quality and economic growth, a causal relationship between these three factors has been investigated. With this motivation, OECD countries were chosen as the research group due to several factors, including their high-income developed economic infrastructure and their active role in developing policies and producing data on environmental sustainability and energy consumption. In addition, the lack of environmental awareness and social inequalities may exacerbate the negative effects of intensive economic activities and energy consumption in industrialised regions on certain groups. This is one of the reasons for selecting OECD countries. Given the availability of data, a panel causality analysis was carried out. 38 OECD countries were considered for the period 1990-2020. The study consists of an introduction, followed by a literature review, a methodology section including the dataset, econometric analysis and results, and a conclusion and evaluation section evaluating the analysis.

LITERATURE REVIEW

Environmental sustainability is defined as the creation and maintenance of conditions in which people and nature can co-exist productively, and in which the social, economic and environmental needs of future generations can be met. Ensuring that human activities do not erode the world's land, air and water resources is the principle of environmental integrity. However, as a result of activities such as industrialisation, urbanisation, rapid population growth, heating, transport and inappropriate land use, which have developed rapidly in recent years, the amount of gases that make up the atmospheric environment is changing. As a result, not only will the structure of the atmosphere change, but there will also be the potential for the formation of hazardous environments for the life of living things. Therefore, the relationship between air quality and economic growth is important when considering the impact of climate change and the aforementioned activities on environmental sustainability. In particular, strengthening renewable energy policies plays a crucial role in combating climate change and has become an important factor in improving air quality. However, renewable energy is crucial for economic growth, promoting innovation and technological progress, reducing energy costs and environmental sustainability. (See: Soukiazis et al. 2019; Wang et al. 2022). While the environmental Kuznets curve is well documented in the literature, there is very little research examining the impact of economic growth and renewable energy on air pollution. Some of them can be considered as the impact of environmental degradation on economic growth (Hashmi et al. 2020; Adedapo et al. 2022; Osuntuyi and Lean 2022; Acheampong and Opoku 2023), natural resources (Muhammad et al. 2021; Majeed et al. 2022) and renewable energy use (Magazzino et al. 2022; Wang et al. 2023). The literature on air pollution to date has been largely focused on specific regions and countries. Therefore, it is essential to explore the link between air quality, energy policies, especially renewable energy, and economic growth.

Alverez-Herranz (2017) examined the areas in which innovative technologies in environmental processes can have a positive impact on pollution, as well as their impact on economic growth and energy. In addition, energy policies and, in particular, the role of renewable energy were analysed. The study used panel data analysis. According to the results of the analyses, it is concluded that renewable energy sources are effective in reducing pollution. The need to implement innovative energy policies is discussed. Based on the results, it is suggested to formulate environmental policy implications, considering effects such as trade openness and water pollution.

Hanif (2018) conducted a panel data analysis using the System Generalised Method of Moments (GMM) with a dataset covering the years 1995-2015, and including 34 developing economies in the sub-

Saharan Africa region. He examined the impact of economic growth, urban population, fossil fuels, solid fuels and renewable energy on environmental degradation. It was found that as GDP per capita increases, fossil fuel consumption contributes to CO2 emissions, while the square of GDP per capita reduces emissions. The relationship was found to be in the form of an inverted U. The negative impact of solid fuel consumption and urbanisation on environmental degradation is also noted. In line with the results obtained, the importance of renewable energy was emphasised, as in many other studies in the literature.

Zeng et al. (2019) analysed China's air pollutants spatially, considering emission reduction and renewable energy policies. In the study, where SO_2, $PM_{2.5}$ and PM10 air pollutants were selected, it was found that emission reduction policies contributed to the reduction of PM_{10}. On the other hand, renewable energy policies were found to have a positive effect on reducing SO_2 and $PM_{2.5}$. It was found that energy policies in one region can have an effect on air pollutant emissions in nearby regions, and the importance of regulations in provincial energy policies was highlighted.

Soukiazis et al (2019) investigated sustainable development. They examined the role of human and physical capital and renewable energy as explanatory variables. The analysis used 28 OECD countries with a data set covering the years 2004-2015. The method used was panel data analysis. The analysis included many variables such as nuclear energy consumption, energy dependence, population, crude oil price. A sensitivity analysis was also carried out taking into account these variables. It is found that R&D expenditure is an effective factor in increasing the use of renewable energy sources. It also explains why nuclear energy poses no threat to renewables. In this context, the impact of oil prices and external energy dependence on renewable energy consumption is highlighted.

Zhang et. al. (2021) investigated the importance of air pollution for environmental sustainability in China. They considered particulate matter as an indicator of air pollution and estimated a spatial econometric model. According to the results, a control mechanism should be established to monitor air pollution to ensure order and follow-up. In some regions, the environmental Kuznet hypothesis was confirmed. The need to strengthen the planning and regulation of energy and road construction is also highlighted.

Mohsin et al. (2021), on the basis of the importance of the role of a clean environment for sustainability, conducted a study with a focus on renewable energy and air pollution. Asian countries were used in the analysis. The method used was panel data analysis. The results of the analysis, like many studies in the literature, showed the importance of renewable energy for sustainable living in Asian countries. Non-renewable energy sources are identified as a critical factor in the study. In light of the findings, it is emphasised that regional policies should be implemented and regulatory authorities should be established to ensure environmental sustainability.

Şahin (2022) examined the effects of $PM_{2.5}$ air pollution, public health expenditure, fertility and mortality rates on life expectancy at birth using data between 2000 and 2019 for 32 categorised countries. The panel quantile regression model was used as the method of analysis. It was stated that the results of the analysis showed that $PM_{2.5}$ air pollution should be included in the economic development, health agendas and planning strategies of countries. It was emphasised that broadening the debate on cost containment would enable environmental health determinants to receive more attention as potential complements to traditional cost containment policies.

Atay Polat and Ergün (2023) analysed the impact of environmental regulations on air pollution in Turkey. The environmental policy stringency index is used to measure the implementation of environmental regulations in Turkey. In the environmental performance, PM_{10} emission is used as air pollution data. In addition, the number of environmental patents as technological activity data is included in the model as an intermediate variable. The ARDL bounds test approach was applied as a method. According to the results obtained, it is found that the number of patents and the environmental policy stringency index have a greater effect on PM_{10} emission in Turkey in the medium and short run, and this effect disappears in the long run.

ul-Haq et al. (2023) conducted a panel unit root and cointegration analysis to investigate the impact of globalisation, renewable energy, population growth and economic growth on $PM_{2.5}$ air pollutants. South Africa was selected as the country and an annual data set between 1998 and 2020 was used. According to the results obtained, a long-term positive relationship was found between GDP and $PM_{2.5}$. On the other hand, it was concluded that non-renewable energy and population increase environmental degradation, while renewable energy decreases it. In line with the results obtained, it is stated that this region should focus on R&D and energy policies.

Budun (2024) conducted a panel data analysis for the period 2000-2020 in his study of the impact of health expenditure on growth and air pollution in the D-8 countries. According to the panel cointegration results, it was concluded that increases in growth also cause increases in health expenditure and that there is a strong relationship between them. On the other hand, the impact of air pollution on health expenditure was found to be negative and significant. It was also stressed that reviewing health and environmental policies, expanding air pollution monitoring systems around the world, and providing education on issues such as public health and the environment will increase environmental awareness.

Ren et al. (2024) use data from 82 countries over 2001-2019 to examine how economic complexity affects carbon emissions. Spatial panel data was used as the method of analysis. They find that economic complexity has a positive direct impact on carbon emissions, but a negative indirect impact. An important factor in reducing carbon emissions is found to be the promotion of regional integration and international cooperation. On the other hand, there is an emphasis on the fact that countries should have an increase in technology accumulation and innovation.

Lohwasser et al. (2025) examined the impact of technological factors, economic growth and urbanisation on air pollution for healthy progress towards sustainability. The study carried out unit root and cointegration analysis using the environmental model. The results showed that urbanisation and population growth cause environmental degradation. In order to reduce air pollution, the importance of public transport and car ownership in the regions was identified. In addition, it is emphasised that policies should be developed to mitigate the negative effects of increasing population density.

METHODOLOGY

Data Set and Model

Panel causality analysis was carried out for the OECD group of countries using the data set between 1990 and 2020. A total of 38 countries (Turkey, USA, Canada, France, Netherlands, Belgium, Luxembourg, Germany, Italy, Portugal, Denmark, Ireland, Greece, Switzerland, Austria, Sweden, Iceland, Norway, Spain, Japan, Finland, Australia, South Korea, New Zealand, Poland, Hungary, Czech Republic, Slovakia, Estonia, Israel, Slovenia, Chile, Mexico, Latvia, Lithuania, Colombia, Costa Rica) were included in the study due to data availability. The study uses $PM_{2.5}$, the concentration of particulate matter in air pollution, as an environmental performance indicator. $PM_{2.5}$ air pollution highlights how economic activities and urban planning strategies can have a significant impact on air quality and sustainability efforts. It is therefore an important environmental performance indicator. It also includes GDP per capita (constant 2015 US dollars) as an economic measure and renewable energy use (% of total final energy use) as a sustainable development measure. When considering the SDGs (Sustainable Development Goals), the consumption of renewable energy is crucial for achieving the targets of SDG 7 on accessible and clean energy and SDG 13 on climate action.

It is therefore of great importance for the sustainable energy policies of countries. For these reasons, the variable of renewable energy consumption is considered as an indicator of sustainable development. Finally, GDP per capita is considered an economic indicator because it allows countries to compare economic performance and level of growth. Table 1 provides details on the variables:

Table 1: Variables and definitions

Variable	Symbol	Description	Source
$PM_{2.5}$	$LPM_{2.5}$	Annual average $PM_{2.5}$ (micrograms per cubic meter)	World Bank
GDP per Capita	LGDP	GDP per capita (constant 2015 USD)	World Bank
Renewable Energy Consumption	LRENEWENERGY	Renewable energy consumption (% of total final energy consumption)	World Bank

The model under consideration for this purpose is the following:

$$LPM_{2.5_{it}} = \alpha_i + \beta_{it} LGDP_{it} + \theta_{it} LRENEWENER_{it} + \varepsilon_{it} \quad i=1,2,3,\ldots..N \quad t=1,2,3,\ldots..T$$

Environmental performance is the dependent variable in the model. The variables are natural logarithms. The independent variables are the renewable energy consumption (% of total final energy consumption) and GDP per capita (constant 2015 USD).

Econometric Methodology

Panel data refers to datasets with more than one unit (N) and a number of periodic observations (T) for each unit. The models which are developed for use with panel data are panel data models. The theoretical foundations of the methods and tests used in panel time series analysis include concepts related to both the structure of panel data and the analysis of time series (Tatoğlu, 2018, p.1). The concept of stationarity is crucial in panel time series analysis. The argument that the use of panel data improves the power of unit root tests based on a single time series is now widely accepted (Maddala and Wu, 1999, p. 631). As with time series, the mean, variance and covariance of panel data should not change over time. In other words, they should be stationary. This feature implies that the series fluctuates around a certain value in the long run and is called weak stationarity or covariance stationarity. Analyses with non-stationary series can lead to spurious regression problems. In this case, due to strong trend effects, non-existent relationships between the series may be detected, leading to misleading results.The nature of the relationships between variables is very important in econometric analysis. It needs to be understood whether there is a relationship between the variables and, if so, what the direction is. It is also important to carry out cointegration and causality tests to assess whether this relationship persists in the long run. The starting point of the analysis is usually a test of stationarity. In panel time series analysis, the determination of whether the series have cross-section dependence is a crucial step in the selection of unit root tests. cross section dependence implies that a relationship exists between the regression residuals of the units in the panel data set. Therefore, the analysis should start with the cross-section dependence test. The appropriate unit root test should be applied according to these results. Pesaran's CD test is generally preferred for the cross-sectional dependence test. This method is considered as a basic step in the analysis.

ANALYSIS RESULTS

The Pesaran CD (2004) test was developed after the Breusch and Pagan (1980) test lost consistency with large unit numbers (N) but limited time dimension (T). This test examines the correlation between units in the panel data set using the residuals from Augmented Dickey Fuller (ADF) regressions. The test is based on the calculation of the pairwise correlations of each of the units with the other units. The test statistic is expressed as follows, depending on the descriptive statistics of the variables and the hypotheses:

$$H_0 : \rho_{ij} = 0$$
$$H_1 : \rho_{ij} \neq 0$$

test statistic for balanced panel data set;

$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right)$ is expressed in the form. For small samples, N>T, non-stationarity, structural breaks and heterogeneity, the test is shown to perform well.

To this end, the descriptive statistical values of the variables determined for the OECD group of countries between 1990 and 2020, according to data availability, are first shown in the table below:

Table 2: Descriptive statistics

Variables	N	Mean	Std Dev.	Minimum	Maximum
$LPM_{2.5}$	1178	2.698272	0.442656	1.58825	3.47504
$LGDP$	1178	10.085	0.769382	8.21964	11.62998
$LRENEWENER$	1178	2.472592	0.03889	-.916290	4.417635

Table 3 shows the results of the cross-section dependency test:

Table 3: Pesaran CD (2004) test

Variable	Test Statistics	P Value
$LPM_{2.5}$	99.26	0.000
LGDP	133.06	0.000
LRENEWENER	55.13	0.000

The table above shows the statistics and probability values of the Pesaran CD test for the measurement of correlation between units. The results indicate that the null hypothesis that there is no inter-unit correlation between the variables is rejected. There is a significant correlation between the units. In this case, second-generation panel unit root tests, which can account for inter-unit dependence, should be used in stationarity analysis instead of first-generation panel unit root tests.

For the stationarity test, Pesaran (2007) proposed an improved method by adding lagged cross section means to the ADF regression. This neutralises the correlation between units. This method aims to eliminate the dependence between units by taking the first difference of the regression. This test is called Cross Sectionally Augmented Dickey-Fuller (CADF). Also included are the results of the Fisher Augmented Dickey Fuller (Fisher ADF), which does not require working with a balanced panel data set, allows using different lag lengths and can be run for any specified unit root test. In this sense, the results of the stationarity tests of the variables included in the analysis are presented below.

Table 4: Cross-sectionally augmented Im, Pesaran, and Shin (CIPS) & Fisher augmented Dickey-Fuller (Fisher ADF) panel unit root test

Variable	***Im, Pesaran, and Shin (CIPS) Panel Unit Root Test***			
	Level		**First Difference**	
	Z [t-bar]	**P Value**	**Z [t-bar]**	**P Value**
$LPM_{2.5}$	-0.770	0.221	-11.804	0.000
LGDP	-2.723	0.003	-	-
LRENEWENER	0.927	0.000	-	-
	Fisher Augmented Dickey-Fuller (Fisher ADF) Panel Unit Root Test			
	χ^2	**P Value**	χ^2	**P Value**
$LPM_{2.5}$	21.880	1.000	578.271	0.000
LGDP	94.37	0.078	-	-
LRENEWENER	143.950	0.000	-	-

The air quality variable $LPM_{2.5}$ has a unit root and is not stationary at the level but at the first difference, and the variables LGSYIH and LYENENJ are stationary at the level, according to the test statistics and the significance values of the variables. Estimation methods to be used, it is important to determine whether the constant and slope parameters are homogeneous or heterogeneous across units. Therefore, homogeneity needs to be tested. For homogeneity analysis, the Swamy S test is preferred. Developed by Swamy (1971), this test provides a statistical measure of parameter homogeneity. The following table gives the mathematical formula for this test.

$$\hat{S} = \chi^2_{k(N-1)} = \sum_{i=1}^{N} (\hat{\beta}_i - \bar{\beta}^*)' \hat{V}_i^{-1} (\hat{\beta}_i - \bar{\beta}^*)$$

Where $\hat{\beta}_i$ is the OLS estimator obtained from unit regressions, $\bar{\beta}^*$ is the weighted WE estimator and $\hat{V}_i$ is the difference between the variance of the two estimators. The test statistic has a χ^2 distribution with $k(N-1)$ degrees of freedom. In this sense, the result of the Swamy S test is given below:

Table 5: Swamy S Test

Test Statistics	P Value
Chi2(111): 91509.11	0.0000

The homogeneity hypothesis is rejected according to the results of the Swamy S test. It is concluded that the parameters are heterogeneous. Therefore, it is necessary to prefer methods that take heterogeneity into account in causality and cointegration analysis.

Determining the appropriate lag length to use in the model is an important step before proceeding with the causality analysis. Choosing the correct lag length improves the reliability of the analysis results and the performance of the model. The following values are provided to help determine the appropriate lag length.

Table 6: Determination of lag length

Lag	CD	J	J pvalue	MBIC	MAIC	MQIC
1	.9999996	80.69851	.0000282	-159.8574	8.698512	-56.06071
2	.9999995	58.48086	.0004158	-121.9361	4.480856	-44.08856
3	.9999985	45.00536	.0004137	-75.27259	9.00536	-23.37425
4	.9999967	.0061364	1	-80.17917	23.99386	-45.58027

As a result of the evaluations related to determining the lag length, it is observed that the R^2 value reaches the highest level at the first lag. According to the Hansen's J test results, the instrumental variables are valid at all lags. The lowest values of the model selection criteria MBIC, MAIC and MQIC also correspond to the first lag. For this reason, 1 has been chosen as the appropriate lag length for the analyses. The panel causality test of Dumitrescu and Hurlin (2012) is used for causality analysis. This test is an extension of Granger causality to heterogeneous panels. Accordingly, the results of the causality analysis which take into account the correlation between the units and the heterogeneity, are presented below.

Table 7: Dumitrechu & Hurlin Causality Test

H_0	Z-bar	P Value	Result
$PM_{2.5} \underset{?}{\Rightarrow}$ GDP	1.5340	0.1250	$PM_{2.5}$ is not the cause of GDP.
GDP $\underset{?}{\Rightarrow}$ $PM_{2.5}$	4.6930	0.0000	GDP is the cause of $PM_{2.5}$
RENEWENER $\underset{?}{\Rightarrow}$ GDP	14.8375	0.0000	RENEWENER, is the cause of GDP
GDP $\underset{?}{\Rightarrow}$ RENEWENER	13.4875	0.0000	GDP is the cause of RENEWENER
RENEWENER $\underset{?}{\Rightarrow}$ $PM_{2.5}$	3.2794	0.0010	RENEWENER is the cause of $PM_{2.5}$
$PM_{2.5} \underset{?}{\Rightarrow}$ RENEWENER	-1.2522	0.2105	$PM_{2.5}$ is not the cause of RENEWENER

The table of causality results shows that the variable GDP per capita is the cause of the environmental performance indicator variable $PM_{2.5}$, which expresses air quality. It also shows that there is a two-way causal relationship between the consumption of renewable energy and the variable GDP per capita and, finally, that the consumption of renewable energy is the cause of the variable $PM_{2.5}$. In order to examine the cointegration relationship between the variables, the variables should be stationary at first difference. As only the environmental performance indicator $PM_{2.5}$ variable was stationary at the first difference, it was not possible to examine the co-integration relationship.

CONCLUSION AND POLICY IMPACTS

Sustainable economic growth is a key economic policy objective for all countries around the world. On the other hand, the health problems caused by air pollution and its negative effects on environmental processes are essential for environmental sustainability. In this context, the aim of the study is to examine the causal relationship between air quality, consumption of renewable energy and economic growth in 38 OECD countries over the period 1990 to 2020. For this purpose, a panel causality analysis was conducted. From the results of the analysis, it has been found that the variable GDP per capita is the cause of the environmental performance indicator $PM_{2.5}$, which is an expression of air quality. Economic growth means more industrialisation and industrial activity. Economic growth is therefore associated with increased energy use, as the increase in national income resulting from growth leads to increased consumption and investment expenditure, which in turn leads to increased energy demand. Using this energy can result in increased waste emissions. This directly leads to increased airborne pollutants including $PM_{2.5}$. This shows that GDP is a factor that worsens air quality and explains the causality. On the other hand, according to Cai et al. (2018), policy authorities do not want to reduce CO_2 emissions at the expense of strong economic growth. This idea can also be considered as a reason to explain the unidirectional relationship. It is therefore essential to promote a change in the use of energy by reducing dependence on fossil fuels and increasing the use of renewable energy, as well as improving energy efficiency to increase the potential for waste reduction. Green production and energy-saving technologies should be strengthened. The result is a reduction in energy consumption for production per unit of GDP. Given the result for renewable energy, there is a two-way causality between the consumption of renewable energy and the GDP per capita variable. The implication is that renewable energy is an important driver of economic growth (See: Bhattacharya et al. 2016). Four hypotheses (Salari et al., 2002, p. 5) have been put forward to explain why renewable energy consumption is linked to economic growth. The growth hypothesis suggests that energy consumption plays a role in economic growth. It does so by directly and indirectly supporting labour and capital in the production process. The implication is that, if the growth hypothesis is correct, energy saving policies could potentially have a negative impact on real GDP per capita. The conservation hypothesis implies that policies aimed at saving energy will not lead to a reduction in real GDP. Neutrality means that there is no relationship between the energy used and the growth of the economy. Reducing energy consumption through energy saving policies therefore has no impact on economic growth. The feedback hypothesis implies a bi-directional causality between renewable energy consumption and real GDP. This confirms that a bidirectional causal relationship exists between renewable energy consumption and real GDP per capita. Some of the most important steps in the deployment of renewable energy are the creation of an investment climate, the development of human expertise and the removal of financial and political barriers. This process has involved the majority of OECD countries. Besides improving environmental conditions, the results support the macroeconomic benefits of government policies promoting renewable energy use. Notably, higher economic growth can also be an important determinant of renewable energy supply and consumption levels.

Finally, $PM_{2.5}$ was found to be caused by the use of renewable energy sources. The transition from fossil fuels to renewable energy is key to achieving climate change targets. To reduce emissions of air pollutants, materials used in renewable energy production can be produced more sustainably. Recyclable materials can be used to ensure sustainability. Regulatory policies can be implemented taking into account the infrastructure feasibility of countries. Cost-effectiveness analysis is important in this direction. If all these factors are taken into account, the process of transition to renewable energy will become more efficient. In addition, innovation, R&D expenditure, commercial activities, internationalization activities, digitalization processes should be integrated into environmental sustainability and incentives for cooperation between countries should be increased.

AUTHOR STATEMENT

Researcher declared that all contributions to the article were his own. Researcher have not declared any conflict of interest.

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