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Relationship between Electricity Consumption, Generation, and Economic Growth: Evidence from Visegrad Countries

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ABSTRACT

The purpose of this study is to determine the relationship between electricity generation, electricity consumption, and economic growth in the Visegrad countries. Visegrad four is one of the most important regional groups in the European region. The countries that make up the Visegrad four are Czechia, Hungary, Poland, and Slovakia. The model has three independent variables. The independent variables are electricity consumption and electricity generation. Electricity generation is represented by two different variables according to the type of resource used. The analysis covers the period 1993-2023 and the Gengenbach–Urbain–Westerlund (GUW) panel co-integration test, Augmented Mean Group (AMG) estimator, and Dumitrescu–Hurlin causality test were applied. Since a co-integration relationship exists between the variables, long-term co-integration coefficients were estimated. According to the AMG estimation results, electricity consumption increases economic growth for the entire panel. While electricity generation from fossil sources reduces economic growth, electricity generation from renewable sources increases economic growth. However, the effect of electricity generation from renewable resources is statistically insignificant. According to the causality test, there is no causal relationship between electricity consumption and economic growth, or between electricity generation from renewable sources and economic growth. There is a bidirectional causal relationship between electricity generation from fossil fuel sources and economic growth. This result shows that the dependence on fossil fuels for electricity generation in Visegrad is high, and electricity generation from renewable sources does not have a sufficient effect on economic growth. The implementation of policies that will increase electricity generation from renewable resources should be given importance, and energy policies should be reviewed accordingly.

Keywords: Economic Growth, Electricity Generation, Electricity Consumption, Visegrad Countries

1. INTRODUCTION

With the industrial revolution, mass production began, and the production of goods and services increased rapidly throughout the world. Intense competition has begun among countries striving for industrialization to produce more goods and services. One of the fundamental inputs to the production of services and goods is energy. Nowadays, there is a transition from an industrial to information society. However, the transition to an information society has further increased the need for energy. Technological developments, changes in consumption habits, increased welfare levels, and population crowding increase energy demand. The share of electrical energy in energy consumption is very high. From machines used in production to computers, from basic items used in homes to communication and transportation, almost everything runs on electrical energy. The diversity in the use of electrical energy and economic and social developments increase the demand for electricity. The increasing demand for electricity has become increasingly difficult. Although the increase in electricity demand is very fast, the increase in electricity supply may not be at the same pace. This situation causes problems such as energy supply and energy security. Many countries around the world are seeking ways to increase their energy supply and are making radical changes to their energy policies. Electricity consumption and generation are not only problematic for the sustainability of production and daily life. Electricity consumption and generation also have economic growth implications. Therefore, the link between electricity generation, consumption, and economic growth is a current and interesting research area.

The purpose of this research is to investigate the relationship among electricity consumption, generation, and economic development in the Visegrad nations. The first contribution of this study to the literature is its consideration of the effects of electricity consumption and generation on economic growth. Many studies in literature have examined the effect of electricity consumption on economic growth or the effect of electricity generation on economic growth. However, the number of studies on both electricity consumption and generation is limited. The second element that reveals the difference of the study is that it examines electricity generation using two different variables: electricity generation from fossil resources and electricity generation from renewable sources. Thus, it will be possible to compare the effect of electricity generation from fossil fuels and renewable sources on economic growth. This is especially important for policy recommendations. The third aspect of the study is the country group. Because of the literature search, no similar studies were found in the Visegrad countries. The more different countries or groups of countries that are investigated on the subject, the better it will be to compare the results and reach accurate findings. For this reason, it is important to conduct analyses on a group of countries that have not been tested previously.

This study first explains the theoretical foundations of the link between electricity generation, consumption, and economic growth are explained. Since the sample group of the study is comprised of Visegrad countries, some general information is provided about these countries. After providing general information about the countries, the changes in electricity consumption and electricity generation data over time are shown with the help of graphics. After a literature review, information about the variables and methods used in this study was provided. In the analysis, cointegration and panel causality analyses were performed using data from the Visegrad countries between 1993 and 2023.

2. RELATIONSHIP BETWEEN ECONOMIC GROWTH AND ELECTRICITY CONSUMPTION

Factors that determine economic growth are among the basic subjects of macroeconomics. Throughout history, various growth theories have been proposed to explain economic growth. However, growth theories generally focus on labor and capital, and the impact of energy on growth is ignored. However, energy is one of the basic inputs of the production process and is a necessary factor for uninterrupted production. It is not possible to consider the economic growth process independently of the energy factor (Javid, Javid and Awan, 2013). There are four hypotheses in the literature that explain the causal link between economic growth and energy consumption. These are growth, conservation, feedback, and neutrality hypotheses (Samu et al. 2019). According to the growth hypothesis, there is a unidirectional relationship between energy consumption and economic growth. The direction of this relationship is from energy consumption toward economic growth (Halkos and Tzeremes, 2014). The conservation hypothesis states that there is a one-way relationship between economic growth and energy usage. Nonetheless, the relationship's direction is from economic expansion to energy use (Omri, 2014). The feedback hypothesis states that there is a bidirectional causal relationship between energy consumption and economic growth. Accordingly, although economic growth affects energy consumption, changes in energy consumption also affect economic growth (Chauhan et al. 2020). According to the neutrality hypothesis, the fourth strategy, there is no causal relationship between energy use and economic growth. Economic growth has no effect on energy consumption. Similarly, fluctuations in energy consumption do not result in economic growth (Menegaki, 2011).

The share of electrical energy consumption is very high. Consequently, there has been a growing interest in the connection between economic growth and electrical energy consumption, particularly in recent years. Electrical energy is an important determinant of economic growth because it affects both total supply and demand. Electric energy is one of the main inputs used in the production process. Electrical energy is needed to ensure production continuity and resource efficiency. In this regard, electrical energy is essential for the total supply. However, the effects of electricity are not limited to the total supply. Electrical energy also impacts total demand. Electrical energy is used to improve the quality of life of individuals who make up society, maximize their benefits, and continue daily life (Long et al. 2018). Electrical energy has become a part of human life since the industrialization process. The industrialization process forms the foundation of modern societies. Electrical energy is needed for industrial production. Changes in economic and social life increase the need for electricity. With industrialization, population growth has occurred, the proportion of the population living in cities has increased, per capita income level has increased and living standards have improved. Improvements in living standards have increased health expenditure, reduced infant and child mortality rates, increased life expectancy, and positively affected public health (Markandya and Wilkinson, 2007). Today, technological developments and digitalization have made the internet an indispensable part of daily life. Computers and mobile phones are important elements of both everyday life and production processes. The increased use of information and communication technologies in production has increased electricity consumption. Therefore, the question of how electricity consumption affects economic growth remains a common research topic (Gurgul and Lach, 2012).

The literature has focused on the causal link between economic growth-electricity consumption. It is important whether the causality is unidirectional or bidirectional, and if there is unidirectional causality, whether it is from electricity consumption to economic growth or from economic growth to electricity consumption. Strategies of policymakers may differ depending on causal relationships (Polemis and Dagoumas, 2013). If the relationship is bidirectional, then policies that affect electricity consumption affect economic growth, and policies that affect economic growth affect electricity consumption. If there is unidirectional causality between them, running from electricity consumption to economic growth, policies to restrict electricity consumption may reduce economic growth. A rise in economic growth may result in an increase in consumption of electricity if there is a unidirectional causal relationship between the two. If there is no causality between them, policies that increase economic growth will not affect electricity consumption (Le Quang, 2011). However, some studies have reached different results regarding the causality relationship. The results may differ depending on the development levels, institutional structures, and environmental and energy policies of the country or country group being considered (Polemis and Dagoumas, 2013).

3. RELATIONSHIP BETWEEN ECONOMIC GROWTH AND ELECTRICITY GENERATION

The basis of economic and social life is energy. Technological developments, changes in production systems and consumption habits, and the proliferation of social media all increase energy consumption. It is anticipated that global energy demand will rise further in the coming years. This situation raises the question of how the increasing energy demand can be met. Meeting energy demand by increasing energy generation and selecting the resources to use are important factors that determine the energy policies of countries (Atems and Hotaling, 2018).

Electricity is one of the basic types of energy required to produce goods and services. However, fossil fuels are mainly used for electricity generation worldwide (Osobase and Bakare, 2014). Fossil resources are among the main factors causing increased carbon emissions. An increase in carbon emissions indicates increased environmental pollution and decreased environmental quality (Akın and Şen, 2024). In addition, carbon emissions cause global warming and trigger climate change. It is possible that climate change will turn into a crisis (Yang and Kim, 2020). Measures to reduce carbon emissions need to be implemented urgently. For this purpose, the use of fossil fuels in energy production and electricity generation, which are among the most used energy types, should be reduced. Fossil resources, in addition to increasing environmental pollution, also bring about different problems. Fossil resources are limited quantities of resources found in nature. Generating more electricity to meet the increasing demand for electricity will require greater use of fossil fuels. Thus, the sustainability of energy supply may be endangered. Consequences such as countries becoming dependent on foreign energy and energy security issues may occur (Becker and Fischer, 2013). Using renewable resources instead of fossil fuels provides countries with various advantages. Renewable resources do not cause environmental pollution, and since these resources cannot be depleted, it becomes easier to ensure sustainable energy supply (Maslyuk and Dharmaratna, 2013). Ensuring sustainability in energy supply ensures that the production of goods and services continues without interruption and that balanced economic growth occurs. In other words, a sustainable energy supply drives economic growth (Zeshan, 2013). In addition to their contribution to the environment, renewable resources reduce unemployment by creating new jobs and supporting countries' energy security policies. However, despite these advantages, there are also some disadvantages to electricity generation based on renewable resources (Azam et al., 2021). First, large capital is needed to build production facilities that use renewable resources. Renewable electricity generation incurs high costs (Timilsina, 2021). Therefore, the policies that governments will implement and the support they will provide to producers in the transition to electricity generation based on renewable resources are crucial. Fossil fuels are used instead of renewable resources, especially in developing countries, because of higher costs. However, action should be taken by considering the long-term benefits of using renewable energy sources. The transformation of energy production systems to renewable resources should not be left to market conditions. The process of change and transformation should be carried out by ensuring cooperation between the private sector and governments (Maslyuk and Dharmaratna, 2013).

4. VISEGRAD COUNTRIES

Visegrad four is one of the most important regional groups in the European region. The countries that make up the Visegrad four are Czechia, Hungary, Poland, and Slovakia (Cabada and Waisova, 2018). The establishment of this group was realized with a declaration signed in Visegrad, Hungary, in 1991. However, when the group was established, it consisted of three countries: Czechoslovakia, Hungary, and Poland, and it was described as the Visegrad trio. Later, the Czechoslovakia was divided, and two independent states emerged: the Czech Republic and the Slovak Republic. Thus, the group was called the Visegrad four in 1993 (Visnovsky, 2020). The countries that make up the Visegrad Four are in the Central European region. In addition to geographical proximity, they share common features regarding economic, historical, cultural, and religious issues. Although they share commonalities, these countries have experienced disagreements at some point throughout history. However, they decided to act together to turn the disagreements into opportunities and to use their common characteristics for their own interests (Strazay, 2014). The main purpose of establishing this group is to cooperate in economic, political, and military matters. This cooperation has become more important since their membership in the EU. Four countries in Visegrad became members of the European Union in 2004. It can be stated that when they joined the union, they were economically and socially more backward than other union members. This cooperation is an important opportunity to close the gap and accelerate economic and social development (Kaposzta and Nagy, 2015). Their cooperation and strategic position can enable them to strengthen both within the EU and on the European continent (Kriz et al. 2018).

When the Visegrad four were established, the development level of Czechia was higher than in the other three countries. Over time, Czechia has further increased its level of development while preserving its advantages. As mentioned above, when they became members of the EU, the economic indicators of the Visegrad countries were behind those of the union members. However, the Czechia has demonstrated a successful performance and has managed to largely reach the European Union average per capita income and other standard indicators. There are many factors that affect the development of Czechia. Attaching importance to technological development, digitalization and improving investment conditions are important parts of this success (Becsey and Mate, 2021).

Another Visegrad country is Hungary. Hungary stands out with its goals and policies, especially digitalization. It has included this issue in its strategic plan and set as its target to be among the top ten countries in the European Union in terms of digitalization performance by 2030. It strives to become the epicenter of 5G technology by becoming one of the most successful countries in Europe. Hungary integrates digital technologies into its daily life in many ways, from infrastructure to transportation, to health and education and public services (Török, 2024).

Poland is a rapidly growing country in the European Union and has been steadily implementing liberal policies since the 1990s. It can export to different sectors, its unemployment rate is quite low, its domestic demand is high, and it is an attractive country for direct foreign investments. It can be characterized as an economic leader in the Central European region. While attempting to increase economic strength, the country does not ignore environmental and energy issues (Lesniak et al., 2022). Poland has given priority to increasing renewable energy use in its energy policies (Swidynska, 2024).

Slovakia is an attractive country for foreign investors in the Central European region. Foreign investments in the country have increased over time due to its convenient geographical location, relatively low wages despite its skilled workforce, and advantages in tax and labor laws. Foreign investments, especially in the automotive industry, play an important role in the country's economy (Tancosova, 2019). Although it has an economically stable structure, its high dependence on foreign energy creates uncertainty regarding energy security. For this reason, Slovakia seeks to increase its development in renewable energy (Karatayev et al. 2023).

5. ELECTRICITY CONSUMPTION AND GENERATION IN VISEGRAD COUNTRIES

In this part of the study, we will explain how electricity consumption and production have changed over time in the Visegrad countries. The Figure 1 shows the electricity consumption changes in Visegrad countries between 1993 and 2023. The data reflect the net electricity consumption. During the time examined, electricity consumption was lower in Czechia, Hungary, and Slovakia than in Poland. In Poland, electricity consumption has increased more than in other countries over time. While electricity consumption in Poland was 104.18 billion kWh in 1993, it reached 124.71 billion kWh in 2003. The increase continued in subsequent years. Between 1993 and 2023, the highest electricity consumption in Poland was in 2018. The electricity consumption for this year was calculated to be 165.71 billion kWh. In Czechia, electricity consumption in the period 1993-2023 was generally in the range of 50-65 billion kWh. During this period, the only year in which electricity consumption was less than 50 billion kWh was 1993, and the only year in which it was more than 65 billion kWh was 2008. The electricity consumption in Czechia was 48.63 billion kWh in 1993 and 65.49 billion kWh in 2008. In 2003, electricity consumption in Czechia was 60.07 billion kWh. After 2003, electricity consumption did not fall below 60 billion kWh, except for in 2023. In 2023, electricity consumption was 57.4 billion kWh. The electricity consumption in Hungary was less than 30 billion kWh in 1993, 1994, and 1995. In 1996, it exceeded 30 billion kWh. It did not fall below 30 billion kWh in 1996-2016. In 2017, it exceeded 40 billion kWh and remained above 40 billion kWh in the following years. The electricity consumption in Hungary in 2023 was calculated to be 42.07 billion kWh. The electricity consumption is lower in Slovakia than in the other three countries. Between 1993 and 2023, electricity generation in Slovakia varied between 20 and 30 billion kWh. During this period, no year has electricity consumption exceeded 30 billion kWh. During the 1993-2023 period, the lowest electricity consumption in Slovakia was in 2023 and the highest in 2021. The electricity consumption was 28.42 billion kWh in 2021 and 22.25 billion kWh in 2023.

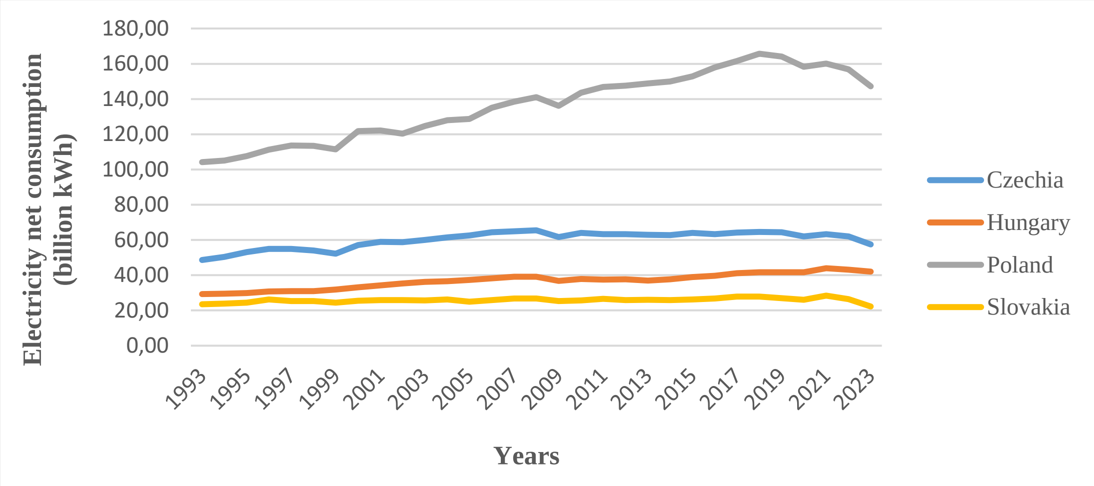

Figure 1. Electricity Consumption in Visegrad Countries (in billion kWh) (1993-2023)
Source: U.S. Energy Information Administration, https://www.eia.gov/

The following electricity consumption, the electricity production in the Visegrad countries will be explained. The electricity generation from fossil fuels and renewable resources will be compared. The Figure 2 shows how electricity production from fossil fuels has changed over time in the Visegrad countries. The data are from 1990 to 2023, and electricity production is measured in terawatt hours (TWh).

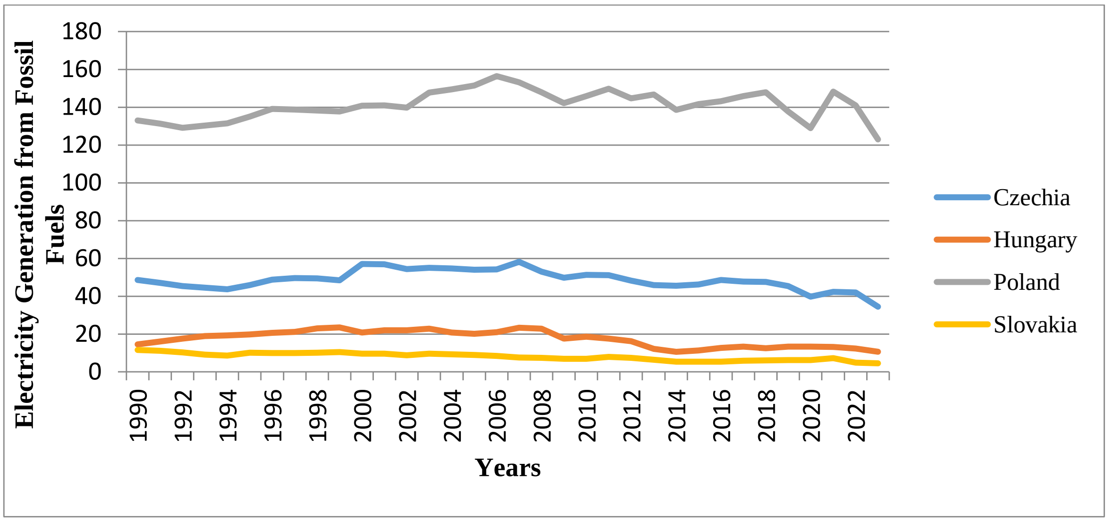

Figure 2. Electricity Generation from Fossil Fuels in Visegrad Countries (in Terawatt-hours) (1990-2023)
Source: Our World in Data, https://ourworldindata.org/

Among the Visegrad countries, Poland has the highest electricity generation from fossil fuels, while Slovakia has the lowest. Electricity generation in Poland did not fall below 100 TWh between 1990 and 2023. Even though there have been increases and decreases over the years, electricity production is considerably higher than those of the other three countries in the group. Czechia's electricity production, although lower than Poland's, is higher than those of Hungary and Slovakia. In the period 1990-2023, the year in which electricity production from fossil fuels was highest was 2007 and the year in which it was lowest was 2023. While Czechia's electricity production in 2007 was 58.18 TWh, its electricity production in 2023 was 34.45 TWh. Electricity production in Hungary was less than 20 TWh between 1990 and 1996. In 1996, electricity production was 20.65 TWh and continued to exceed 20 TWh in the 1996-2008 period. Electricity generation, which was 22.85 TWh in 2008, decreased to 17.59 TWh in 2009. After 2009, it was not possible to exceed 20 TWh. In 2023, electricity generation from fossil fuels in Hungary will reach 10.68 TWh. Slovakia has the lowest electricity generation from fossil fuels among the Visegrad countries. Electricity generation in Slovakia was generally below 10 TWh between 1990 and 2023. During this period, the year in which electricity production was highest was 1990 at 11.57 TWh. Electricity production was over 11 TWh in 1990 and 1991 alone. In other years, 11 TWh was not exceeded in electricity production. In 2022 and 2023, electricity production dropped to below 5 TWh. Electricity generation in Slovakia was 4.8 and 4.5 TWh in 2022 and 4.5 TWh in 2023.

After examining the evolution of electricity production from fossil fuels over time in Visegrad countries, the changes in electricity production from renewable sources are examined. The Figure 3 presents data on electricity production from renewable energy sources.

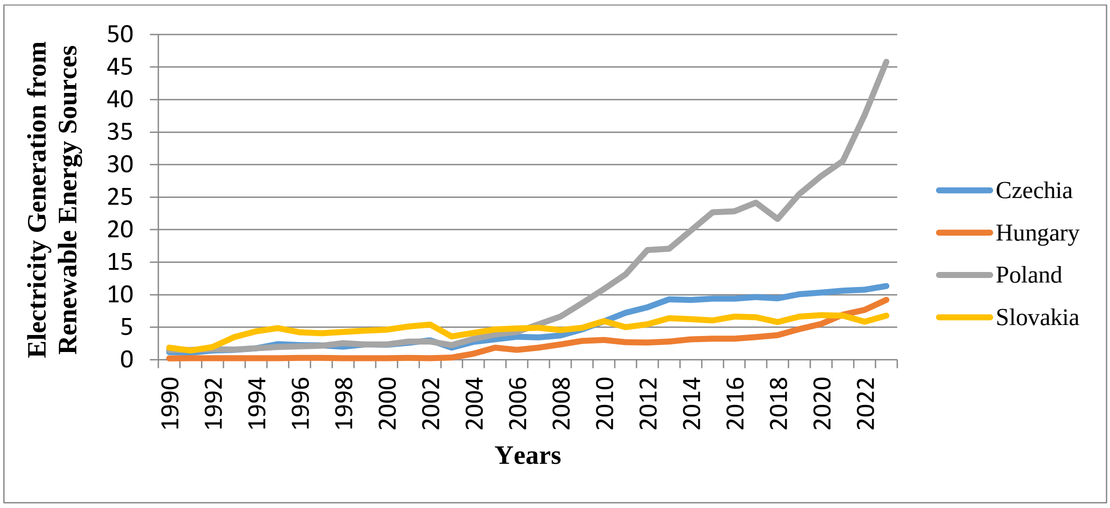

Figure 3. Electricity Generation from Renewable Energy Sources in Visegrad Countries (in Terawatt-hours) (1990-2023)
Source: Our World in Data, https://ourworldindata.org/

Poland is at the forefront of electricity production from renewable energy sources, and from fossil fuels. All four countries have experienced increased electricity generation from renewable energy sources over time. However, the increase in Poland is higher than in other countries. In Poland, electricity production from renewable energy sources was between 1 and 2 TWh in the period 1990-1995. Since 1996, electricity production has increased by more than 2 TWh. This increase continued in subsequent years. Electricity production in Poland was over 3 TWh in 2004 and over 10 TWh in 2010. In 2010 and thereafter, electricity production reached increasingly higher levels. Electricity production from renewable sources in Czechia has increased over time. Electricity production between 1990 and 1994 was between 1 and 2 TWh. The increase continued in subsequent years. As of 2013, electricity production from renewable energy sources in Czechia exceeded 9 TWh. In the period 2013-2018, electricity production remained above 9 TWh. In 2019, electricity production exceeded 10 TWh. Hungary demonstrated lower performance compared to the other three countries in electricity production from renewable energy sources. Energy production was below 1 TWh between 1990 and 2004. There was an increase in 2005 and thereafter. The electricity production first increased to 2 TWh and then increased to more than 3 TWh. However, real acceleration occurred in 2018 and thereafter. The electricity generation, which was 4.7 TWh in 2019, increased to 5.52 TWh in 2020 and 6.91 TWh in 2021. Electricity generation from renewable energy sources in Hungary was 7.66 TWh in 2022 and 9.2 TWh in 2023. While Slovakia lags behind Visegrad in the production of electricity from fossil fuels, it shows better performance in the production of electricity from renewable energy sources. Unlike Hungary, electricity production from renewable energy sources in Slovakia never fell below 1 TWh between 1990 and 2023. In 1990, the electricity generation capacity was 1.88 TWh. The electricity production increased above 4 TWh in 1994 and to 5 TWh in 2001. In 2010 and thereafter, electricity production did not fall below 5 TWh, and in some years, it was above 6 TWh.

6. LITERATURE REVIEW

It is common practice to discuss the relationship between electricity generation, consumption, and economic growth in terms of either electricity generation or consumption. Very few studies have examined electricity consumption, electricity generation, and economic growth using the same model. One of such studies, which examines the relationship between electricity consumption and economic growth, belongs to Kasperowicz. Kasperowicz (2014) investigated the relationship between electricity consumption and economic growth in Poland. In the study where the ordinary least squares estimator and Granger causality test were used; the dataset covers the period between 2000 and 2012. In Poland, there is bidirectional causality between electricity consumption and economic growth. In addition, the increase in electricity consumption leads to economic growth. Iyke (2015) investigated the relationship between electricity consumption and economic growth in Nigeria. Data from 1971 to 2012 were used, and the vector error correction model (VECM) was applied. There is a causal relationship between electricity consumption and economic growth in the short and long term in Nigeria. The direction of this relation is from electricity consumption to economic growth. Nigeria needs policies to increase electricity generation to meet its increasing electricity consumption. Osei-Gyebi and Dramani (2023) explored the relationship between electricity consumption and economic growth in Ghana. In addition to electricity consumption, the effects of electrical transmission losses are also included in the model. Data from 1980-2021 were used. The electrical transmission losses adversely affect electricity consumption. Electricity transmission losses decrease economic growth by reducing electricity consumption. Wani et al. (2024) used data between 2002 and 2019 to examine the relationship between economic growth and electricity consumption in Afghanistan. There is a positive relationship between economic growth and electricity consumption in the short and long term. The causal relationship varies in the short- and long term. Direction of this relation is from economic growth to electricity consumption in short term. There is bidirectional causality among variables in the long term. Wahyudi (2024) examined how the relationship between economic growth and electricity consumption in the BRICS countries has been shaped. The FMOLS method was applied using country data covering the period 1992-2021. In addition to electricity consumption, variables representing labor force and investment are also included. Electricity consumption, workforce, and investment volume are important factors that determine economic growth in BRICS countries. The effects of these factors on economic growth are positive in the long term.

While some studies addressing the relationship between electricity generation and economic growth have addressed total electricity generation, others have focused on electricity produced from renewable sources. Yoo and Kim (2006) examined the relationship between electricity generation and economic growth in Indonesia. In this study using data from 1971 to 2002, a unidirectional causal relationship between electricity generation and economic growth in Indonesia was determined. The direction of causality is from economic growth to electricity generation. Economic growth promotes increased electricity generation. Sarker and Alam (2010) investigated the relationship between electricity generation and economic growth in Bangladesh. The data set covering the years 1973-2006 was used, and a Granger Causality analysis was performed. The causal relationship between electricity generation and economic growth in Bangladesh is unidirectional and runs from electricity generation to economic growth. Bayraktutan et al. (2011) examined the relationship between renewable energy sources and economic growth. Panel data analysis was conducted using data from OECD countries between 1980 and 2007. There is a positive relationship between renewable electricity generation and economic growth in OECD countries in the long term. Additionally, there is a causal relationship between the variables, and the causality is bidirectional. Khobai (2018) examined the relationship between renewable energy generation and economic growth in South Africa. In addition to economic growth, employment, capital, and CO2 emissions variables are included in the model. According to the Johansen co-integration test, renewable electricity generation has a long-term relationship with economic growth, employment, capital, and CO2 emissions. Increasing electricity generation from renewable sources will increase economic growth. Hlongwane and Daw (2022) discussed the relationship between electricity generation and economic growth in South Africa. Electricity generation is included in the model with two different variables: electricity from coal and electricity from renewable sources. The dataset covers the period 1971-2015 and ARDL analysis was used as the method. Electricity produced from coal has a positive impact on economic growth in the short and long term. However, this effect is statistically insignificant in the short term and significant in the long term. The impact of electricity produced from renewable resources on economic growth is positive and significant in both the short and long term. Villanthenkodath and Mohammed (2023) investigated how the relationship between electricity generation, economic growth, and the environment occurs in Japan. ARDL test was applied using data from Japan between 1966 and 2014. There is a long-run relationship between the variables. In the present study, different results were obtained depending on which sources electrical energy was obtained from. Electricity produced from natural gas, oil, hydropower, and nuclear energy increases economic growth and improves environmental quality. Electricity generated from coal is not feasible in terms of economic growth and the environment. Coal-generated electricity generation should be limited in Japan. Ansari et al. (2023) examined the relationship between electricity generation and economic growth. India's data between 1991 and 2019 were used, and ARDL and NARDL methods were applied. Electricity generation is reflected in two variables: renewable and non-renewable electricity generation. There is a long-run relationship between variables. Renewable and non-renewable electricity generation positively affects economic growth in India. Huseynli and Huseynli (2024) researched the relationship between renewable electricity generation, R&D expenditure, and economic growth. The research was carried out for Norway and Brazil, which are among the leading countries in renewable energy. Data from 2003 to 2014 were used. Results differ for Norway and Brazil. There is a unidirectional relationship between renewable electricity generation and economic growth in Brazil. The direction of this relationship is from economic growth to renewable energy generation. There is no causal relationship between renewable electricity generation and economic growth in Norway.

There are few studies that examine the relationship between electricity consumption, electricity generation, and economic growth, and no such study has been found in Visegrad countries. Ali et al. (2020) examined the relationship between electricity generation, electricity consumption, economic growth, population, and environment. The review was carried out for Malaysia. There is a positive linear relationship among the variables. Increasing population and economic growth increase electricity consumption and production. Increasing electricity consumption and generation negatively affects the environment by increasing carbon emissions. Keskin and Kara (2021) examined the relationship between electricity generation, electricity consumption, and economic growth in Turkiye. Data from 1975 to 2019 were used, and the Toda-Yamamoto causality test was applied. There is unidirectional causality from electricity generation to economic growth. The causal relationship between electricity consumption and economic growth is also one-way. The direction of this relation is from electricity consumption to economic growth. Stungwa et al. (2022) researched the effects of electricity generation and consumption on economic growth. This research covers the period 1971-2014 and was carried out for South Africa. There is a positive and statistically significant relationship between electricity consumption and economic growth in the short term. The relationship between electricity consumption and economic growth in the long term is negative but statistically insignificant. There are negative and significant relationships between renewable electricity generation and economic growth in the short term and positive and significant relationships in the long term.

In some studies, total energy generation or consumption data were used rather than electricity generation or consumption. Saad and Taleb (2018) investigated the relationship between renewable energy consumption and economic growth. Data from 1990 to 2014 from 12 countries that are EU members were used. The VECM and the Granger causality test were applied. There is unidirectional causality between renewable energy consumption and economic growth in the short term. The direction of causality is from economic growth to renewable energy consumption. There is bidirectional causality between variables in the long run.

7. METHODOLOGY AND DATA

This study investigates how the relationship between electricity consumption, electricity generation, and economic growth occurs in the Visegrad countries. Co-integration analysis and causality tests were applied to explain the relationship between the variables. The variables and their explanations used in the created model are listed in the table below. The dependent variable in the model is economic growth. GDP per capita represents economic growth. The model has three independent variables. The independent variables are electricity consumption and electricity generation. For electricity consumption, the net electricity consumption values of the countries were used. There are two different variables for electricity generation: fossil fuel and renewable resources. It is necessary to increase electricity generation to meet increasing electricity consumption. The use of fossil fuels for electricity generation is common in all countries around the world. However, efforts are being made to reduce fossil fuel consumption for reasons such as not renewing fossil fuels, existing in fixed amounts in nature, and polluting the environment by increasing carbon emissions (Hoel and Kverndokk, 1996). The aim is to increase the use of renewable resources in electrical energy production and in total energy generation. For this reason, this study seeks to determine whether the effects of electricity generation from fossil fuels and renewable resources on economic growth are different. According to the results, healthier suggestions can be made for the future energy policies of countries.

Data on variables covers the years 1993-2023. The dataset starts from 1993 because electricity consumption data for the Czechia and Slovakia were available from 1993 onwards. Because the most current data are available for 2023, the analysis was conducted for the period 1993-2023.

Table 1. Variables and description

Variable	Symbols	Description	Data Source
Economic Growth	GDP	GDP per capita (constant 2015 US$)	World Bank
Electricity consumption	CONS	Net electricity consumption (billion kWh)	U.S. Energy Information Administration
Electricity generation	FOSSILGEN	Electricity generation from fossil fuels (Measured in terawatt-hours)	Our World in Data
Electricity generation	RENEWGEN	Electricity generation from renewables (Measured in terawatt-hours)	Our World in Data

Panel co-integration and panel causality tests were applied in this study. First, we examined whether there was cross-sectional dependence among the variables. Unit root tests were performed according to the cross-sectional dependence results. In the final stage, cointegration and causality tests were performed. In this study, the model established to examine the relationship between electricity consumption, electricity generation, and economic growth is as follows:

GDP = f(CONS, FOSSILGEN, RENEWGEN) **(1)**

The logarithmic form of the model used for panel data analysis is shown in equation number 2:

$$lnGDP = \alpha_{0i} + \beta_{1i}\, lnCONS + \beta_{2i}\, lnFOSSILGEN + \beta_{3i}\, lnRENEWGEN + \varepsilon_{it}, \quad \textbf{(2)}$$

Examining cross-sectional dependency in panel data analysis is essential. Because the unit root tests to be applied differ depending on the cross-sectional dependence. If there is no cross-sectional dependency, first generation unit root tests are applied, whereas if there is a cross-sectional dependency, second generation unit root tests are applied. In this study, Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD tests were used to assess cross-sectional dependence.

Here, T represents the time dimension, and N represents the cross-section dimension. For the Breusch-Pagan LM (1980) test to be used, T > N must be. The equation used for Breusch-Pagan LM (1980) test is as follows:

$$LM = T\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{p}_{ij}^{2} \quad \textbf{(3)}$$

The Breusch-Pagan LM (1980) test was developed by Pesaran (2004) and introduced a test in the literature. This test can be used when both T > N and N > T. The Pesaran (2004) test is described in equation (4):

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{p}_{ij}^{2} - 1) \quad \textbf{(4)}$$

Although the CDLM test is used in cases where N > T, deviation increase, and distortions occur as N grows. Therefore, Pesaran developed the CD test. The equation used for Pesaran CD testing is as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{P}_{ij} \quad \textbf{(5)}$$

Pesaran et al. (2008) rearranged the LM test statistic. In the modified form, the variance and mean were added to the test statistics. Therefore, the modified version of the test is known as the Bias-corrected scaled LM test. The Bias-corrected scaled LM test is described in equation 6:

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{TP}_{ij}\, \frac{(T-k)\hat{P}_{ij}^{2} - U_{Tij}}{\sqrt{U_{Tij}^{2}}} \quad \textbf{(6)}$$

The hypotheses for cross-sectional dependence are as follows:

H_0: no cross-sectional dependence is observed.

H_1: Cross-sectional dependency.

To decide on the correct method, it is necessary to test the homogeneity and cross-sectional dependency. The Pesaran and Yamagata (2008) test was used to examine homogeneity. This test is based on the Swamy (1970) test and describes whether the slope coefficients are homogeneous with the help of $\tilde{\Delta}$ and $\tilde{\Delta}$adj statistics. The null hypothesis states that the slope coefficients are homogeneous, whereas the alternative hypothesis states that they are heterogeneous. The homogeneity test equations are given below. In these equations, N represents the number of cross-sections, k represents the number of explanatory variables, and S represents the Swamy statistic.

$$\tilde{\Delta} = \sqrt{N}\,\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}$$

(7)

$$\tilde{\Delta}adj = \sqrt{N}\,\frac{N^{-1}\tilde{S} - k}{var\,(t,k)}$$

(8)

Because cross-sectional dependence was determined in this study, second generation unit root tests were used in the next stage. CADF and CIPS tests are usually used as second-generation unit root tests. The CADF test performs a unit root test separately for each country that constitutes the panel. The CIPS test, on the other hand, performs a unit root test for the entire panel. In this study, the CIPS test, a second-generation unit root test, was used. The calculation of the CIPS test is illustrated in equation 7:

$$CIPS = \frac{\sum_{i=1}^{n} CADF_i}{N} \quad \textbf{(9)}$$

The co-integration test was applied to determine whether there is a long-term relationship between the variables. In the literature, co-integration tests are divided into two groups according to their cross-sectional dependence. While the first-generation co-integration tests do not consider cross-sectional dependence, the second-generation co-integration tests do. Since cross-sectional dependency was detected in this study, the Gengenbach, Urbain, and Westerlund (GUW) (2016) panel co-integration test, one of the second-generation co-integration tests, was applied.

During the application of the GUW test, the OLS estimation of the model is first made for each unit and the hypothesis $H_0: a_{y_i} = 0$ is tested using the t-test. The null hypothesis states that there is no co-integration relationship, whereas the alternative hypothesis states that there is a co-integration relationship (Baghirov and Sarkhanov, 2023). The equations used to test the co-integration relationship are as follows:

$$\Delta yi,t = \delta'_{y,}x_i d_t + a_{yi} y_{i,t-1} + \Upsilon'_i w_{i,t-1} + B_{yy_i}(L)\Delta y_{i,t-1} + A_{yx,xi}(L)\Delta x_{i,t} + A_{yF,x_i}(L)\Delta F_t + \eta'_{y,xi} f_{it} + \varepsilon y, x_i, t \quad \textbf{(10)}$$

$$\Delta yi = d\delta y, x_i + a_{yi} y_{i,-1} + w_{i,-1}\Upsilon i + v_i \pi_i + \varepsilon y, x_i = a_{yi} y_{i,-1} + g_i^d \lambda_i + \varepsilon y, x_i \quad \textbf{(11)}$$

$$\hat{a}y_i = \frac{y'_{i,-1} M g_i^d \Delta y_i}{y'_{i,-1} M g_i^d y_{i,-1}} \quad \textbf{(12)}$$

$$\hat{\sigma}^2_{\hat{a}y_i} = \frac{\hat{\sigma}^2_{y.xi}}{y'_{i,-1} M g_i^d y_{i,-1}} \quad \textbf{(13)}$$

$$Ta_{yi}(F,0) = \frac{\hat{a}y_i}{\hat{\sigma}_{\hat{a}y_i}} \quad \textbf{(14)}$$

In this study, the cross-sectional dependence and co-integration relationship were determined. The panel augmented mean group (AMG) is one of the methods used to estimate long-term cointegration coefficients. Eberhardt and Bond (2009) developed this method. To use the Panel AMG method, the series must be I (1). The AMG method considers cross-sectional dependence and common dynamic effects and includes robust autocorrelation and heteroscedasticity estimators (Eberhardt and Teal, 2010). The equations used for the application of the AMG method are as follows:

Provided that i = 1,2, …, N, t = 1, 2, …, T, m = 1, 2, …, k and $f_{mt} \subset f_t$:

$$y_{it} = \beta'_i x_{it} + u_{it} \text{ ve } u_{it} = a_i + \lambda'_i f_t + \varepsilon_{it} \quad \textbf{(15)}$$

$$x_{mit} = \Pi_{mi} + \delta'_{m_i} g_{m_t} + p_1 m_i f 1 m_t + \ldots + p_{nmi} f_{nmt} + v_{mit} \quad \textbf{(16)}$$

$$f_t = \varrho f_{t-1} + \varepsilon_t \text{ , } g_t = k' g_{t-1} + \varepsilon_t \quad \textbf{(17)}$$

(x_{it} is the vector of independent variables, a_i is the group-specific fixed effects, λ_i is the country-specific factor loadings, and f_t is the common factor set.)

After performing cointegration tests, the causality relationship between the variables was examined. A method often used in panel causality analysis is the Dumitrescu-Hurlin test. Dumitrescu-Hurlin causality test was applied in this study. Dumitrescu-Hurlin test is an improved version of the Granger causality test. The following equation is used to determine causality between variables. In this equation, x and y represent variables, and k represents the lag length (Dumitrescu and Hurlin, 2012).

$$y_{i,t} = a_i + \sum_{k=1}^{k} y_i^k y_{i,t-k} + \sum_{k=1}^{k} B_i^k x_{i,t-k} \quad \textbf{(18)}$$

The hypotheses for the Dumitrescu-Hurlin causality test are as follows:

H_0: βi=0, ∀i=1,…,N

H_1: βi=0, ∀i=1,…,N_1

βi≠0, ∀i=N_1+1, N_1+2,…,N

8. RESULTS

In this study, the descriptive statistics of the variables were first determined. The total number of observations was 124, as seen in the Table 2. The variable with the highest mean and median is lnGDP, and the variable with the lowest is lnRENEWGEN. lnRENEWGEN is the variable with the highest standard deviation, and lnGDP is the variable with the lowest standard deviation. The standard deviation of lnFOSSILGEN is higher than that of lnGDP and lnCONS. This situation indicates that electricity generation in the Visegrad countries exhibits a fluctuating trend, whereas economic growth is more stable and there are no major changes.

Table 2. Descriptive Statistics

	lnGDP	lnCONS	lnFOSSILGEN	lnRENEWGEN
Mean	9.387265	3.961800	3.423155	1.351002
Median	9.390846	3.833830	3.348042	1.464379
Maximum	9.915282	5.110214	5.052481	3.824502
Minimum	8.518862	3.102445	1.504077	-1.560.648
Std. Dev.	0.334057	0.632498	1.124214	1.141671
Skewness	-0.432794	0.470419	0.064969	-0.791800
Kurtosis	2.407037	1.891118	1.671348	4.080225
Jarque-Bera	5.687720	10.92643	9.208034	18.98582
Probability	0.058201	0.004240	0.010012	0.000075
Sum	1164.021	491.2632	424.4712	167.5242
Sum Sq. Dev.	13.72609	49.20663	155.4543	160.3198
Observations	124	124	124	124

Figure 4 shows the time series of the variables used in the model. The fluctuations are less in the variables lnGDP and lnCONS, and the fluctuations in the variables lnFOSSILGEN and lnRENEWGEN are quite high. The variable with the highest fluctuation among the four variables is lnRENEWGEN.

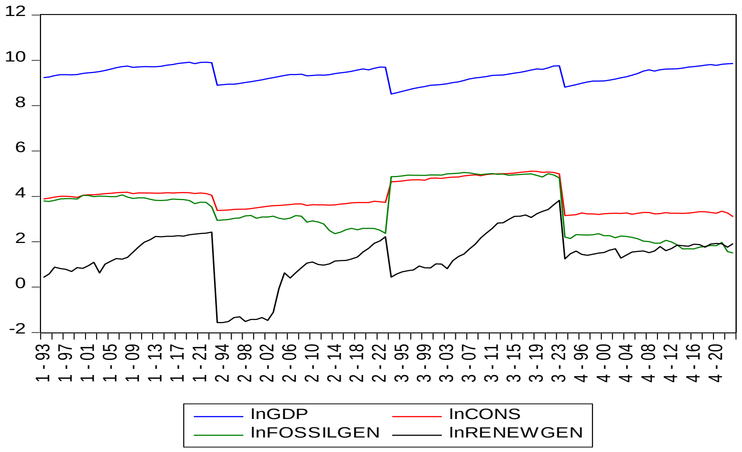

Figure 4. Time series graphs of Variables

Before the unit root tests, we tested whether there was a cross-sectional dependence between the variables. The Table 3 shows the cross-sectional dependence test results. As seen in the table, four different tests were applied: Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD. For each variable, the probability value of all four tests was less than 0.05. This indicates that there is cross-sectional dependence among the variables.

Table 3. Results of Cross-Sectional Dependence

Variable	Test	Statistic	Prob.
lnGDP	Breusch-Pagan LM	179.4102	0.0000*
	Pesaran scaled LM	50.05921	0.0000*
	Bias-corrected scaled LM	49.99254	0.0000*
	Pesaran CD	13.39402	0.0000*
lnCONS	Breusch-Pagan LM	108.7391	0.0000*
	Pesaran scaled LM	29.65823	0.0000*
	Bias-corrected scaled LM	29.59157	0.0000*
	Pesaran CD	10.22980	0.0000*
lnFOSSILGEN	Breusch-Pagan LM	68.39317	0.0000*
	Pesaran scaled LM	18.01136	0.0000*
	Bias-corrected scaled LM	17.94469	0.0000*
	Pesaran CD	7.392118	0.0000*
lnRENEWGEN	Breusch-Pagan LM	153.3851	0.0000*
	Pesaran scaled LM	42.54643	0.0000*
	Bias-corrected scaled LM	42.47976	0.0000*
	Pesaran CD	12.35380	0.0000*
Model	Breusch-Pagan LM	83.65000	0.0000*
	Pesaran scaled LM	116.0500	0.0000*
	Bias-corrected scaled LM	167.4900	0.0000*
	Pesaran CD	93.6400	0.0000*

Note: *indicates significance at a 1% level

The results of the homogeneity test are shown in Table 4. The test results show that the parameters are heterogeneous.

Table 4. Homogeneity Test Results

Test	Test statistics	p-value
$\tilde{\Delta}$	12.092	0.000*
$\tilde{\Delta}\,adj$	13.204	0.000*

Note: * indicates a 1% level of significance.

According to the results of the analysis, cross-sectional dependence and heterogeneity were detected. Therefore, one of the second-generation unit root tests must be used. The CIPS test was used as the second-generation unit root test. The unit root test results are included in the Table 5. The variables are not stationary at this level. Because the test statistics are less than critical values, the variables contain unit roots. For this reason, the first differences between the variables were taken, and the process was repeated. The variables became stationary after the first differences were taken. Thus, we conclude that all variables in the model are first-order stationary, that is, I (1). There is no obstacle to applying cointegration and causality tests to variables.

Table 5. Results of the CIPS unit root test

	CIPS at levels			CIPS at the first difference		
Variable	Test Statistic	5%	1%	Test Statistic	5%	1%
lnGDP	-1.266	-2.33	-2.55	-3.566	-2.33**	-2.57*
lnCONS	-1.172	-2.33	-2.55	-5.187	-2.33**	-2.57*
lnFOSSILGEN	-2.022	-2.33	-2.55	-5.485	-2.33**	-2.57*
lnRENEWGEN	-2.303	-2.33	-2.55	-4.046	-2.33**	-2.57*

Note: * and ** indicate the significance levels at %1 and 5%, respectively

Since the model includes cross-sectional dependence and heterogeneity, the GUW co-integration test, which is one of the second-generation co-integration tests, was applied. The GUW test results are listed in the Table 6. According to the test results, since the p-value is less than 0.01, a co-integration relationship exists between the series.

Table 6. GUW Co-integration Test Results

d.y.	Coefficient	T-bar	P-val.*
Y (t-1)	-0.511	-2.669	< = 0.01

Because a co-integration relationship was identified between the series, the long-run coefficients were interpreted in the next step. The panel AMG method was used to interpret the long-term co-integration coefficients. Estimation results have been obtained for both the overall panel and the countries that make up the panel, and these results are presented in Table 7. For the panel as a whole, electricity consumption increases economic growth, whereas electricity generation from fossil sources decreases it. Renewable energy generation increases economic growth, but this effect is statistically insignificant. Considering the countries in the panel, the Czechia's electricity consumption increases economic growth. The impact of electricity generation economic growth is negative and insignificant for both fossil and renewable resources. In Hungary, electricity consumption increases economic growth, whereas electricity generation from fossil resources decreases economic growth. The impact of electricity generation from renewable sources is insignificant. Unlike other Visegrad countries, electricity generation from renewable sources increases economic growth in Poland, and this effect is significant. The impact of electricity consumption and generation from fossil fuels on economic growth is insignificant. The effect of electricity consumption on economic growth in Slovakia is positive and significant at the 10% level. The impact of fossil fuel and renewable energy generation is insignificant.

Table 7. Panel AMG Estimation Results

Country	C	CONS	FOSSILGEN	RENEWGEN
Czechia	7.447645 (0.000) *	0.5782467 (0.000) *	-0.1263116 (0.102)	-0.0094757 (0.561)
Hungary	4.903266 (0.000) *	1.247664 (0.000) *	-0.0812174 (0.020) **	-0.005166 (0.698)
Poland	9.631989 (0.000) *	-0.0142268 (0.938)	-0.2120165 (0.154)	0.0444777 (0.046) **
Slovakia	8.043287 (0.000) *	0.3113563 (0.057) ***	-0.0920686 (0.138)	0.0086116 (0.887)
Panel	7.506547 (0.000) *	0.5307601 (0.048) **	-0.1279035 (0.000) *	0.0096119 (0.432)

Note: *, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. The values in parentheses are the probability values.

According to the cointegration tests, after it was determined that there was a cointegration relationship between the variables, a causality analysis was conducted. Dumitrescu-Hurlin panel causality test was applied to examine whether there was a causal relationship between the variables. The testing results are shown in the Table 8.

Table 8. Pairwise Dumitrescu-Hurlin Panel Causality Test

Null Hypothesis	W-Stat.	Zbar-Stat.	Prob.
lnCONS does not homogeneously cause lnGDP.	133.316	0.30594	0.7597
lnGDP does not homogeneously cause lnCONS	0.77819	-0.37368	0.7086
lnFOSSILGEN does not homogeneously cause lnGDP.	259.084	184.610	0.0649***
lnGDP does not homogeneously cause lnFOSSILGEN	373.904	325.218	0.0011*
lnRENEWGEN does not homogeneously cause lnGDP.	0.78242	-0.36850	0.7125
lnGDP does not homogeneously cause lnRENEWGEN	126.518	0.22269	0.8238

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

According to the test results, there was no causal relationship between lnGDP and lnCONS. Because the probability values were greater than 0.05. There is also no causal relationship between LnGDP and lnRENEWGEN. However, there is a bidirectional causality between lnGDP and lnFOSSILGEN. In Visegrad, electricity generation from fossil fuels is a cause of economic growth. Economic growth is also the reason for the generation of electricity from fossil fuels. These results show that economic growth in Visegrad depends on the generation of electricity from fossil fuels. Although electricity generation from renewable sources has increased over time, the main source of growth is still fossil fuels. Electricity generation from renewable energy sources is not yet at a level that will affect growth.

9. CONCLUSION

In this study, the relationship between electricity consumption, electricity generation, and economic growth was examined for the Visegrad countries. Electricity generation is represented by 2 different variables according to the type of resource used. Thus, the impacts of electricity from fossil fuels and renewable sources on economic growth are compared. The data set covers the period 1993-2023. First, we investigated whether there was a long-term cointegration relationship between the variables, and then a causality analysis was performed. According to the GUW cointegration test, variables move together eventually. In other words, a co-integration relationship exists between the variables. According to the AMG forecast results, electricity consumption increases economic growth for Czechia, Hungary, Slovakia, and the entire panel. Only in Poland does electricity consumption reduce economic growth; however, this relationship is insignificant. Electricity generation from fossil fuels decreases economic growth for the four countries that make up the panel and the panel as a whole. This relationship is significant for Hungary and the panel as a whole but insignificant for the other three countries. Electricity generation from renewable sources increases economic growth in Poland, Slovakia, and the entire panel. In the Czechia and Hungary, there is a negative relationship between renewable energy generation and economic growth. However, Poland is the only country in which the effect of electricity generation from renewable sources on economic growth is statistically significant. According to the Dumitrescu-Hurlin causality test, there is only a causal relationship between economic growth and electricity generation from fossil fuels. Causality is bidirectional. Economic growth is the reason for the production of electricity from fossil sources. At the same time, electricity generation from fossil fuels is also a cause of economic growth. Causal relationships between electricity consumption and economic growth have not been determined. There is no causal relationship between electricity generation from renewable sources and economic growth. This result is important in terms of the energy policies of the Visegrad countries.

The absence of a causal relationship between electricity generation from renewable sources and economic growth shows that renewable sources do not sufficiently affect economic growth in Visegrad. When we look at the electricity generation data, the amount of electricity produced from renewable sources is very low compared to that produced from fossil fuel sources. In Visegrad, the dependence on fossil fuels for electricity generation continues. For this reason, countries should increase their use of renewable energy sources in electricity generation. Although an increase in the use of renewable resources has been observed over time, additional efforts should be made to accelerate this increase. Thus, dependence on fossil fuels for economic growth can be avoided. Because fossil resources tend to deplete and increase environmental pollution. If renewable resources can be turned into the driving force of growth, not only sustainable economic growth will be achieved, and environmental quality will be improved. In addition to economic cooperation, Visegrad countries can develop common policies on renewable energy or revise the common policies implemented.

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