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Evaluation of Sustainable Economic Growth in Nordic Countries Based on the Ecological Growth Model

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Abstract

The structure of the consumer society that has emerged in the world since the 1950s has led to an increase in the impact of economic activities on the environment. Recently, the incidence rates of various diseases have increased, especially in Eastern Europe , owing to environmental pollution and degradation. Therefore, this study aims to explain the impact of economic activities on the environment in Nordic countries using an ecological growth model. This study analyses causality relationships based on data on economic growth, capital accumulation, employment level, energy consumption, carbon dioxide emissions, carbon dioxide emissions, renewable energy production, environmental taxes, waste amounts and climate change in Nordic countries between 1995 and 2022. The analysis reveals a unidirectional causality relationship between economic growth and capital accumulation, energy consumption, carbon dioxide emissions, environmental taxes, air pollution, renewable energy and climate change in Nordic countries.

Keywords: Sustainable economic growth, ecological growth model, panel data analysis, environment and growth

JEL Classification: Q01, Q57, C23, O44

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1. Introduction

Historically, environmental degradation has increased along with technological and industrial advances. One key sign is the environmental contamination that first appeared in Europe in the 18th century, coinciding with the start of the industrial revolution (Costanza *et al*., 1997). In the 20th century, there were discussions over how economic expansion affects pollution in the environment. The general deterioration of soil structure between 1930 and 1950 and the increasing air pollution and environmental degradation after the 1950s made it important to examine the impact of economic activities on the environment (Uddin *et al*., 2019). During this period, the increasing production capacities of the developing automobile industry and factories, as well as the increase in death rates as a result of the damage they caused to the environment, caused the relationship between ecology and economics to be examined. The energy and environmental events that occurred in the 1960s and the 1970s brought new perspectives on ecology and economics. Ecologists emphasised the significance of energy in the dynamics and structure of ecological and economic systems at that time. However, research indicates that the utilisation of natural resources to boost economic growth and productivity leads to an increase in environmental waste. Therefore, an expanding economy is believed to cause changes that degrade the environment. Prices do not reflect the costs of environmental degradation. The International Society for Ecological Economics (ISEE) was established in 1988, under the influence of various meetings of economists based on studies conducted in the 1970s. In the 1970s, the focus was on pollution control, with life support systems being developed despite the increasing growth in energy production, population growth and technological advances (Costanza *et al*., 1997).

The concepts of ecology and economics have emerged from different disciplines. However, throughout the historical process, they were in exchange with each other and acted based on common thought patterns. In the following period, it emerged as an understanding of ecological economics and occurred in the literature as an integrated discipline. Thus, ensuring that ecological and economic systems are assessed using the same conceptual framework is the primary goal of ecological economics (Costanza *et al*., 1997). Thus, an ecological economics approach asserts a positive correlation between economic expansion and environmental degradation. The ecological economics approach reveals that instead of continuous growth, achieving an ecologically stable situation between individuals living in society and the ecosphere will be more effective in terms of sustainability. Therefore, such stable growth is believed to support social development by contributing to qualitative rather than quantitative growth (Rees, 2003). Additionally, the idea of an ecological economy suggests that the capital accumulation obtained as a result of economic activities should be used to solve environmental and social problems. In this way, contrary to the idea of rapid growth and development, it aims to achieve more stable and cleaner growth, as well as development and sustainable growth (Daly and Goodland, 1994). However, in the ecological economics approach, physical and human capital, which constitute capital accumulation, are complementary. Energy is required to increase human capital and production in an economy. As a matter of fact, the continuity of economic activities can be ensured with the energy obtained from nature. Therefore, nature is considered a producer and the economy is considered a consumer. Energy input is required to sustain the production of goods and services in an economy. Ecological economists argue that the economic cycle is driven by energy flow rather than a monetary cycle (Rees, 2003). In this context, the concept of economic growth is questioned by considering social, economic and ecological developments. This new thinking combines all aspects of human life and views them as interdependent to achieve economic and social development. Therefore, it is important to consider this dependency in the new definitions of growth and development. This dependence is believed to be achieved through an ecological economic system. In this way, it is stated that there will be radical changes in thinking about ensuring an efficient resource distribution. In other words, it is recommended that resources in an economic system be distributed by considering ecological and economic factors. However, the main problem in ecological economics is the sustainability of the contact between the economic and ecological systems. The idea of solving the ecological sustainability problem primarily through preferences and technological factors, ignoring the optimum price level, overlaps with that of economic sustainability. In this context, protecting natural assets that do not cause ecological collapse and investing in these areas plays an important role in ensuring ecological and socioeconomic sustainability and economic development (Costanza *et al*., 1997). In fact, it is said that the goal of this strategy is to provide structural answers for environmental issues that stem from economic growth (Van den Bergh, 2001).

In addition, ecological economists argue that the assumptions put forward by Malthus in his population theory have not yet been realised, but many countries have fallen into the Malthusian trap and some developed countries are in danger of falling into it. For this reason, it has been observed that, in some industrialised countries, living standards are increased by shifting industries that cause ecological degradation into different regions. In addition, the issue of energy scarcity remains uncertain and fossil fuel supply has become increasingly difficult over time. For this reason, it is claimed that there are uncertainties about resources that ensure the sustainability of economic growth. Therefore, it is believed that energy and environmental problems will become more central in the future; therefore, it will be more useful to monitor energy and resource flows through ecological and economic systems. The ecosystem is considered natural capital and it is suggested that it should be well protected to secure this natural capital stock. We refer to this state of affairs as ecological sustainability. The linkages between ecological and economic systems serve as a foundation for the development of an ecological economy in this environment. In this way, traditional ecological thought also contributes to the realisation of integrated thinking between various aspects of environmental economics and economic systems. Therefore, the relationships between ecosystems and economic systems are affected by sustainability, global warming and wealth distribution. In other words, it includes issues related to efficient and effective use of scarce resources (Costanza *et al*., 1997).

The ecological economics approach aims to reconcile economic theory with policy by combining information from other disciplines. Neoclassical welfare economics was the dominant economic policy. However, neoclassical welfare theory has been claimed to experience a crisis between consumer theory and production theory. Neoclassical economists have largely abandoned the assumptions of an economic man (*Homo economicus*) and of perfect competition. In addition, the solution proposals of neoclassical welfare economics for environmental and social issues such as increasing income inequality, global climate change and a decrease in biodiversity have failed. Recent developments in consumer behaviour and firm theory have posed questions for neoclassical welfare economics. According to the ecological economics method, the focus is on achieving an efficient result in which marginal costs are equal to marginal benefits in accordance with the neoclassical welfare model. However, in an ecological economics approach, for scarce resources to be used to reduce climate change, economic output must result in a net increase. Since the greenhouse effect, which is considered environmentally in welfare economics, is thought to affect GNP results (Gowdy and Erickson, 2005). According to this argument, the degree to which natural resources are used and the emission values that represent environmental pollution determine how different the relationship is between economic growth and the environment (Uddin *et al*., 2019).

In this context, the present study aims to analyse sustainable economic growth in Nordic countries, which have advanced policies on ecological growth, environmentally friendly energy production, promotion of biofuel use and combating climate change, compared to other countries in the European continent, based on the ecological growth model. It is accepted that Nordic countries have successfully implemented ecological economic policies and harmonised environmental sustainability with economic growth. These countries are considered examples in the world of the implementation of environmentally friendly economic models. Therefore, the variables included in the study were economic parameters, such as economic growth, capital accumulation, energy consumption and employment level and environmental parameters, such as carbon dioxide emissions, renewable energy production, environmental taxes, waste amounts and climate change parameters for testing and evaluating the ecological economy. Therefore, the inclusion of environmental data on the ecological economy in the analysis makes this study more comprehensive than other studies. In the literature, analyses are generally based on economic growth, energy consumption and carbon emission values. The results of the analyses indicate that the effects of capital accumulation, employment level, energy consumption, carbon dioxide emissions, renewable energy production, environmental taxes, waste amounts and climate change data on sustainable environmental policies and growth in Nordic countries constitute the primary contributions of this study. Owing to these contributions, this study aims to fill the gap in the literature by addressing the developments related to the ecological economy in Nordic countries from a broader perspective.

2. Literature

In economic literature, the relationship between ecology and economics has recently become an important research issue. Ecological economics is a social science that aims to bring structural solutions to environmental problems and is integrated into the interaction of the environment and economy. In particular, when considered within the framework of sustainable growth and development, it is important to reveal the effects of environmental degradation. Therefore, studies that directly and indirectly examine the relationship between ecology and economics are included in this section. Among those studies, Midttun and Kamfjord (1999) evaluated the energy and environmental management processes in Nordic countries within the framework of ecological modernisation. The study argued that sustainable development would be achieved through renewable energy investments and the adoption of environmentally friendly technologies and that these environmentally friendly energy practices implemented in the Nordic countries can be an example for all countries in terms of sustainable economic growth.

Kartal (2007) examined models of ecological economics based on development theories and concluded that environmental problems cannot be solved with the assumptions of ecological economics put forward in development theories. Bayraktutan and Uçak (2011) analysed growth in the means of production and consumption within the framework of sustainable development. They concluded that sustainable development could be achieved by reducing the amount of greenhouse gases emitted into the atmosphere, reducing fossil fuel consumption and increasing the proportion of renewable energy sources in production. Uysal (2013), in his study analysing the issue of sustainable growth, argued that sustainable growth can be examined in two dimensions, environment and economy, and that increases in GNP can occur without environmental degradation with sustainable growth. Hannerz *et al.* (2014) analysed the transition to a biologically based economy using renewable energy sources instead of fossil fuels in the forest sectors of Nordic countries. The results of the study suggest that dependence on fossil fuels can be reduced by the continuous use and development of biomass fuels.

Thus, economic growth and sustainability could be achieved. Ateş and Ateş (2015), in their study in which they analysed the necessity of green growth in Turkey based on multi-perspective analysis, argued that ecological transformation is a necessity rather than a preference and suggested that sustainable growth, international competitiveness and increasing employment opportunities would be seen with ecological transformation. In his study analysing the theory of ecological modernisation, Kurucu (2016) argued that environmental problems can be solved while economic growth and production increase continue. They concluded that sustainable growth can be achieved by preventing environmental degradation and global warming by substituting renewable energy sources with fossil fuels while production continues. Irandoust (2016) analysed the relationship between renewable energy, economic growth, carbon emissions and technological innovations in Nordic countries. The study concluded that the use of renewable energy affects economic growth and reduces fossil fuel consumption. It has been suggested that technological innovations contribute to economic growth by increasing the efficiency of renewable energy resources. Ulucak (2018), in a study comparing the ecological economics approach and basic economic approaches, concluded that the predictions of the ecological economics approach are more realistic and feasible than the idea that classical approaches act on certain assumptions, and that technological development will prevent environmental degradation.

Midttun and Olsson (2018) examined how environmental and socioeconomic sustainability goals are realised in Nordic countries based on an ecological modernisation model. They concluded that it is difficult to realise environmental and socioeconomic sustainability together in Nordic countries; therefore, more comprehensive studies should be conducted on this issue. Taşdemir (2021) analysed the relationship between economy and environment based on the ecological economics approach and neoclassical environmental economics approaches and concluded that there are differences between the ecological economics approach and neoclassical environmental economics on the relationship between economy and the environment, but the ecological approach is more inclusive and explanatory.

Aydın (2021) analysed the relationship between energy and economic growth by examining the economic development literature. According to Aydın, energy is considered a complementary factor of production in the economy, based on an environmental economics approach. In their study analysing the validity and applicability of the green growth concept in Nordic countries, Tilsted *et al*. (2021) concluded that economic growth reduces carbon emissions only in terms of production, but when the consumption amounts of imported goods are considered, the alleged reductions in carbon emissions do not reflect reality. Therefore, the environmental progress in Nordic countries may be exaggerated. Hansen *et al*. (2021) evaluated the effects of biofuel production activities and fossil fuel consumption reduction policies on environmental degradation in the Nordic countries. The study suggested that economic sustainability can be achieved if the environmental degradation resulting from biofuel production activities is considered. However, biofuel production policies differ among the Nordic countries. Yağlıkara (2022) analysed the relationship between urbanisation and carbon dioxide emissions within the framework of ecological modernisation theory and concluded that in countries where ecological modernisation theory is supported, environmental degradation decreases after reaching a certain level of prosperity due to an efficient energy structure and environmentally friendly technologies.

Yıldız and Yıldız (2022) analysed the relationship between environmental sustainability and economic growth in Turkey and found a positive relationship between economic growth and ecological footprint. Şahin (2022) analysed environmental policy based on the theory of ecological modernisation and concluded that renewable energy resources should be used in order to reduce environmental degradation and increase productivity and that production patterns that increase environmental pollution should be abandoned and ecological growth models should be preferred. Luczak and Kalinowski (2022) analysed poverty levels in European Union countries in a multidimensional way and concluded that environmental factors affect poverty. Grzebyk and Stec (2023) analysed renewable energy policies in European Union countries in terms of economic, environmental and social dimensions. They argued that there are significant differences between EU countries in terms of renewable energy utilisation. Ağaoğlu (2023) analysed growth approaches to sustainable development based on the concepts of green growth and economic non-growth and concluded that green growth is necessary to ensure sustainable development. Berber *et al*. (2023) analysed how sustainable economic growth is achieved in environmental and economic terms and concluded that energy and carbon dioxide emissions are important for sustainable growth. Kapçak (2023) analysed the effect of energy consumption on economic growth in developing countries under the ecological economics approach and concluded that the energy factor is the primary input for ensuring sustainable growth.

3. Dataset and Model

The present study analyses and evaluates sustainable economic growth in Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) based on an ecological growth model, which uses economic growth, capital accumulation, employment level, energy consumption, carbon dioxide emissions, renewable energy production, environmental taxes, waste amounts and climate change data for Nordic countries between 1995 and 2022. The data used in the analysis were obtained from the Nordic Statistics database and Energy Institute Statistical Review of World Energy and Total Economy Database. The relationship between the variables was analysed with the Dumitrescu–Hurlin panel causality test using Stata 16 and Eviews 13. The linear model established to analyse the variables in this study is as follows:

$$\text{GDPit} = \beta_0 + \beta_1 Capital_{it} + \beta_2 Labor_{it} + \beta_3 Energy_{it} + \beta_4 Carbon_{it} + \beta_5 Env\_tax_{it}$$
$$\beta_6 Waste_{it} + \beta_7 Renew\_energy_{it} + \beta_8 Climate_{it}\varepsilon_{it} \quad (1)$$

In the linear model, *GDP* represents the GDP growth rate, *Capital* stands for capital accumulation growth rate, *Labour* stands for employment rate, *Energy* stands for proportional change in energy consumption, *Carbon* stands for carbon dioxide emission values, *Env_tax* stands for environmental pollution taxes, *Waste* stands for total waste percentage, *Renew_energy* stands for renewable energy production amount and *Climate* stands for climate change data.

4. Methodological Approach

Although there are many methods for analysing panel data in the literature, some *a priori* tests should be performed to determine which method should be used in the data analysis. The *a priori* tests consist of a homogeneity test, a horizontal cross-sectional dependence test and unit root tests. The most appropriate panel data analysis method can be selected based on the results of the *a priori* tests. Therefore, in this study, the Dumitrescu–Hurlin panel causality test is used in the data analysis because of the heterogeneity of the series resulting from the *a priori* tests. The Dumitrescu–Hurlin panel causality test differs from other tests in terms of analysing dynamic relationships in panel data, considering different causality relationships between units, ensuring a balance between time and cross-sectional dimensions and providing more consistent results than traditional causality tests.

4.1 Swamy-S homogeneity test

Homogeneity tests for series test the homogeneity or heterogeneity of the constant and slope coefficients of the units used in the analysis. In this context, the causality and co-integration analyses to test the relationship between variables may also vary depending on the homogeneity or heterogeneity condition obtained from the homogeneity test applied to the series. The Swamy-S test is one of the widely used methods in measuring homogeneity between batches (Tatoğlu, 2020). In this context, the homogeneity test proposed by Swamy (1971):

$$\hat{S} = \mathrm{X}^2_{k(N-1)} = \sum_{i-1}^{N} \left(\hat{\beta}_i - \overline{\beta}^*\right)' \hat{V}_i^{-1} \left(\hat{\beta}_i - \overline{\beta}^*\right) \tag{2}$$

is defined as: $\hat{\beta}_i$ refers to the OLS estimators obtained from the regressions according to the units, $\overline{\beta}^*$ is the weighted WE estimator and $\hat{V}_i^{-1}$ refers to the difference between the variances obtained from the two estimators (Tatoğlu, 2020). Accordingly, in the basic hypothesis established for the Swamy-S test calculated, the homogeneity of the series slope coefficients is examined, and the following standard hypothesis tests are performed (Yaman and Sungur, 2020):

H_0: $\beta_i = \beta$ – Slope coefficients between series are homogeneous. (3)

H_0: $\beta_i \neq \beta$ – Slope coefficients between series are heterogeneous.

4.2 Cross-sectional dependence

One of the important *a priori* tests used in panel data analysis is the cross-sectional dependence test. Assuming that shocks occurring in any of the variables included in the study would also influence the other variables, the cross-sectional dependence test is conducted. The reason is that if cross-sectional dependence is neglected or ignored, inconsistencies and distortions may occur in the analysis results (Alataş and Peker, 2016). The literature contains several cross-sectional dependence tests, such as the Breusch–Pagan LM test, the Pesaran CD test, CD_{LM} and LM_{adj}. Choosing which of these tests to perform depends on the cross-sectional and temporal dimensions of the panel data used in the analysis (Göçer *et al*., 2012).

In this particular context, the Breusch–Pagan Lagrange multiplier (LM) test, created in 1980, is the first cross-sectional dependence test. When the time dimension T is greater than the section dimension N ($T > N$), the Breusch–Pagan LM test can be used. The Breusch–Pagan LM test was applicable in this instance. It is calculated as follows:

$$\text{LM} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\tilde{\rho}_{ij}^{\,2} \tag{4}$$

The ρ coefficient expresses the sample estimate of the binary relationships between the errors (Koçbulut and Altıntaş, 2016).

Another test for cross-sectional dependence analysis is the CD_{LM} test, which was developed by Pesaran in 2004 and is thought to be a better version of the Breusch–Pagan LM test. When the cross-sectional size (N) and temporal dimension (T) are large, the CD_{LM} test can be applied (Turna and Polat, 2024). It is expressed as follows:

$$\text{CD}_{\text{LM}} \sqrt{\frac{1}{N\left(N-1\right)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(\tilde{p}_{ij}^{2}-1) \tag{5}$$

According to the defined CD_{LM} test, it is claimed that if the time and section dimensions approach infinity, there is no cross-sectional dependence. However, because the CD_{LM} test produces deviant and inconsistent results in cases where $N > T$ and the results obtained become inconsistent due to the increase in the number of sections, the CD test, which provides more consistent results in cases where $N > T$, was developed by Pesaran in 2004. It is defined as follows:

$$\text{CD} = \sqrt{\frac{2T}{N\left(N-1\right)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(\tilde{p}_{ij)} \tag{6}$$

The CD test in the equation is obtained by summing the correlation coefficients between the error terms. At the same time, the CD test proposed by Pesaran complies with the standard normal distribution (Koçbulut and Altıntaş, 2016). In addition to these three cross-sectional dependence tests, Pesaran proposed LM_{adj} in 2008 to analyse deviations from error terms by correcting them. It is expressed as follows:

$$LM_{adj}\sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\tilde{}_{ij}\right)\frac{(T-k)\tilde{n}_{ij}^{2}-\mu_{Tij}}{\sqrt{u_{Tij}^{2}}} \tag{7}$$

The equation findings for the cross-sectional dependence test demonstrate an asymptotic normal distribution characteristic. The hypothesis tests established for the cross-sectional dependence tests explained in this framework are as follows (Koçbulut and Altıntaş, 2016):

H_0: Cross-sectional dependence does not exist.

H_1: A cross-sectional dependence is observed.

4.3 Pesaran CIPS and CADF panel unit root test

When selecting which unit root tests to run on the variables, the cross-sectional dependence between the units utilised in the panel data analysis is a crucial factor to consider. First-generation unit root tests can be used for stationarity analysis if there is no cross-sectional dependence between the variables. Unit root tests of the second generation are employed when there is cross-sectional dependence among the variables. Therefore, Pesaran CIPS and CADF tests are also among the second-generation panel unit root tests. The CADF test was developed by Pesaran in 2007 to analyse the cross-sectional dependence of each section. The CADF test is also important in terms of measuring the cross-sectional dependence between units in the application of the Pesaran CIPS test. The CIPS test is obtained from the arithmetic mean of the unit root values obtained from the CADF test. Therefore, while the CADF test is used to analyse stationarity between units, CIPS is used to test stationarity of the panel (Gençoğlu *et al.*, 2020). In this context, the CIPS test, which has an asymptotic normal distribution, is calculated as follows (Acaravcı *et al.*, 2015):

$$\text{CIPS} = N^{-1}\sum_{i=1}^{N} CADF_i \tag{8}$$

4.4 Dumitrescu–Hurlin panel causality test

Proposed by Elena Ivana Dumitrescu and Christophe Hurlin in 2012, the Dumitrescu–Hurlin panel causality test is regarded as an enhanced variant of the Granger causality test for heterogeneous panels. This test is employed in the examination of the causal link between variables in the literature. Dumitrescu and Hurlin sought to improve their existing approach by removing some inadequacies related to causality checks. This makes the newly devised causality test significant.

The Dumitrescu–Hurlin causality test is considered more advantageous than other causality tests because it takes into account the correlation between units in the series, can be applied to unbalanced panels, can test the causality relationship between variables with different lag lengths and gives more consistent results. In addition, Dumitrescu–Hurlin causality analysis differs from other panel causality tests because it tests heterogeneous causality relationships. In this causality test, the linear model is created from two stationary series such as X and Y. It is defined as follows:

$$y_{it} = \alpha_i + \sum_{k=1}^{K} \theta_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{it} \tag{9}$$

where: H_0: $\beta_i = 0$ (not all unites have a causal relationship between X and Y); and H_1: $\beta_i \neq 0$.

Consequently, it is determined that there is a causal link between the variables if the fundamental premise is disproved. In testing the basic hypothesis used in the analysis, Wald test statistics averages, which take into account the causality of each unit, are used. The Wald test statistic used in the analysis is as follows (Tatoğlu, 2020):

$$\bar{W}_{N,T} = \frac{1}{N} \sum_{i=1}^{N} W_{it} \tag{10}$$

5. Empirical Application Results

Based on the explanations above, homogeneity and horizontal cross-sectional dependence tests were first performed for the variables used in the analysis. According to the results obtained from the homogeneity and horizontal cross-sectional dependence, second-generation panel unit root tests were applied to the series and a stationarity analysis of the series was performed. According to the results obtained from the stationarity analysis and the homogeneity tests, the Dumitrescu–Hurlin panel causality test was used to test the relationship p between the variables. The results of the homogeneity test are given in Table 1 below.

Table 1: Swamy-S test results

Test	Test value (chi-square)	Probability value
Model	324.12	0***
Parameter constancy	6,984.22	0***

Note: ***, **, * indicate 1%, 5% and 10% significance levels, respectively.
Source: Author's own calculations

According to the slope homogeneity test results, the hypothesis H_0 was rejected; that is, it was concluded that the parameters were not homogeneous and varied from unit to unit. Accordingly, not all the slope coefficients have the same horizontal section unit. Therefore, the established model has a heterogeneous structure. After the homogeneity tests, to choose which unit root tests to run on the data in the panel data analysis, it is imperative to evaluate the cross-sectional dependence between the variables. The table below displays the findings of the cross-sectional dependence tests carried out using this approach.

Table 2: Cross-sectional dependence test results

Test	Statistics	Probability value
Breusch–Pagan LM	70.44652	0.0000***
Pesaran scaled LM	13.5162	0.0000***
Pesaran CD	0.499176	0.6177

Note: ***, **, * indicate 1%, 5% and 10% significance levels, respectively.
Source: Author's own calculations

There is a cross-sectional dependence between the variables, as shown by the Breusch–Pagan LM, Pesaran scaled LM and Pesaran CD cross-sectional dependence test findings in Table 2. For this reason, the stationarity tests for the variables should be second-generation unit root tests. Consequently, the stationarity levels of the variables included in the analysis were tested using the second-generation unit root tests, the cross-sectionally augmented Dickey–Fuller (CADF) and cross-sectionally augmented Im–Pesaran–Shin (CIPS) unit root tests. Table 3 below displays the results of the CADF and CIPS unit root tests.

Table 3: CIPS and CADF unit root test results

Tests	CIPS	CADF	
Variables	***T*-statistics**	***T*-statistics**	**Stationary**
GDP_{it}	−1.6602*	−2.9062**	I(1)
$CAPITAL_{it}$	−2.6397***	−2.5310*	I(0)
$LABOR_{it}$	−2.5515***	−3.7171***	I(0)
$ENERGY_{it}$	−2.0238**	−4.2313**	I(0)
CO_{2it}	−2.0164***	−2.6996*	I(0)
ENV_TAX_{it}	−2.0721***	−3.1839**	I(0)
$WASTE_{it}$	−5.1737***	−6.8049	I(1)
$RENEW\_ENERGY_{it}$	−4.5290***	−7.6835***	I(1)
$CLIMATE_{it}$	−2.8040***	−2.3679***	I(0)

Note: ***, **, * indicate 1%, 5% and 10% significance levels, respectively.
Source: Author's own calculations

According to the results of the CIPS and CADF unit root tests, the series is stationary at level and difference. Based on the results of the unit root test and the Swamy-S homogeneity test, the Dumitrescu–Hurlin panel causality test, which can be applied to heterogeneous series and gives more stable results, was preferred to test the relationship between variables. Accordingly, the Dumitrescu–Hurlin panel causality results showing the causality relationship between variables are given in Table 4 below.

Table 4: Dumitrescu–Hurlin panel causality test results

$Z^{Hnc}_{N,T}$ test statistics

H_0 hypothesis	*W*-bar statistics	*Z*-bar statistics	Probability
$GDP_{it} \rightarrow LABOR_{it}$	0.9511	−0.0773	0.9384
$GDP_{it} \rightarrow CAPITAL_{it}$	4.8339	6.0619	0.0000***
$GDP_{it} \rightarrow ENERGY_{it}$	7.0556	9.5747	0.0000***
$GDP_{it} \rightarrow CO2_{it}$	6.7657	9.1164	0.0000***
$GDP_{it} \rightarrow ENV\_TAX_{it}$	6.3940	8.5286	0.0000***
$GDP_{it} \rightarrow WASTE_{it}$	2.7753	2.8070	0.0050***
$GDP_{it} \rightarrow RENEW\_ENERGY_{it}$	5.7125	7.4510	0.0000***
$GDP_{it} \rightarrow CLIMATE_{it}$	9.6656	13.7014	0.0000***
$LABOR_{it} \rightarrow GDP_{it}$	2.0608	1.6773	0.0935*
$CAPITAL_{it} \rightarrow GDP_{it}$	2.0732	1.6969	0.0897*
$ENERGY_{it} \rightarrow GDP_{it}$	1.2515	0.3976	0.6909
$CO2_{it} \rightarrow GDPit$	1.4998	0.7903	0.4293
$ENV\_TAX_{it} \rightarrow GDP_{it}$	0.8044	−0.3093	0.7571
$WASTE_{it} \rightarrow GDP_{it}$	0.7629	−0.3748	0.7078
$RENEW\_ENERGY_{it} \rightarrow GDP_{it}$	0.6575	−0.5416	0.5881
$CLIMATE_{it} \rightarrow GDP_{it}$	0.3848	−0.9727	0.3399

Note: ***, **, * indicate 1%, 5% and 10% significance levels, respectively.
Source: Author's own calculations

According to the Dumitrescu–Hurlin panel causality test results, there is a unidirectional causality relationship between economic growth and capital accumulation, energy consumption, carbon dioxide emissions, environmental taxes, air pollution, renewable energy and climate change in Nordic countries. It is also observed that there is a causal relationship between capital accumulation, employment level and economic growth. Thus, the causality relationship between economic growth and capital accumulation is bidirectional, whereas the causality relationship with other variables is unidirectional.

6. Results and Discussion

In this study, sustainable economic growth performance in Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) between 1995 and 2022, based on the ecological growth model, was analysed based on the causality relations between variables. According to the results obtained from the Dumitrescu–Hurlin panel causality test, capital accumulation and employment levels directly cause economic growth in the Nordic countries. Other variables cannot be considered direct causes of economic growth. However, when the direction of causality changes, economic growth affects economic variables, such as capital accumulation, energy consumption, carbon dioxide emissions, environmental taxes, waste amounts, renewable energy production and climate change. These results support the views of Tilsted *et al*. (2021) that economic growth increases carbon emissions when consumption amounts are considered and Midttun and Olsson's (2018) view that it is difficult to realise environmental and socio-economic sustainability together in Nordic countries. Although economic growth affects carbon emissions and capital accumulation, it also affects the amount of waste, climate change and environmental taxes. However, Midttun and Kamfjord (1999) and Irandoust (2016) have stated that the use of renewable energy affects economic growth and Hannerz *et al*. (2014) concluded that economic growth would be achieved through the continuous use and development of biomass fuels. This is because no causal relationship was found between renewable energy production and economic growth in the analysis.

When the results obtained in this study are evaluated as a whole, the increasing effect of capital accumulation on economic growth can be considered a positive effect in terms of employment. However, an increase in carbon emissions, waste amounts and climate change as a result of economic growth appears to be a negative indicator. This situation confirms the basic problem put forward in ecological economics, that environmental pollution increases with economic growth. At the same time, the increase in energy consumption with the realisation of economic growth reveals the effect of energy consumption in industry, but the increase in carbon dioxide emissions, waste, environmental taxes and climate change shows that the type of energy used can be regarded as fossil fuels. At the same time, the fact that renewable energy production does not affect economic growth can be interpreted as indicating that renewable energy is not yet effective in production. Therefore, it can be considered that supporting the use of renewable energy in production more to realise sustainable growth in Nordic countries can reduce carbon dioxide emissions, environmental wastes, environmental taxes and climate change. At the same time, carbon dioxide emissions, waste amounts, environmental taxes and climate change resulting from economic growth can be regarded as indicators that environmental pollution has increased as a result of production activities in Nordic countries; therefore, more environmental protection measures should be taken in production industries. This situation coincides with the idea proposed by Tilsted *et al*. (2021) that the reduction in carbon emissions does not reflect reality.

As a result of these evaluations, this situation emerging in the Nordic countries can be considered a deviation from the sustainable growth phenomenon put forward by the ecological economics approach. For this reason, it may be important to continuously monitor the extent of environmental degradation resulting from economic activities in Nordic countries and to increase the necessary measures to ensure sustainable economic growth and prevent environmental degradation. Increasing investments in solar, wind and hydroelectric energy production from renewable energy sources can increase the share of renewable energy in production. As for waste management, ensuring the recycling of all environmental waste would eliminate the negative impact of waste. It may be useful to support zero-waste projects. Simultaneously, carbon capture and storage technologies can be used to achieve carbon emission reduction targets. In addition, carbon emissions can be reduced by expanding the use of electric and hybrid vehicles in the transport sector.

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