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Energy Diversification: A Friend or Foe to Economic Growth in Nordic Countries? A Novel Energy Diversification Approach

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Abstract: Energy is essential to achieving economic growth, yet the production of energy results in the emission of carbon dioxide, the primary factor in the deterioration of the environment and the acceleration of climate change. In this sense, the diversity of energy sources can contribute to achieving both environmentally sustainable development. This study investigates the relationship between energy diversification and economic growth in Nordic nations by employing a unique measure of energy diversity. The Nonlinear Panel Autoregressive Distributed Lag (NPARDL) approach is utilized in the research, and it looks at data from 1998 through 2018. According to our results, these nations experience favorable economic growth when there is an increase in the long-term diversity of their energy sources. However, in the near term, they have seen negative economic development due to the diversification of their energy sources. According to these findings, energy diversification benefits Nordic economic growth; however, further research is required for developing economies. As a result, further preventative actions must be implemented while simultaneously diversifying energy sources.

Keywords: energy diversification; renewable energy; sustainable development; economic growth; SDGs; climate change; environment

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1. Introduction

Energy has been recognized as a crucial factor in the manufacturing process since the early 1850s. Additionally, it has been a crucial component in understanding the economy's expansion, particularly since the 1950s [1–3]. Nevertheless, each nation relies on a unique mix of resources for its energy consumption in varying proportions. The problem is being referred to as the "energy mix". The introduction of new types of energy sources into the energy mix is meant by the term "energy diversification". Specifically, it may be described as increasing the proportion of energy sources to reduce reliance on a single energy source [4]. When referring to energy, "energy concentration" refers to the degree to which a nation is dependent on a single energy source. Different policy ramifications are associated with the energy mix regarding economic performance, climate change, and the energy indicators, such as energy security, energy transition, energy intensity, energy efficiency, and carbon intensity [5,6].

There is a significant inequality in the distribution of the world's energy resources. Some nations have a competitive edge in terms of productivity and opportunity cost when it comes to the production of certain types of energy [7]. According to Ricardo's theory of comparative advantage, nations that have distinct sources of production will be able to specialize in a variety of different economic activities due to the disparities in their relative levels of productivity [8]. According to Ricardo's concept of comparative advantage, the nations that have a comparative advantage in the production of energy goods need; as a result, to focus their efforts on developing expertise in this sector. It is anticipated that these nations would have better economic development rates due to their participation in international commerce (namely, the exportation of items based on energy). Since the 1970s, the export of energy-based goods has contributed to the robust economic performance of several nations, including Saudi Arabia, Qatar, Kuwait, Brunei Darussalam, and Bahrain, amongst others [9]. The robust economic performance of these nations, which is dependent on the export of energy-related goods, has led to their classification as "high-income economies" according to the criteria established by the World Bank.

However, everything does not go well for all the economies dependent on energy exports. Some nations, such as Algeria, Angola, Azerbaijan, Libya, Nigeria, and Venezuela, who export a significant number of energy-based items to total merchandise, did not have robust economic development during this time period. To put it another way, the way their economies have performed has been erratic [10]. In addition, several nations have had to deal with an unstable demand for energy, geopolitical worries, and uncertainty relating to the supply of oil, natural gas, and electricity [11]. As a result, it has come to our attention that is specializing in a particular energy-based product, despite the existence of a competitive advantage, does not ensure that energy production would contribute positively to the expansion of the economy.

At this point, a number of different economies, both established and developing, have made attempts to diversify their economic structures as well as their energy sources. Diversification is essential for the development of a sustainable economy and increases in economic activity, as well as for buffering the adverse impacts of external shocks on the performance of the economy [12–14]. Diversification helps the economy expand more effectively while reducing the risk of fluctuations in production [15]. For example, even Saudi Arabia has declared a plan to diversify its economy (called Strategic Vision 2030) as a response to the increasing cost of oil and the impact that this has on the country's budgetary and financial uncertainties [16]. This program's economic component aims to raise exports of goods other than oil to 50%of overall exports through improving manufacturing equipment and armaments [9].

The diversity of energy sources may be beneficial in several different ways. To begin, it boosts productivity by elevating the overall degree of technological sophistication. Energy is still a very important factor in the functioning of the economy [17]. Since the 1990s, however, the most important element that has been driving economic development is innovation in technology fields [18]. Since the 1990s, a number of countries with low incomes and those still in the process of development have made efforts to diversify their energy sources away from fossil fuels and toward renewables, thanks to technical advancements in the generation of energy [19]. Recent research [20–22] indicates that the adoption of environmentally friendly technology has contributed significantly to the improvement of energy efficiency and the decrease of carbon emissions. According to this research, green technology has played a significant part in bringing about an increase in energy efficiency as well as a reduction in carbon emissions. This matter is consistent with the trends that have emerged throughout history. A great number of nations have reaped the benefits of transitioning from one kind of energy to another, such as from firewood to coal and from coal to fossil fuels [23–26]. Consequently, the accumulation of past events lends credence to the hypothesis that the transition away from fossil fuels and toward renewable energy sources may boost economic performance as a result of advances in technology.

Many nations have been short on ample fossil fuel energy supplies for quite some time. The oil and natural gas reserves and output of the vast majority of emerging and industrialized nations are meager. In order to use these energy-based items in the manufacturing process, these nations are forced to import them from other parts of the globe. However, the cost of energy has been quite unpredictable, particularly since the beginning of the 2000s [27]. As a result, the prices of energy imports are susceptible to vary from year to year. Because of this problem, nations that import energy are more susceptible to the shocks of uncertainty caused by changes in energy prices, energy supply, and geopolitical difficulties. In particular, the idea that energy mix concentration should be prioritized above energy diversification is seen as an early warning indication of vulnerability [5].

On the other hand, the sensitivity of pricing in the energy market is a crucial factor for energy exporters. Because of this, these nations are more susceptible to the shocks of uncertainty caused by energy markets [28]. For instance, the majority of nations that are energy exporters benefited from the rise in commodity prices between 2002 and 2007 as a direct result of the growing demand for energy on a worldwide scale (especially from China and India). In July of 2008, the price of a barrel of crude oil reached an all-time high of 147 USD. However, as a result of the global financial crisis that occurred in 2008–9, the price plummeted to 34 USD in December of that same year [27].

In a similar vein, on 21 April 2020, the price of Brent Crude dropped below 20 USD as a result of the uncertainties surrounding the COVID-19 epidemic. Other forms of carbon-based energy, for instance natural gas and coal, also experience major price shifts on a regular basis. In general, the consumption of energy-based products can result in terms-of-trade shocks and uncertainty shocks, both of which are detrimental to the economic performance of all categories of countries, such as developing countries, advanced countries, and energy-importing and energy-exporting countries.

Energy diversification may help mitigate the adverse effects of the "resource curse", which include the decline in the overall quality of institutions brought on by authoritarian governments [29–31]. Diversifying energy sources may lessen the likelihood of internal upheaval as well as international dangers, such as threats to energy security [6,32]. Diversifying our energy sources may also assist reduce the impact of the lingering unpredictability around oil and gas supply brought on by the cessation of armed wars. However, during the periods of structural change in energy sources, countries (especially developing countries) may experience weaker economic performances as a result of structural and functional changes in their economic system [5]. This is due to the fact that countries' economies undergo both structural and functional changes.

Energy diversification may reduce the influence of energy costs on food prices, as well as domestic tensions and violence caused by price spikes and volatility. This can be accomplished by reducing the number of sources of energy [33]. In conclusion, the primary reason for climate change is the warming of the planet caused by emissions of greenhouse gases. As a result, a great number of nations are now through the process of the energy transition, often known as the "low carbon energy system". Several pieces of research have identified energy diversification as a critical factor in achieving decarbonization and reductions in greenhouse gas emissions, which are necessary for achieving sustainable economic development and reducing the rate of climate change [34,35]. It is anticipated that lowering emissions of greenhouse gases caused by fossil fuels would require diversifying the energy sector by increasing investment in renewable sources of energy. As a result, it will assist in achieving sustainable economic development and will help halt the progression of the adverse effects of climate change.

The Nordic nations have made significant and fruitful efforts in the field of using renewable energy sources (RES). For example, despite the fact that this region accounted for less than 1% of the world's population [36] and only 3.35% of the world's GDP share (PPP) in 2020 [36], the Nordic countries are among the most successful countries in the spread of renewable energy resources. Because of this, a few researchers have discussed the drivers of energy diversification in this region as a package that includes all five countries. Therefore, the study of this area in terms of diversification policies and the development of renewable energy and, as a result, energy security is one of the best-case studies for other nations and regions to follow and should be one of their top priorities. Countries such as Finland and Sweden, for instance, are at the forefront of the global movement toward increased use of bioenergy. Examples of successful applications of renewable energy resources include Iceland with geothermal, Denmark with solid growth in the usage of wind power, and Norway with the development of hydropower. The study of energy security in this region, as one of the primary drivers of sustainable development, is beneficial and noticeable. On the other hand, given that the countries that make up the Nordic region have unique and recognizable approaches to the political, economic, and social welfare of their populations (the Nordic model), this research is instrumental.

The production of electricity in the Nordic countries comes from a variety of sources, the most important of which are hydroelectric, nuclear, and wind power. The Nordic area is home to a significant number of energy-intensive enterprises as well as a high proportion of electrically heated homes. As a result, the consumption of electricity, as well as the proportion of overall power usage that is contributed by electricity, is greater than in the rest of the EU. When compared to the rest of the EU, the Nordic nations have a greater proportion of their energy output coming from renewable sources. Hydroelectricity accounts for more than half of the nation's total electricity generation.

Both Norway and Iceland are among the top 10 renewable power producers in the world, with 96.6% and 100% of their electricity output coming from renewable energy resources, respectively. Norway and Iceland are both among the top 10 countries producing the most wind energy. The top 33 wealthiest nations have a percentage of renewable energy resources in power production that is 23.58%, whereas the share for Nordic countries is 62.82% (2.66 times more than the top 33 wealthiest countries). Figure 1 provides details 147 USD about an average energy consumption in Nordic countries.

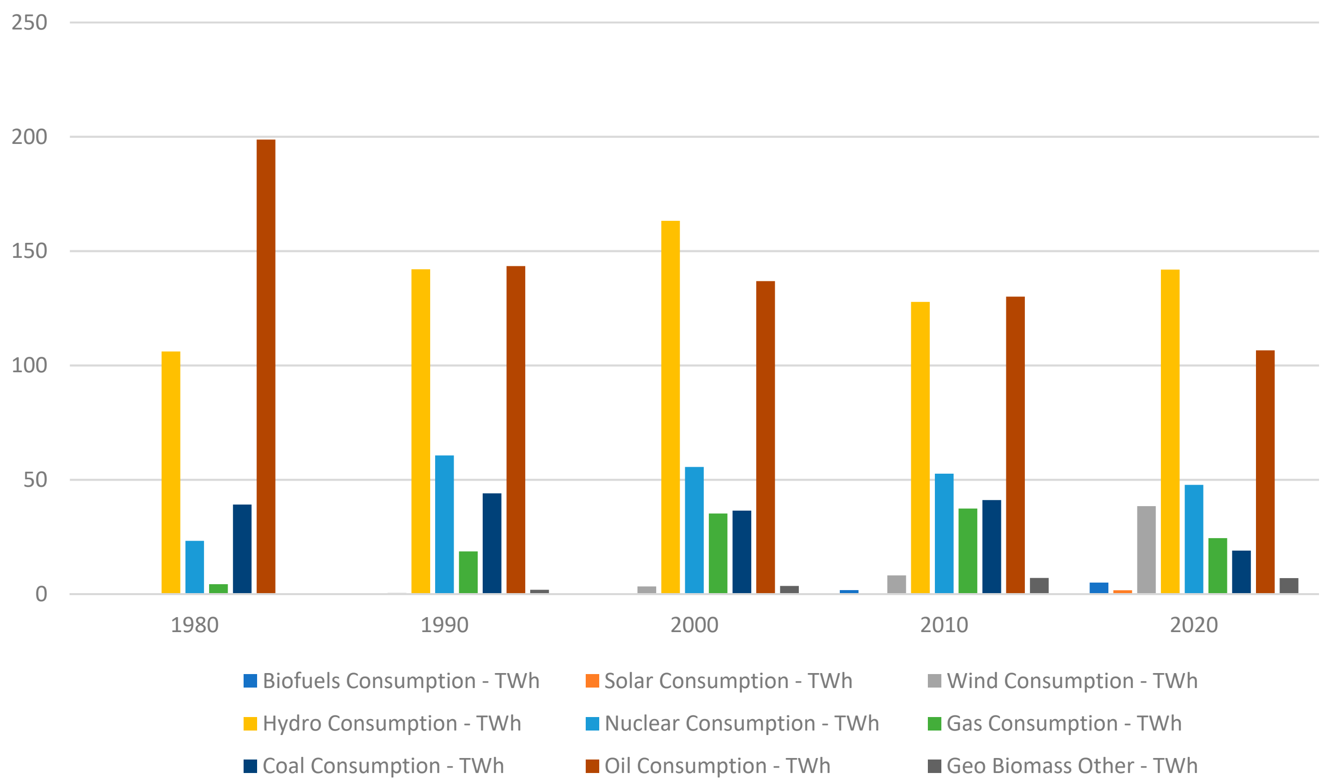

Figure 1. Average energy consumption by source in the region.

This article proposes a new metric to assess the degree to which different types of energy sources are used. This research covers the panel data for 21 years, beginning in

1998 and continuing through 2018, and includes participation from four Nordic countries: Denmark, Finland, Sweden, and Norway. The purpose of the research is to establish a link between the diversity of energy sources and increased economic activity.

The following is a list of the contributions that the paper makes. In this research, we will use an innovative approach to the measurement of energy diversification. A variety of energy sources and their corresponding sub-levels have been studied in the past, with an eye toward determining the total level of energy consumption [37]. As a result, it provides a significant contribution to the empirical literature.

This study follows Gozgor and Paramati [38] lead and introduces a new measure of energy diversity along with an analysis of its effect on economic growth. Only a comparative examination of the evolution of energy diversification across nations and over time has been presented in the previous articles. In addition, in order to derive both the short-term and the long-term impacts of energy diversification on economic growth, we make use of a variety of estimating methodologies, one of which is the NPARDL. It is essential to the process of policy creation that both the short-term and long-term effects of energy diversification on economic growth be understood. It is helpful to understand how the development of the economy reacts to structural changes in the energy mix, such as the transition from energy sources based on fossil fuels to energy sources based on renewable resources.

The remaining parts of this work are structured as described below. The prior studies in the literature are discussed in Section 2 of the article. The methodology used in this article, including the data and its sources, the index of energy consumption diversification, and the econometric approaches, are all discussed in Section 3. The empirical findings are discussed in Section 4, together with their robustness tests and the policy implications of those findings. The last part of the document is Section 5, which wraps everything up.

2. Literature

Coal, crude oil, and petroleum are examples of conventional energy sources that both developing and established nations rely on to propel their economies to greater levels of economic growth. Despite this, this problem has a detrimental impact on both the health of humans and the environment. Because there is potentially a trade-off between economic growth and the state of the environment, nations with varying degrees of wealth investigate the possibility of imposing various constraints on the use of fossil fuels as a source of energy. Nevertheless, the destruction of the environment is a substantial contributor to climate change. Additionally, it will have a detrimental impact on the rate of economic expansion in a particular area, such as Africa [39,40]. In order to reduce the amount of carbon dioxide released into the atmosphere, governments are looking into alternative energy sources. A new indicator of the energy mix, which we refer to as the index of energy sources diversification, is something that our study suggests in light of this context.

Numerous articles have used a variety of econometric approaches to study the link between alternate forms of energy and economic growth using time-series and panel datasets [13,37,41–44]. Previous research has yielded a variety of empirical findings, which may be broken down into the following four categories: the conservation, the growth, the feedback, the growth, and the neutrality hypotheses [45]. The conservation theory suggests that increases in economic activity are caused by increases in energy indicators. In relation to this scenario, as nations develop, they will look for alternate sources of energy. The growth hypothesis posits that there is a causal link between increases in energy indicators and increases in economic growth. The growth hypothesis states that the use of alternate energy sources will result in faster economic development. At this point, the growth hypothesis that our research presents are put to the test to see whether or not it is viable for predicting the impacts of energy diversification on economic growth. The feedback hypothesis focuses on the correlation that exists between energy indicators and economic growth, which may be interpreted to suggest that energy sources diversification and economic performance drive each other. At last, the neutrality hypothesis states that there is no substantial causal link between the expansion of the economy and the indicators of energy use. Therefore, the economic performance is not affected by the use of alternating sources of energy and vice versa [46]. There is no widespread agreement about which theory holds water in certain nations. Both the selection of the sample and the econometric technique have a role in determining the outcomes. In the meanwhile, new avenues of study activity are opened up as a result of this problem.

The energy ladder theory and the Jevons' paradox are two further ideas that investigate the connection between the types of energy used and the performance of the economy (effect). According to the energy ladder theory, increasing economic performance should lead to an improvement in the quality of the energy source, which should in turn promote energy efficiency and environmental quality [47,48]. Moreover, the theory further states that economic performance (as measured by per capita income) and an increase in the diversity of energy sources through time have unidirectional and positive causation. This is because economic performance is positively correlated with a diversification of energy sources. As nations get wealthy, they are able to diversify their energy mix by adding sources of energy with a greater quality. In the future, the energy portfolio will not include sources of energy that are harmful to the environment, such as coal.

The energy ladder hypothesis' applicability has been experimentally examined to see whether or not it is valid. For example, Burke [49] makes use of the panel data of 134 nations spanning the years 1960 to 2010. According to the author's findings, economic growth results in a considerable transfer of energy from biomass to fossil fuels, which is followed by a transfer of energy from fossil fuels to primary electricity. Though, as was said at the beginning of the article, various countries have distinct comparative advantages in terms of the energy sources they use, the prices of production, and the amount of energy they use. Due to the dynamics of energy supply and demand, the link between energy diversification and economic performance might thus evolve in either direction (that is, from energy diversification to economic development).

There is just a limited amount of empirical information about the diversity of energy sources. Anecdotal evidence on energy diversification is offered in the majority of the publications that have been published in the energy literature [50]. When it comes to empirical works, for instance, Rubio Varas and Muñoz Delgado [5] measures the energy mixes of many countries, including France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. According to the findings of the authors, smaller economies, such as Portugal and Sweden, have a tendency to suffer more rapid energy changes from the year 1800 to the year 2010. Hence, the evidence is in-line with [26,51,52]. The findings of these publications lead to the conclusion that large energy consumer economies have distinct dynamics in relation to the patterns of energy diversification and energy transition than do smaller energy consumer economies. Hence, they were consistent with an article by [51]. At this point, our strategy is identical to the one used by [5]. Akrofi [53] investigates the energy diversification patterns in Africa's top 10 countries from the years 2000 to 2017 using the EMCI approach developed by [5]. The author makes the observation that Kenya and Morocco are the two nations in the area with the greatest energy diversification.

According to Jevons' paradox, energy diversity could not be beneficial to economic performance, and this is another point that has to be brought up (effect). According to Jevons' dilemma, the variety of energy sources may be increased either by technical advancement or by the policies of governments. Nevertheless, it may cut down on essential sources of energy (e.g., coal). Therefore, there will be no improvement in economic performance as a result of the declining demand for conventional sources of energy. In the near term, we anticipate that Jevons' paradox will be shown to be genuine.

3. Materials and Methods

Since the 1990s, there has been a growth in the range of energy sources. On the other hand, the fact that this problem exists does not necessarily indicate that all nations adhere to the same patterns of energy diversification or utilize the same sources of energy [53]. It is anticipated that the diversification of the energy portfolio would take place from conventional sources of energy, such as fossil fuels, to emerging sources of energy (renewables). As a consequence, there is a mechanism for feedback between the change in energy mixes and the diversification of energy sources.

We use the statistics from British Petroleum's Statistical Review of World Energy [54] to create the index of energy source diversity for each country from the period of 1998 to 2018. The Herfindahl–Hirschman export market diversification index is what we base our decisions on (World Bank, 2013: 26). To be more specific, we use the Herfindahl–Hirschman index for the energy diversification index; as such

$$\frac{\sum_{j=1}^{n_i}\left(\frac{x_{it}}{x_{it}}\right)^2-\frac{1}{n_i}}{1-\frac{1}{n_i}} \tag{1}$$

In Equation (1), x_{it} represents the total primary energy consumption (in millions of tons of oil equivalent) in country i at time t, x it represents the energy consumption from various energy sources (including coal, hydroelectricity, natural gas, nuclear energy, oil, and renewable energy) in country i at time t, and n_i represents the number of energy sources in country i. Note that we will not be able to compute the index if a nation solely uses energy from a single source (i.e., n_i = 1, and there is complete energy concentration and no diversification), since this would mean that there is no room for energy diversity. If the number is "0", it indicates that a country's main energy consumption is evenly distributed among the six energy sources that are relevant to the study.

As a result, our energy diversification index is able to determine whether or not the energy portfolios of various nations have grown more varied. In addition, we have the ability to determine whether or not certain nations followed similar diversification trends. We are also able to examine the degrees of energy diversification and investigate whether or not they converge over the course of the various time periods. The beginning of the process of energy diversification may also be determined with the assistance of our index, which also allows us to compare the beginning dates of the process between nations.

We next concentrate on the traditional growth models, such as the Solow growth model, which implies capital and labor are the primary drivers of economic development [55,56] and then include globalization and energy diversification. Our new model may be described as follows:

$$Y = (K,\ L,\ GLB,\ ED) \tag{2}$$

Equation (3) presents our model in logarithmic form

$$lnY_{it} = a_o + a_1 lnK_{it} + a_2 lnL_{it} + a_3 lnGLB_{it} + a_4 lnED_{it} + \varepsilon_{it} \tag{3}$$

where Y_{it} is the economic growth, K_{it} represents the capital, L_{it} represents the labor, GLB_{it} is used for globalization, energy diversification is denoted by ED_{it}, i and t are used for the country and time, respectively, and ε_{it} is the error term.

In addition, using the NPARDL estimation method, we estimate the following model in order to investigate the asymmetric impacts of energy diversification on economic development in both the short-term and the long-term future:

$$\begin{aligned}\Delta GDP_{i,t} = \beta_o \ + \ & \beta_1 X_{i,t} + \beta_2 ECT_{i,t} + \mathrm{p}GDP_{i,t-1} + \theta^+ {ED^+}_{i,t-1} + \theta^- {ED^-}_{i,t-1} \\ & + \sum\nolimits_{i=1}^{p-1} \varphi_i \Delta GDP_{i,t-k} + \sum\nolimits_{i=0}^{q} {\pi_i}^+ \Delta {ED^+}_{i,t-k} \\ & + \sum\nolimits_{i=0}^{q} {\pi_i}^- \Delta {ED^-}_{i,t-k} + \ \mu_{i,t}\end{aligned} \tag{4}$$

In Equation (4), $\Delta GDP_{i,t}$ represents the growth of the economy, $X_{i,t}$ represents the control variables, and the acronym $ECT_{i,t}$ stands for the error correction term. The long-term asymmetric effect is denoted by the $GDP_{i,t-1}$, the long-term positive impact of energy diversification is denoted by the $ED^{+}{}_{i,t-1}$ value, and the long-term negative impact of energy diversification is denoted by the $ED^{-}{}_{i,t-1}$ value. The short-term asymmetric effect is denoted by $\Delta GDP_{i,t-k}$, the short-term positive impact of energy diversification is denoted by $\Delta ED^{+}{}_{i,t-k}$, and the short-term negative impact of energy diversification is denoted by $\Delta ED^{-}{}_{i,t-k}$. The error term is denoted by the symbols i and t. Table 1 provides the descriptive properties of the variables used in the study.

Table 1. Description of the variables.

Variable	Symbol	Unit	Source
Labor	L	Total labor force	Nordic statistics database
Capital	K	Gross capital formation	
Economic growth	EG	GDP and GDP per capita constant USD 2010	
Globalization	GLB	KOF Overall Globalization Index	Gygli et al. [57]
Energy diversification	ED		British petroleum 2021

Note: Author(s) compilation.

The index of energy diversification is computed in this research using the data on energy consumption acquired from the source mentioned above.

Our sample coverage spans the years 1998 to 2018, and it includes all four Nordic nations. As was suggested by earlier research, the values of all the variables have been represented using natural logarithms [44,58].

We utilize various panel data estimation techniques to obtain the short-term and long-term parameters. The overview of the methodology used in this article is depicted in the Figure 2 below.

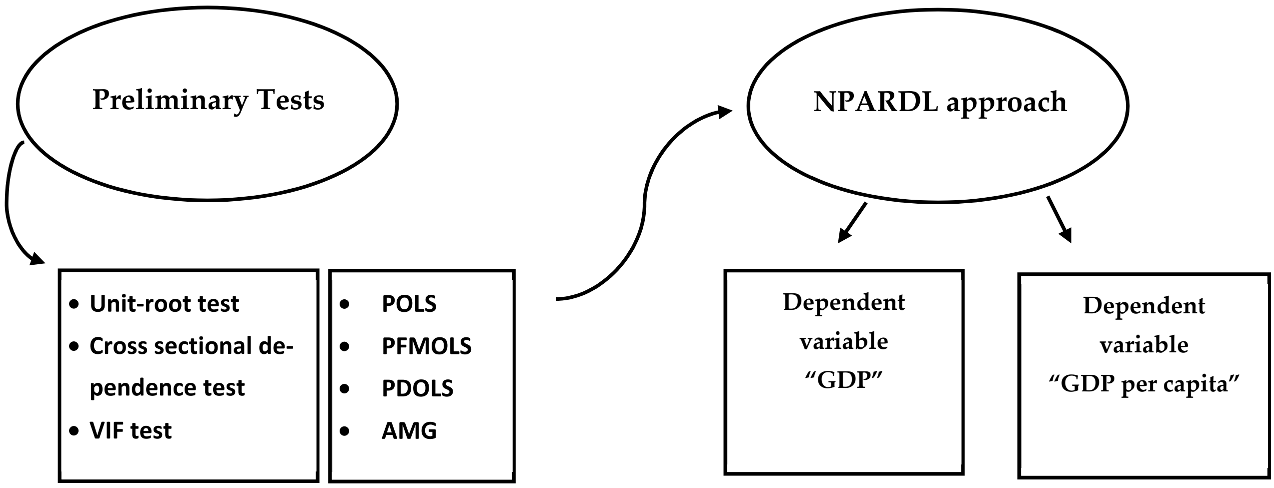

Figure 2. Overview of the methodology.

The POLS approach is less reliable than the PFMOLS and PDOLS methods because the POLS method uses an endogenous estimating process, which might result in biased conclusions. The PFMOLS and PDOLS methods are more resilient than the POLS method [59]. Due to the fact that there are normally distributed asymptotic standard errors, the PFMOLS estimator, which was presented by [60,61], offers evidence that is free from bias. This problem gives elastic and efficient parameters over the long term. Phillips and Hansen [62] demonstrates that the semi-parametric correction of the FMOLS may eliminate the possibility of endogeneity as well as residual autocorrelation in the data. On the other hand, when all of the indicators in the model are cointegrated, we should think about using the PFMOLS technique [63]. The PFMOLS methodology uses either the group mean or the between-group estimator as its foundation. It makes it possible for the panel datasets to have a high degree of variability [64].

Eberhardt and Bond's research from 2009 demonstrates that the AMG is adaptable when dealing with nonstationary variables (cointegrated or not). It is possible to use it in situations involving cross-sectional dependency. As a result, it is a helpful estimator and is taken into consideration in the empirical literature on energy economics (see, e.g., [65,66].

Lastly, the NPARDL estimate approach was introduced by [67] as a method for modeling the possible asymmetric effect of energy diversification on economic growth in both the short-term and the long-term future. The literature on energy economics often discusses asymmetric impacts and other nonlinear consequences. For example, Hamilton [68] demonstrates that a rise (positive impact) in oil prices has higher impact on economic development than a decline. This is because a rise in oil prices indicates increased demand (negative impact). At this point, asymmetry is the most important factor to consider while conducting an investigation into the short-term and long-term impacts that energy indicators have on the performance of the economy. These topics are adapted to focus on the implications of diversified energy sources on economic growth.

4. Results and Discussion

Our investigation begins with findings of the variables' unconditional correlations. According to the findings in Table 2, the rate of economic growth (GDP) has a positive correlation with the rate of globalization (GLB), the labor force (LF), and gross capital creation (GFC).

Table 2. Unconditional correlations among the variables.

Series	GDP	GCF	LF	GLB	ED
GDP	1				
GCF	0.993	1			
LF	0.970	0.968	1		
GLB	0.339	0.325	0.470	1	
ED	−0.340	−0.317	−0.084	−0.515	1

Note: Author(s) depictions.

Gross capital creation and labor force participation are two measures that have a robust positive correlation with economic growth. Additionally, among these countries, economic development had a more significant positive link with internationalization, which is one aspect of globalization. According to our preliminary statistical analysis, a negative correlation exists between the rate of economic growth and the energy diversification (ED) indicator. In general, these early figures point to the fact that a greater level of energy diversification is linked with a negative correlation with economic growth. On the other hand, the remaining indicators play a significant part in the growth narrative of those countries.

The major purpose of this research is to experimentally evaluate the impact that energy diversification has on economic growth while simultaneously controlling for the influence of other factors. These factors include both modern and traditional factors that play a significant part in the development of economies in different parts of the world. As a result of this, we begin our empirical research by using the POLS, PDOLS, and PFMOLS estimators. The outcomes of all of these different methodologies are outlined in Table 3.

Table 3. Results of the POLS, the PDOLS, the PFMOLS, and the AMG estimations.

Dependent Variable Log GDP					
POLS			PDOLS		
GCF	0.772 [a]	<0.01	GCF	0.312 [a]	<0.01
LF	0.081 [a]	<0.01	LF	0.161	<0.05
GLB	0.428 [a]	<0.01	GLB	0.919 [a]	<0.01
ED	−0.04 [a]	<0.01	ED	−0.072 [c]	<0.10
Constant	0.732 [a]	<0.01			
R-squared	0.872				
PFMOLS			AMG		
GCF	0.264 [a]	<0.01	GCF	0.194 [a]	<0.01
LF	0.738 [a]	<0.01	LF	0.132 [b]	<0.05
GLB	0.669 [a]	<0.01	GLB	0.098 [c]	0.07
ED	−0.019	0.14	ED	0.06 [b]	<0.05
			Constant	8.414 [a]	<0.01
			Wald Chi	168 [a]	<0.01

Note: a, b, and c denote significance at 1, 5, and 10%, respectively.

According to the results of the POLS study, diversifying energy sources away from fossil fuels and toward renewable energy sources does not have a detrimental effect. This shows that the shift away from fossil fuels and towards a greener economy would be beneficial to the long-term economic growth of these countries. It should come as no surprise that the capital and labor forces each play a significant part in the process of propelling economic expansion across these panels. It is essential to take into account the fact that the world's leading developed economies have reaped the benefits of globalization.

The aforementioned findings provide a summary of the connection between the dependent and independent variables; nevertheless, they do not address a number of concerns that need to be resolved in order to get conclusions that can be relied upon. The PDOLS and PFMOLS approaches are used in this work to carry out additional estimations of this model. The primary benefit of both methods is that the PDOLS approach employs both leads and lags to handle endogeneity and serial correlation difficulties in the model. This allows the model to be more accurate. The PFMOLS technique, on the other hand, takes a non-parametric approach to the problem at hand in order to solve it. Consequently, as a consequence of resolving the difficulties of endogeneity and serial correlation that the model presents, these two strategies provide more accurate findings. Based on the findings of the PDOLS study, it seems that the influence of energy diversification is detrimental to the growth of the economy.

The findings of the PFMOLS point to the conclusion that the influence of energy diversification on economic expansion is negligible and relatively modest. The remainder of the control variables, as was to be predicted, were found to be generally significant and had a strong positive influence on growth. As was said before, the influence of globalization on the expansion of the economy is enormous.

In conclusion, this research makes use of yet another alternative method, namely the AMG, in order to take into consideration cross-sectional dependency in the model. The findings indicate that all of the factors are, to a large extent, compatible with the anticipated outcomes.

Due to the fact that the data presented above give contradictory evidence in terms of the influence of energy diversification on economic expansion across the various research approaches, these seemingly contradictory findings might be explained by the existence of a nonlinear link between the diversity of energy sources and the expansion of the economy. The fact that governments have made significant efforts over the last two decades to transition from an energy system based on fossil fuels to one that relies more heavily on renewable energy sources lends credence to this thesis. During this period of transition, both the expansion of the economy and the diversification of its energy sources have encountered significant nonlinearity as a result of both internal and foreign causes. Given this, the NPARDL approach is the one that we use in order to deal with the nonlinearity present in the model. Table 4 presents the findings in their entirety.

Table 4. Results of the NPARDL approach.

Dependent Variable Log GDP					
	Short term			Long term	
	Coefficient	P > z		Coefficient	P > z
ΔCAP	0.158	<0.01	CAP	0.469	<0.01
ΔLF	0.107	0.325	LF	−0.080	0.095
ΔGLB	0.030	0.466	GLB	0.040	0.485
ΔED+	−0.012	0.071	ED+	0.384	<0.01
ΔED−	0.040	<0.05	ED−	−0.197	<0.01
Constant	0.732	<0.01			
ECT	−0.086	<0.01			
Asymmetric Impacts					
Short-term asymmetric impacts				361.21	<0.01
Long-term asymmetric impacts				1.01	0.291
Obs				21	

Note: + and − denote positive and negative impact, respectively.

According to our first projections, the current upward trend of energy diversification is having a depressing effect on the expansion of the economy. At the same time, the unfavorable trend of increasing energy diversification seems to be beneficial to the expansion of the economy. The short-term error correction (EC) term is found to be negative and statistically significant, indicating that the model converges to a long-term relationship and is dynamically stable. This was shown to be the case, as was anticipated. The most important piece of information that can be gleaned from the investigation of the NPARDL technique is the fact that nations often go through a period of negative economic development when they start the process of switching from fossil fuels to renewable energy in the short term. On the other hand, if nations in the near term see a slowdown or a negative trend in energy diversification owing to internal or external forces, this will once again promote economic development. The findings also demonstrate that there are substantial long-term and short-term asymmetric effects across all of the panels. This demonstrates that the positive and the negative trends of energy diversification each play a unique role in the expansion of the economy.

The findings show that a rise in the variety of energy sources has a considerable and beneficial effect on the expansion of the economy over the long term. On the other hand, the declining trend of energy diversification seems to be detrimental to the growth of the economy. The findings provide more credence to the significant influence that globalization has had on the expansion of the economy, as was shown before. These data once again demonstrate that globalization has been beneficial to the economies that were already formed.

In addition, as a dependent variable for the robustness check, we use GDP per capita rather than total GDP as a replacement for GDP. The models are then re-estimated with the NPARDL approach. Table 5 summarizes the findings for your perusal.

Table 5. Results of the NPARDL approach.

Dependent Variable Log GDP Per Capita					
	Short term			Long term	
	Coefficient	P > z		Coefficient	P > z
ΔCAP	0.164	<0.01	CAP	0.475	<0.01
ΔLF	0.050	0.584	LF	−0.885	<0.01
ΔGLB	0.051	0.247	GLB	0.131	<0.05
ΔED+	0.053	0.993	ED+	0.270	<0.01
ΔED−	0.047	0.099	ED−	−0.247	<0.01
Constant	0.509	<0.01			
ECT	−0.089	<0.01			
Asymmetric Impacts					
Short-term Asymmetric Impacts				0.794	0.49692
Long-term Asymmetric Impacts				426.32	<0.01
Obs				21	

Note: + and − denotes positive and negative impact, respectively.

According to the results, expanding the variety of energy sources has, over the course of time, a considerable and positively impactful effect on the process of fostering economic growth. It is fascinating to note that the unfavorable trend of energy diversification has a significant negative influence on the expansion of the economy over the long term. According to the facts shown here, once nations transition away from fossil fuels and toward renewable energy sources, they will not go back to using fossil fuels. According to what was documented earlier, increasing energy diversity works against short-term economic development, but decreasing energy diversity works to improve long-term economic development. The other findings are, for the most part, in line with the projections made before.

5. Conclusions and Policy Implications

The purpose of this study is to investigate the impact that the diversity of energy sources has on economic performance across the panel datasets of four Nordic nations using data dating from 1998 to 2018. In order to accomplish this goal, we use the data on yearly energy consumption as a novel measurement of the diversity of energy sources. According to the findings of the NPARDL estimate model, energy diversification does not contribute to improvements in short-term economic performance. However, in the short term, a decline in energy diversification promotes economic activity. On the other hand, there is no evidence that shows that energy diversification has a detrimental effect on economic performance over the long term.

In light of these data, we argue that the adverse effects of energy diversification on economic growth are relatively temporary. Nevertheless, after the nations have passed a certain point in the time of their energy transition, they will begin to appreciate the good influence that energy diversity has had on their economic production. According to published research, emerging and low-income nations are unable to escape their dependence on traditional energy sources, which account for around 90%of their overall energy production. As a result, the shift to renewable energy is proceeding at a glacial pace, which is detrimental to the growth and prosperity of the economy. However, this shift might take place more quickly in these nations if the world's leading organizations (the Nordic countries), working on expanding the accessibility of renewable energy sources, offer the necessary financial and technical assistance. According to this research, technical advancement and financial support for renewable energy might potentially assist in diversifying energy sources. Therefore, expanding energy diversification from conventional to renewable energy helps enhance economic growth and alleviates overall environmental and public health, all of which are essential in fulfilling the United Nations' sustainable development objectives.

This study makes a contribution to the existing body of research on the topic by using a novel method for calculating the energy diversification index in Nordic nations. This allows for analyzing the impact that this index plays in the economic growth of various countries. Investigation into the factors that determine energy diversification is another avenue for further study that might be pursued. Our research initiates a new conversation in the literature devoted to the topic of energy growth, which calls for more research to investigate the topic and give specific consequences for both policy and practice.

When countries begin the transition from energy derived from fossil fuels to energy derived from renewable sources, their economies may experience a slowdown in economic activity in the short term. On the other hand, if energy diversification continues from the short term into the long term, then the major economies are likely to experience positive economic performance. In light of this, we contend that the majority of industrialized and significant economies throughout the globe have already passed through the era of transition in the energy sector and have started to reap the potential advantages of energy diversification.

It is essential, however, to grasp the idea that greenhouse gases and climate change are not limited to a particular geographic area. The only way to effectively address problems on this global scale is for all countries to work together and contribute their own resources. These countries need to get the necessary financial assistance as well as the technical expertise from international organizations like the United Nations (UN) and the World Bank in order to further the development of alternative energy sources. In addition, industrialized countries should provide low-income countries with financial and technical assistance in order to help them increase the proportion of renewable energy sources in their overall energy mix.

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