Štreimikienė,D. (2024). Renewable energy penetration in Nordic and Baltic countries of the EU. *Journal of International Studies, 17*(1), 97-107. doi:10.14254/2071-8330.2024/17-1/6

Journal of International Studies

Centre of Sociological Research

Scientific Papers

Renewable energy penetration in Nordic and Baltic countries of the EU

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Abstract. The low carbon transition of the energy sector towards a greater penetration of renewable energy sources (RES) is one of the most impressive examples of political and economic change in the European Union. For nearly two decades, the European Union was rightly considered to be a frontrunner in RES development and deployment around the world. This culminated in March 2007 when the 20-20-20-targets were agreed under the European Council Conclusions. They aimed at creating a carbon neutral society by 2050 and replacing fossil fuels with renewables. This target requires huge transformations of energy systems and transformative shifts in economics and society. Even as renewables can provide numerous environmental, social, and economic benefits, their fast penetration may cause various societal challenges and encounter many barriers. Therefore, this paper aims to analyse the achievements of select EU countries in renewable energy development. For this purpose, an indicators framework is applied to monitor the RES drivers and achievements, RES penetration, and attained benefits of low carbon transformations. The case study focuses on Nordic and Baltic countries that are EU member states.

Keywords: sustainable energy development; renewable energy indicators, comparative assessment, EU, Nordic and Baltic countries.

JEL Classification: Q42, Q48, P46

Received: June, 2023
1st Revision: March, 2024
Accepted: March, 2024

DOI: 10.14254/2071-8330.2024/17-1/6

1. INTRODUCTION

The energy sector accounts for more than 75% of the greenhouse gas (GHG) emissions in the European Union. The EU aims to reduce GHG emissions by at least 55% by 2030 and become a climate-neutral society by 2050. Increasing the share of renewable energy sources (RES) in all sectors of the economy is the main way of achieving both. Thus, low-carbon energy transition is a priority policy in many developed countries. In 2022, the share of total renewables in EU's final energy utilisation was at 23%. In 2018, a target

was set for 2030 - to reach 32% of RES in final energy consumption. However, a new target was set - to achieve at least 42.5% and aim for 45% of RES in final energy consumption by 2030 – in the revised Renewable Energy Directive in 2023.

Several studies (Butnaru et al., 2020; Presno & Landajo, 2021) have analysed the progress toward the 2020 renewable energy share among EU countries and found big differences among countries in all sectors except electricity. Only the power sector has shown convergence in the deployment of RES, possibly as a consequence of the vigorous growth in solar energy. In the case of transport, heating, and cooling sectors, market uncertainties had a negative effect on convergence. Thus, new policies and measures are necessary to promote convergence among EU countries in the penetration of renewables in all sectors and ensure transition to carbon neutrality by 2050.

Although some studies (Apergis & Payne, 2010; Al-Mulali et al., 2013; Salim & Shafiei, 2014; Doytch, Narayan, 2016; Khan et al. 2020; Versal & Sholoiko, 2022; Ballesta et al., 2022; Mukhtarov et al., 2023; Stankevičienė & Borisova, 2022) have analyzed the pace of renewable energy penetration in EU member states, it is essential to carry out a new study to ascertain the current situation, compare the advancement achieved by the European Union countries, and reveal the main reasons for the differences among them.

This paper aims to close this gap and develop a comparative case study assessing the progress of selected EU countries from the Nordic and Baltic regions in the penetration of renewable energy sources (Streimikiene, 2023; 2023a). The rest of the article is organized in the following way: the literature review is given in section 2, and the renewable energy indicators framework developed to evaluate the progress of RES penetration, drivers, and outcomes in EU countries is developed in section 3. The case study results on assessing renewable energy penetration performance in selected EU countries are deliberated in section 4, and conclusions and implications are specified in section 5.

2. LITERATURE REVIEW

Understanding the determinants or barriers and drivers of renewable energy consumption (REC) is crucial when designing effective energy policies for fostering fast penetration of renewables. The current trends of renewable energy development are supported by the growing interest in sustainability issues (Androniceanu et al., 2021; Bilan et al., 2017; Mishchuk et al., 2023). The studies (Painuly, 2011; Marra & Calantonio, 2021; Sitenko et al., 2023) analysed barriers of renewable energy penetration and other studies (Aguire, Imbinkulne, 2014; Omri et al., 2015; Sen, Ganguly, 2017; Zhao et al., 2020; Ballesta et al., 2022; Adamek & Wancerz, 2023) were investigating the main drivers of renewable energy consumption and some studies were dealing with both of them (Liu et al., 2020; Streimikiene et al., 2021; Sotnyk et al., 2023; Bublyk et al., 2023).

Research on the determinants and drivers of REC typically uses several primary variables representing REC, which are total renewable energy consumption (TREC), renewable energy consumption per capita (RECpc), renewable electric energy consumption (REEC), and the portion of REC in total consumption of energy (REC%). Several studies (Apergis & Payne, 2010; Al-Mulali et al., 2013; Salim & Shafiei, 2014; Ballesta et al., 2022) have investigated these renewable energy-related variables, including many others. Therefore, these variables can be considered as renewable energy penetration indicators as they show the level of renewable energy deployment in the country.

Many studies use the TREC indicator and consider Gross Domestic Product (GDP) or Gross National Product (GNP) per capita as an explanatory factor showing the level of national income or the country's economic development level. There are other explanatory factors of economic development level used in several studies, such as foreign direct investments (FDI), income inequality (IE), trade openness (TO), etc. Regarding FDI, studies have examined the influence of FDI sectoral allocation upon REC in industries

between 1985 and 2012 in 74 world countries, and they have found that overall FDI boosts REC in industries but that the impact differs between sectors (Doytch & Narayan, 2016).

Studies (Anton & AfloareiNucu, 2020; Doytch & Narayan, 2016; Drożdż et al., 2023) indicated that financial service and foreign direct investment (FDI) contribute to the growth of renewable energy consumption. Ergun et al. (2019) conducted a study on 21 African nations between 1990 and 2013 and found a positive correlation between FDI and REC percentage. However, Khan et al. (2020) analysed data from 192 countries from 1980 to 2018 and obtained varying results for FDI impacts on REC. Khan et al. (2020) found non-significant results in lower-income countries but significant and positive results in high-income countries through panel quantile regression. Therefore, it has been concluded that FDI reduces Renewable Energy Consumption in lower-income nations while it boosts REC in higher-income countries. However, a study by Anton & AfloareiNucu (2020) showed an adverse association between FDI and REC% in European Union member states from 1990 to 2015. On the other hand, Lei et al. (2021) did not reveal any connection between foreign direct investments and REC% indicators in their analysis for China. The results of studies on the linkages between trade openness and renewable energy consumption are inconsistent. Several studies (Amri, 2019; Rasoulinezhad & Saboori, 2018; Sebri & Ben-Salha, 2018) have found a direct positive connection between TO and REC. However, other analyses have shown a negative association between trade openness and renewable energy consumption.

A study conducted by Rasoulinezhad & Saboori (2018) analysed 12 Commonwealth of Independent States (CIS) countries during 1992 - 2015 period and revealed a two-way association between TO and REC. Meanwhile, Sebri & Ben-Salha (2014) studied the BRICS countries between 1971 and 2010 and discovered a significant impact of TO on renewable electric energy consumption (REEC). However, insignificant links between TO and CO_2 emission were found for Canada (Mukhtarov et al., 2024).

Additionally, Hashemizadeh et al. (2021) analysed 20 emerging countries between 1990 and 2016 and found that TO reduces RECpc. Similarly, Khan et al. (2020) and Ergun et al. (2019) concluded that TO hurts REC%. Finally, Zhao et al. (2020) analysed China and found that TO increases the use of non-renewable energy. Therefore, TO impact on REC varies by country type. Developed countries showed a U-shape relationship between TO and REC. The relationship between TO and REC in developing countries follows the inverted U-shape (Naqvi et al. 2020; Amri, 2019).

It's worth noting that social factors are not typically considered in many studies. Some examples of studies that do consider social factors include Apergis et al. (2018), Ergun et al. (2019), Baye et al. (2021), Khribich et al. (2021). Apergis et al. (2018), for instance, analysed the relationship between REC and health indicators in a group of 42 African states between the years 1995 and 2011. In a study of the Sub-Saharan African region, Baye et al. (2021) found that there is a long-term causal association between REC and healthcare expenditures. The study also assessed the influence of governance on REC% and found a positive relationship between REC% and the growth of governance quality. In another study by Ben Jebli (2016) on Tunisia, a bi-directional association was found between health expenditures and REC. In 2019, Ergun et al. conducted a study investigating the influence of the Human Development Index and the democracy indicators on REC% in Africa. Their findings indicate that HDI has a negative impact on REC%, whereas the impact of democracy is not substantial.

A study by Khribich et al. (2021) constructed an index for assessing social development based on 17 variables linked to health, education, equality, etc. and used data of 27 high-income states from 1995 to 2015. They discovered that the social development index has a positive effect on REC% just in the long term. Finally, Marra & Colantonio (2021) conducted a study on the impact of socio-technical factors, such as educational attainment, on REC% in 12 European Union countries. They found a positive relationship with renewable energy consumption.

A study by Jia et al. (2022) analysed the impact of urbanization and education on renewable energy consumption in China. Manate et al. (2023) investigated low carbon energy transition policies' impacts on the use of renewable energy sources in buildings.

Most of the analyses on renewable energy consumption use the TREC as the dependent variable. Studies covered China, India, Tunisia, the USA, OECD countries, EU members, CIS region countries, African countries, and developed and developing states. Khan et al. (2020) conducted the widest study regarding the number of countries covered (192) for assessing the relationship between renewable energy consumption, carbon emission, and financial development. The relationship shape differs for different countries based on economic development level, financial development, etc.

The main outcomes of renewable energy consumption addressed in most studies are CO_2 or GHG emission reduction (Aperigis & Payne, 2012; Attiaoui et al., 2017; Ben Jebli, 2016; Cherni & Jouini, 2017; Rasoulinezhad & Saboori, 2018; Sebri & Ben-Salha, 2014; Tarczyński et al., 2023), and ecological footprint reduction (Naqvi et al., 2020).

3. METHODS AND DATA

The main approach followed in this article is the application of an indicators framework to measure the progress of renewable energy development in EU countries.

3.1 Renewable energy indicators framework

There are several indicator frameworks to measure the progression of renewable energy penetration progression. World Bank (2023) developed Sustainable Energy for All indicators, including renewable energy consumption indicators. There is an energy for sustainable development indicators framework developed by several international organizations like International Atomic Energy Agency (IAEA), United Nations Department of Economic and Social Affairs (UNDESA), International Energy Agency (IEA), EUROSTAT and European Environment Agency (EEA), including also renewable energy consumption indicators (IAEA, 2005).

The EU has established several indicators for assessing the progress of EU countries to RES objectives set by the EU Directive. These indicators are based on the share of RES in energy consumption for specific sectors and are regularly calculated by EUROSTAT (EC, 2019).

Also, The EurObserv'ER barometer since 1998 has measured the progress made by RES penetration in every sector and in each European Union country. Then, EurObserv'ER issues a series of RES indicators covering technological, economic, and social dimensions (EC, 2022).

Therefore, the RES indicators are used to monitor and analyse the development of RES in the EU countries to assess the RES penetration progression compared to EU objectives set for 2020, and 2030.

The main renewable energy indicators from EU policy documents are selected and presented in Table 1 and grouped as RES state, driving force, and outcome indicators. Eurostat developed these indicators to assess the results achieved by EU countries in terms of renewable energy penetration.

Table 1

Renewable energy penetration indicators

Indicator	Measure	Description
RES penetration state indicators		
Overall portion of energy from renewables	%	This indicator calculates the share of renewable energy consumption in gross final energy consumption according to the Renewable Energy Directive. The gross final energy consumption is the energy utilised by end-users (final energy consumption) plus grid losses and self-energy use of power plants.
Portion of energy from renewable sources in transport	%	This indicator shows the percentage of energy consumed in the transport sector that comes from renewable energy sources. Values are tracked at the EU and country levels.
Portion of energy from renewables in gross electricity consumption	%	This indicator is calculated as gross final consumption of electricity from renewable sources divided by gross final consumption of electricity.
Share of energy from renewable sources for heating and cooling	%	This indicator is calculated as gross final consumption of energy from renewable sources for heating and cooling divided by gross final consumption of energy for heating and cooling.
RES penetration driving force indicators		
Patents in renewable energy technologies	Number of patterns per trillion of GDP	This indicator measures the number of patent applications in the respective renewable energy technology field divided by GDP in current prices.
Share of public research and development investments in renewable energy technologies	%	This indicator measures the share of R&D investments performed by the public (government and higher education) sectors in all investments regarding renewable energy technologies. The basic aim of public R&D investments is to create follow-up investments from the private sector and generate spill-over effects.
Private research and development expenditures in renewable energy technologies as a share of GDP	%	This indicator measures the R&D investments performed by public sectors regarding renewable energy technologies as the share of the GDP of the country.
Number of collective action initiatives by renewable energy communities per thousand inhabitants	Number of collective actions per thousand inhabitants	This indicator addressed the Number of Collective Action Initiatives (CAIs) initiated in specific EU countries and identified through the COMETS project (2023).
RES penetration outcome indicators		
The share of gross value added by renewable energy sectors in GDP	%	This indicator is calculated as the gross value added of the renewable energy sector divided by GDP in current prices.
Employment in renewable energy sectors	Number of workplaces per thousand inhabitants	The indicator shows the development of the number of people employed in the renewable energy sector.

Source: created by authors based on (EC, 2022; 2023)

Renewable energy indicators were assessed for selected EU countries for the Nordic and Baltic regions in 2021 using the latest data in the Eurostat database (EC, 2023) and the 21st EurObserv'ER Report (EC, 2022).

4. CASE STUDY OF RENEWABLE ENERGY PENETRATION COMPARATIVE ASSESSMENT IN NORDIC AND BALTIC COUNTRIES

The data was collected from Eurostat and EurObserv'ER Report, and indicators of renewable energy penetration representing state, drivers, and outcomes of RES penetration were calculated for Nordic and Baltic countries using the newest available data, which is 2021 (see Table 2).

Table 2

Renewable energy indicators for selected EU countries from Nordic and Baltic regions in 2021

Indicator	Sweden	Finland	Denmark	Latvia	Estonia	Lithuania
Overall portion of energy from renewables, %	62.6	43.1	34.7	42.1	38.0	28.2
Portion of energy from renewable sources in transport. %	30.4	20.5	10.5	6.4	11.2	6.5
Portion of energy from renewables in gross electricity consumption, %	75.7	39.5	62.6	51.4	29.3	21.3
Share of energy from renewable sources for heating and cooling, %	68.6	52.6	41.5	57.4	61.3	48.6
Patents in renewable energy technologies, number of patterns per trillion of GDP	48	85	1026	114	-	31
Share of public research and development investments in renewable energy technologies in total investments, %	0.0089	0.0077	0.0133	-	0.0006	0.0043
Private research and development expenditures in renewable energy technologies as a share of private R&D expenditures in GDP, %	0.012	0.023	0.272	0.021	-	-
Number of collective action initiatives by renewable energy communities per thousand inhabitants	0.03	0.01	0.002	-	0.003	0.003
The share of gross value added by renewable energy sectors in GDP, %	1.0	2.0	0.2	1.7	0.1	1.1
Employment in renewable energy sectors, workplaces per thousand inhabitants	6.3	6.4	0.7	12.0	0.3	8.4

Source: created by authors based on (EC, 2023).

In general, Nordic countries have the highest indicators of RES penetration in terms of state, drivers, and outcomes with small exemptions. One can notice that Sweden has the highest overall share of renewable energy in gross final energy consumption and shares of RES in other sectors, such as electricity, heating and cooling, and the transport sector. Denmark has the best results in renewable energy driver indicators such

as patent intensity of GDP, share of public R&D investments in total investments, and share of private R&D expenditures in GDP. Finland has the highest gross value-added share of renewable energy in total GDP. Surprisingly, Denmark has the lowest share of renewables in the heating and cooling sector and quite low values for the share of gross value added by renewables energy sectors in GD P and employment in the renewable energy sector.

Latvia has the highest overall renewables in gross final energy consumption among the Baltic States but holds just the third position among Nordic countries. Though Latvia has the lowest share of RES in transport, it has the highest employment per thousand inhabitants in the renewable energy sector.

Table 3

Ranking of selected EU countries from Nordic and Baltic regions according to renewable energy penetration criteria in 2021

Indicator	Sweden	Finland	Denmark	Latvia	Estonia	Lithuania
Overall portion of energy from renewables, %	1	2	5	3	4	6
Portion of energy from renewable sources in transport. %	1	2	4	6	3	5
Portion of energy from renewables in gross electricity consumption, %	1	4	2	3	5	6
Share of energy from renewable sources for heating and cooling, %	1	4	6	3	2	5
Patents in renewable energy technologies, number of patterns per trillion of GDP	4	3	1	2	6	5
Share of public research and development investments in renewable energy technologies in total investments, %	2	3	1	6	5	4
Private research and development expenditures in renewable energy technologies as a share of private R&D expenditures in GDP, %	4	2	1	3	5	5
Number of collective action initiatives by renewable energy communities per thousand inhabitants	1	2	3	5	4	4
The share of gross value added by renewable energy sectors in GDP, %	4	1	5	2	6	3
Employment in renewable energy sectors, workplaces per thousand inhabitants	4	3	5	1	6	2
Final ranking of countries	1	2	3	4	6	5

Source: created by authors

As one can see from the ranking given in Table 3, Sweden was ranked as the best-performing nation regarding RES penetration among analysed countries situated in different EU regions. Finland was the second best-performing country in terms of RES penetration in 2021, followed by Denmark. High RES penetration state indicators and drivers of RES expansion produce these high positions of Nordic countries

in RES penetration. Estonia received the lowest ranking in RES penetration in 2021, mainly due to the lowest indicators on RES drivers and outcomes. Latvia and Lithuania received higher total scores in RES penetration compared to Estonia and showed quite high indicators of employment in RES sectors; however, one can notice that Nordic countries have achieved better results in RES penetration in comparison with Baltic States. Though countries share similar climate conditions due to higher economic development level of Nordic countries these economies have more resources and can provide higher public and private R&D investments in renewable energy technologies having impact on fast penetration of renewables in all main sectors.

5. CONCLUSIONS

Fast penetration of renewable energy sources in various sectors of the economy is the main way to achieve low carbon energy transition and create a carbon-neutral society in the EU by 2050.

The system of RES indicators was created based on available RES indicator frameworks and statistical data provided for EU countries by Eurostat and other agencies to analyze the main drivers of RES penetration and their outcome indicators in EU countries and measure and compare the progression of RES penetration.

The developed renewable energy penetration indicators system consists of drivers of RES penetration, indicators of the state of RES penetration, and indicators of outcomes of RES penetration. The developed RES penetration framework was applied for an empirical case study in Nordic and Baltic countries and EU member states.

The analysis showed that in 2021, Sweden achieved the best results in the penetration of RES. Other Nordic countries (Finland and Denmark) were also leaders in RES penetration. Estonia was found to be the most lagging country in terms of achievements in renewable energy penetration among all analysed countries, including Baltic countries. Among the Baltic countries, the leader is Latvia, mainly because of its high share of renewables in electricity generation and final energy consumption, caused by the availability of large hydroenergy resources.

The study showed that Sweden has the highest overall share of renewable energy in gross final energy consumption and shares of RES in other sectors, such as electricity, heating and cooling, and the transport sector. Denmark showed the best results in renewable energy driver indicators such as patent intensity of GDP, share of public R&D investments in total investments, and share of private R&D expenditures in GDP. Finland has the highest gross value-added share of renewable energy in total GDP. However, Denmark has the lowest share of renewables in the heating and cooling sector and quite low values for the share of gross value added by renewables energy sectors in GDP and employment in the renewable energy sector.

Latvia has the highest overall renewables in gross final energy consumption among the Baltic States but holds just the third position among Nordic countries. Though Latvia has the lowest share of RES in transport, it has the highest employment per thousand inhabitants in the renewable energy sector.

The study has a few limitations as renewable energy promotion policy analysis in analysed countries would be useful to comprehend the differences in renewable energy penetration in Nordic and Baltic countries. Future research is necessary for the analysis of policies and measures and assessing their impacts on the fast penetration of renewable energy sources in Nordic countries.

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