

Comparative Assessment Model of Natural Resources Mix In The European Context*

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Abstract

This paper presents an analysis of primary energy production from renewable and non-renewable sources. It determines which energy from non-renewable sources is replaced by energy from renewable sources for each EU member country considered. Additionally, the present paper also shows us a cluster analysis of EU member countries according to the share of renewable sources in total electricity production from renewable sources and biofuels. All data used for the study were taken from the EUROSTAT and IRENA 2024 databases. The countries considered are: Romania, Bulgaria, Italy, Greece, Croatia, Poland, Hungary, Slovakia, Spain, Czech Republic, Belgium, Portugal, France, Germany, Slovenia, Lithuania, Estonia, Latvia, Austria, Denmark, Netherlands and Sweden.

Keywords: primary energy production, renewable and non-renewable resources, cluster analysis, model

Introduction

Primary energy sources are natural resources such as coal, oil, natural gas, nuclear energy and renewable sources such as wind, solar, hydro, biomass and geothermal energy. So, primary energy can be defined as energy that is extracted directly from natural resources.

In all countries of the European Union, primary energy production has changed significantly over the last thirty years. During this period, there has been a downward trend in total production. Instead, the consumption showed an increasing trend. In conclusion, the primary energy deficit has deepened, requiring the import of increasingly larger quantities of energy.

There is also a difference between the structure of energy production and consumption in EU member countries. In the early 1990s, fossil fuels held the largest share of primary energy production, and by the end of the decade, they had dropped to second place. After 2009, they reached third place. In the early 1990s, nuclear energy was in second place, and from 1998 to 2015 it was in first place, then returned to second place. In the 1990s, natural gas was in third place in the structure of primary energy production, and since 2005, it has reached fourth place. Renewable energy has experienced significant growth. In the period 1990-2022, electricity production from other sources, such as oil, remained insignificant.

The structure of primary energy consumption in EU countries differs from the structure of production. Between 1990 and 2022, oil remained the primary source of energy consumption. The consumption of solid fossil fuels ranked second in the early 1990s, reaching fourth place in 2018, fifth place in 2019, and in 2022 it returned to fourth place. Natural gas consumption ranked second in the period 1990-2022. Nuclear energy maintained its

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fourth position overall in the period 1990-2022. However, between 2015-2018 and 2022, it ranked fifth. Renewable energy consumption ranked fifth in 1990 and reached third place in 2022.

In 1990, the primary energy production structure in the EU member states was represented by: solid fossil fuels 41.2% of total production, nuclear energy 25.4%, natural gas 16.6%, crude oil 5.5%, and renewable energy sources 9.5%.

In 2022, the structure of primary energy production was represented by renewable energy sources 43.3%, nuclear energy 27.7%, solid fossil fuels 16.5%, natural gas 6.2%, and crude oil 3.3%.

So, in the period 1990-2022, energy production increased only for renewable energy sources, and production from other sources decreased. The largest decrease was for solid fossil fuels by -70%, then for natural gas it was -72%, for nuclear energy the decrease was -18% and energy production from crude oil decreased by -53%.

The highest capacity to meet energy demand from domestic production for the year 2022 (see Fig. 1) is observed in Estonia (99.49%), Sweden (84.07%) and followed by Romania (71.65%). Luxembourg (8.2%) presents a very low proportion of primary energy production in relation to consumption. From Fig. 1, it is observed that Spain, Germany, France, Italy, and Portugal have a relatively low ratio between primary energy production and consumption.

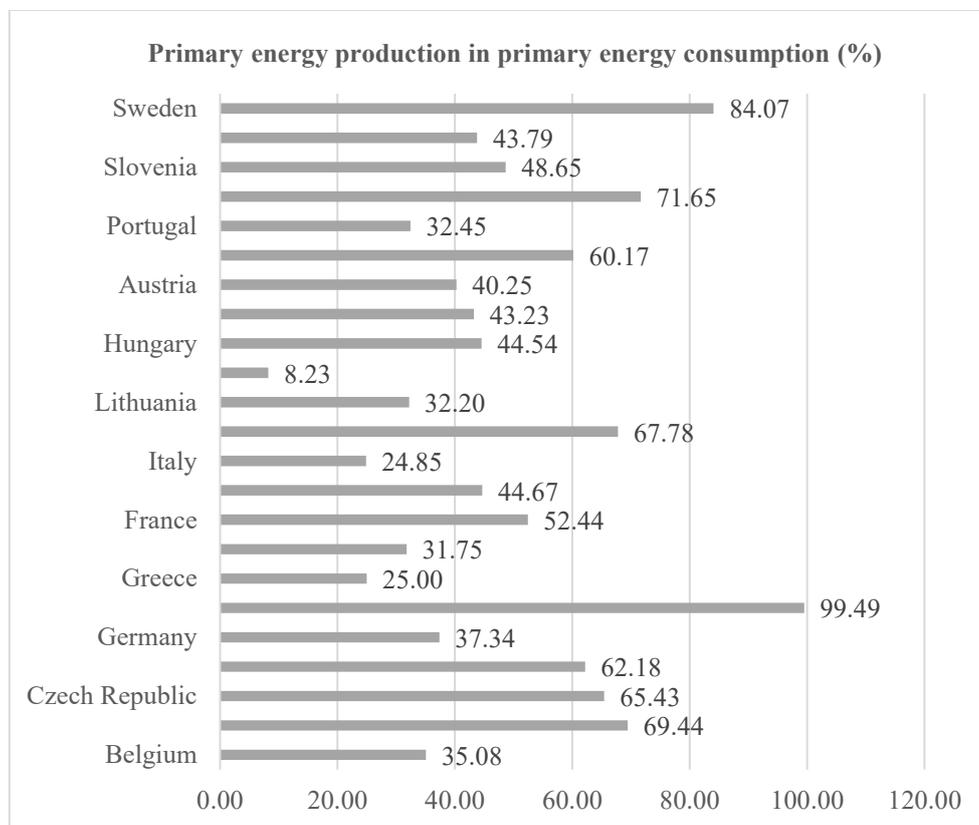


Fig 1. Ranking of countries by groups according to the level of industry and service development and the energy security index during 2020-2022

Source: Own computation. The percentage of Primary energy production in primary energy consumption was calculated from the EUROSTAT database.

Literature Review

Total global demand for electricity is increasing in both developed and developing economies. The increase in fossil fuel consumption has increased by 96% from 1965 to 2021 (Caglar A.E. et al 2022), leading to negative environmental impacts. Fossil fuels have a negative impact on air quality, the environment, health and water resources. Gaseous emissions that can be released into the air due to the consumption of fossil fuels include greenhouse gases such as carbon oxides (carbon monoxide and carbon dioxide), sulfur oxides (sulfur dioxide and

sulfur trioxide), nitrogen oxides (nitrous oxide and nitrogen dioxide), and volatile organic compounds and aerosols such as PM10 particles.

Decarbonising economies means replacing fossil fuels with renewable energy sources. In Europe, renewable energy sources account for 20% of gross final energy consumption, while in Asia, renewable energy sources account for 24%, of which 18% is hydropower (Eurostat, Renewable Energy Statistics, 2020, Elavarasan, R.M., 2019). Replacing fossil fuel infrastructure requires an optimal combination of renewable energy production systems, such as wind turbines, solar panels, hydroelectric power plants, which also requires combined efforts of governments, business entrepreneurs, as well as serious support from the population (Singh, A.k., Idrisi, A.H., 2020, Li, A., Xu, Y., Shiroyama, H., 2019, Pardo-Cueva, M., Davila, G.A., Chamba-Rueda, 2020, Oryani, B., Koo, Y., Rezania, S., Shafiee, A., 2021).

Recent technological advances in renewable energy systems have led to a reduction in both economic costs and environmental impact.

Renewable energy systems can be based on a single source or a combination of multiple sources. A single-source system uses a single power generation option, such as wind, solar thermal, solar photovoltaic, hydro, biomass, etc., in combination with appropriate energy storage. On the other hand, a hybrid power system combines energy storage with two or more power generation options, including renewable and non-renewable sources. In a hybrid power system, there can be different configurations to generate electricity, such as: photovoltaic-wind-diesel, hydro-wind-photovoltaic, biomass-wind-photovoltaic, wind-photovoltaic, and photovoltaic-wind-hydrogen/fuel cell systems.

The main problem of single-source renewable energy systems is that they operate intermittently. To solve this problem, energy storage systems are needed with their advantages and disadvantages, lifetime, storage capacity, environmental compatibility, battery cost, lithium-ion battery safety, high costs of platinum catalysts, etc. (Wu.,F., Maier, J., Yu, Y., 2020, Zhang, H., Sun, C., 2021, Negro,E., Delpeuch, A.B., Vezzu, K., Nawn, G., Bertasi, F., Ansaldo, A., Pellegrini, V., Dembinska, B., Zoladek, S., Miecznikowski, K., et al. 2018, Sun C., Negro, E., Nale, A., Meda. L. et al 2021).

A study by Brodny J et al (2021) assessed the level of development of renewable energy in the member states of the European Union and found that between 2008 and 2018 the average gross production of electricity from renewable energy sources in the European Union increased from 21.18% to 38.16% of total electricity production.

Hache E. (2018) also noted that the spread of renewable energies would complicate global energy geopolitics and energy security issues.

Forecast studies have been conducted for Europe up to 2050 on the feasibility of 100% renewable energy systems. These studies were carried out by Child M. et al (2019) and Hansen K. et al. (2019) and indicate that renewable energy will continue to grow.

Also, the negative effects of solar energy sources are associated with the use of large areas of land, water consumption, habitat loss, and harmful materials used in the production of solar panels (Rabaia M.K.H., et al 2021).

Another issue that may arise in the operation of renewable energy sources is cybersecurity, as many renewable energy projects use advanced ICT solutions and tools and rely heavily on the internet (Tvaronaviciene, M., Pleta, T., et al 2020, Dafalla, Y., Liu, B., Hahn, D.A., et al, 2020, Pleta, T., Tvaronaviciene, M., et al, 2020).

Renewable energy has become an important source of electricity, and more and more investments are being made in wind and solar power projects. However, natural gas is a resource to compensate for problems with fluctuations in sunlight or wind.

Lee et al. (2012) argue that the volatility of natural gas prices is balanced by the costs of investments in renewable energy.

Shrimali and Kniefel (2011) find a significant negative relationship between the share of renewable energy capacity (wind, solar) and total net generation.

Török L. (2025) built a model to determine how GDP/capita, investment rate and energy intensity influence the

evolution of the share of renewable energy. The results of the model show that the investment rate has a positive and significant impact on the increase in the share of renewable energy in EU member countries. It was also found that energy efficiency is not a direct factor in the growth of renewable energy.

Another mathematical model was designed with differential equations to study and analyse clean energy. It is found that wind energy is the most important source of clean energy for cities. Solar energy contributes to obtaining clean energy for homes and schools at a lower cost.

Another study (Mohammadi H., Saghaian S., Gharibi, 2023) showed that renewable and non-renewable energy consumption have a significant positive impact on economic growth in developed and developing countries.

Kocak E., Ulug E.E, Oralhan B. (2023) built an econometric model to estimate the impact of electricity production from different sources, coal, natural gas, hydropower, nuclear and renewable energy, on energy poverty and CO2 emissions. Thus, it was found that electricity production from coal contributes to the increase of GHG emissions in middle and upper-income countries but has no significant effect on energy poverty. Also, the effect of electricity production from natural gas and nuclear energy production on GHG emissions and energy poverty is mixed. Electricity from nuclear energy has an effect of reducing energy poverty in middle and low-income countries and has no significant effect in high-income countries. Electricity production from renewable and hydro sources contributes significantly to the reduction of GHG emissions and energy poverty.

Correlation between gross inland energy consumption from renewable and non-renewable sources

Our goal is to analyse the gross inland energy consumption of EU member countries and determine which energy from non-renewable sources is being replaced by energy from renewable sources. The countries considered are: Romania, Bulgaria, Italy, Greece, Croatia, Poland, Hungary, Slovakia, Spain, Czech Republic, Belgium, Portugal, France, Germany, Slovenia, Lithuania, Estonia, Latvia, Austria, Luxembourg, Denmark, Netherlands and Sweden.

Gross inland energy consumption is the amount of energy, expressed in oil equivalent, consumed within the national territory of a country. Gross inland energy consumption corresponds to the sum of final consumption, distribution losses, transmission losses, and transformation losses. This indicator is a sustainable development indicator, chosen to assess progress towards the objectives and targets of the EU Sustainable Development Strategy.

To determine the correlation coefficient, we took into account the period 2013-2023. The data used are taken from the Eurostat database.

The substitution of energy sources among themselves was assessed at the 5% significance level. The correlation coefficient r is calculated from a sample with n elements, $n=11$ - the number of years. The magnitude of the degree of freedom is f ($f = n-2 = 9$). To calculate significance, we use the T-distribution: $T = r \cdot \sqrt{\frac{f}{1-r^2}} \rightarrow r = \pm \sqrt{\frac{T^2}{T^2+f}}$.

For $f = 9$ $T_{0,95} = 2,262 \rightarrow r_{1,2} = \pm 0,602$. Positive correlation at the 5% significance level occurs at r values > 0.602 , and negative correlation occurs at r values < -0.602 . Correlation analysis shows us the type of energy each country under consideration relies on.

The Table 1 shows that most EU member states are replacing energy from solid fossil fuels with energy from renewable sources (gross inland consumption of renewable energy is negatively correlated with gross inland consumption of energy from solid fossil fuels): Germany (-0.78); Estonia (-0.84); Belgium (-0.9); Bulgaria (-0.88); Czech Republic (-0.92); Denmark (-0.95); Greece (-0.91); France (-0.69); Italy (-0.85); Latvia (-0.75); Lithuania (-0.78); Luxembourg (-0.9); Netherlands (-0.71); Austria (-0.63); Poland (-0.85); Romania (-0.76); Slovakia (-0.93); Sweden (-0.85).

Countries that are replacing energy from natural gas sources with energy from renewable sources (gross inland consumption of renewable energy is negatively correlated with gross inland consumption of energy from natural gas) are: Denmark (-0.89); Estonia (-0.8); Latvia (-0.7); Lithuania (-0.88); Luxembourg (-0.56).

It is noted that Poland (0.92) still relies on electricity from natural gas (gross inland consumption of renewable energy is positively correlated with gross inland consumption of energy from natural gas).

Countries that are replacing energy from oil or oil products with energy from renewable sources (gross inland consumption of renewable energy is negatively correlated with gross inland consumption of energy from oil or oil products) are: Belgium (-0.7); Estonia (-0.95), Greece (-0.79); Spain (-0.68); France (0.78); Italy (-0.86); Netherlands (-0.76); Sweden (-0.91).

It is noted that Lithuania (0.86), Poland (0.73) and Bulgaria (0.75) still rely on energy obtained from sources based on oil or oil products.

Countries that are replacing nuclear fuel with renewable sources for electricity production are: Germany (-0.93), France (-0.77), and Romania (-0.75).

Table 1: Correlation between gross inland consumption of energy from renewable sources and that from non-renewable resources for EU member countries

| Country | Renewable sources and biofuels – Solid fossil fuels | Renewable sources and biofuels – Natural gas | Renewable sources and biofuels – Oil and petroleum products | Renewable sources and biofuels – Nuclear |
|----------------|---|--|---|--|
| Belgium | -0.90 | 0.04 | -0.7 | -0.41 |
| Bulgaria | -0.88 | 0.19 | 0.75 | 0.58 |
| Czech Republic | -0.92 | -0.2 | 0.09 | -0.009 |
| Denmark | -0.95 | -0.89 | -0.62 | |
| Germany | -0.78 | 0.28 | -0.53 | -0.93 |
| Estonia | -0.84 | -0.8 | -0.95 | |
| Greece | -0.91 | 0.58 | -0.79 | |
| Spain | -0.45 | -0.36 | -0.68 | -0.53 |
| France | -0.69 | -0.16 | -0.78 | -0.77 |
| Croatia | -0.5 | -0.14 | -0.45 | |
| Italy | -0.85 | -0.45 | -0.86 | |
| Latvia | -0.75 | -0.7 | 0.51 | |
| Lithuania | -0.78 | -0.88 | 0.89 | |
| Luxembourg | -0.9 | -0.86 | -0.43 | |
| Hungary | -0.09 | -0.44 | -0.46 | -0.18 |
| Netherlands | -0.71 | -0.25 | -0.76 | 0.16 |
| Austria | -0.63 | -0.31 | -0.33 | |
| Poland | -0.85 | 0.92 | 0.73 | |
| Portugal | -0.4 | 0.34 | -0.37 | |
| Romania | -0.76 | -0.8 | 0.4 | -0.75 |
| Slovenia | -0.26 | -0.31 | -0.37 | -0.04 |
| Slovakia | -0.93 | -0.42 | 0.43 | 0.14 |
| Sweden | -0.85 | -0.24 | -0.91 | -0.3 |

Source: Own computation

Cluster analysis of the structure of primary energy production from renewable and non-renewable sources

In our case, the purpose of the cluster analysis is to classify the EU member states according to the similarities in their electricity production structures. The cluster analysis is performed for the years 1990 and 2022 and uses data from the EUROSTAT database.

To build the clusters, we use the K-means (Jain, A. K., 2010) algorithm developed by MacQueen. This algorithm allows dividing data points into distinct groups by iteratively minimising the variation within the cluster by optimally placing the centroid. The algorithm is implemented in the R language.

The application of the clustering algorithm led to the following results:

For the year 1990:

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Cluster means:
  Solid.fossil.fuels  Natural.gas  Oil.and.petroleum.products
1      4616.00000    332.50000    115.50000
2      171.05000     17.80000     15.70000
3      327.00000    105.00000    146.00000
4       64.23077     31.32846     43.00769
5     1519.00000      8.00000      7.00000
6       0.00000    2282.00000    174.00000
7     178.00000     773.00000    261.00000

  Renewable.soures.and.biofuels  Nuclear
1      144.00000    829.50000
2      254.00000    594.33333
3     633.00000   3392.00000
4      48.51538     37.23077
5      47.00000    135.00000
6      31.00000     37.00000
7     166.50000      0.00000

Clustering vector:
  Belgium      Bulgaria  Czech Republic      Denmark      Germany
      2          4          5          4          1
  Estonia      Greece      Spain      France      Croatia
      4          4          2          3          4
      Italy      Latvia      Lithuania      Luxembourg      Hungary
      7          4          4          4          4
  Netherlands  Austria      Poland      Portugal      Romania
      6          4          1          4          7
  Slovenia      Slovakia      Sweden
      4          4          2

```

Each cluster was assigned a name that reflects its specific energy production structure. The groups of countries obtained from the cluster analysis of the structure of primary energy production for 1990 are characterised as follows:

Cluster1: Solid Fossil Fuel-Nuclear-Natural Gas

This cluster contains countries that show a strong dependence on solid fossil fuel and nuclear fuel as primary energy sources. The countries included in the cluster are: Germany and Poland.

Cluster 2: Nuclear – Renewables

This cluster comprises the group of countries that rely primarily on nuclear fuels and secondarily on renewables and biofuels as their primary energy sources. The countries belonging to this cluster are: Belgium, Sweden and Spain.

Cluster 3: Nuclear

This cluster includes France, which relies on nuclear fuels as its main primary energy source. However, it also uses other primary energy sources, but in small quantities.

Cluster 4: Solid Fossil Fuel – Renewable

This cluster includes countries that have few resources and rely mainly on their import. The following countries belong to this cluster: Lithuania, Latvia, Luxembourg, Portugal, Slovenia, Slovakia, Austria, Greece, Croatia, Hungary, Denmark, Bulgaria and Estonia. Estonia is heavily dependent on oil shale, which has high carbon emissions.

Cluster 5: Solid Fossil Fuel-Nuclear

This cluster includes countries that rely primarily on solid fossil fuels and secondarily on nuclear fuels as their primary energy sources. The Czech Republic is part of this cluster.

Cluster 6: Natural Gas

This cluster includes countries that show a strong dependence on natural gas as a primary energy source. The Netherlands is part of this cluster.

Cluster 7: Natural Gas-Oil

This cluster includes countries that indicate a strong dependence on natural gas, oil and petroleum products. Romania and Italy belong to this category. It should be noted that in 1990, Romania also relied quite heavily on solid fossil fuels.

For the year 2022:

| Cluster means: | | | | |
|--------------------------------|--------------------|----------------|----------------------------|-----------|
| | Solid.fossil.fuels | Natural.gas | Oil.and.petroleum.products | |
| 1 | 15.11111 | 8.572222 | | 7.922222 |
| 2 | 0.00000 | 35.733333 | | 67.100000 |
| 3 | 1447.00000 | 143.500000 | | 78.000000 |
| 4 | 58.00000 | 427.000000 | | 78.500000 |
| 5 | 240.66667 | 2.676667 | | 1.033333 |
| 6 | 0.00000 | 24.666667 | | 52.333333 |
| 7 | 0.00000 | 0.700000 | | 33.000000 |
| Renewable.sources.and.biofuels | | Nuclear | | |
| 1 | | 90.55556 | 43.77778 | |
| 2 | | 959.33333 | 386.33333 | |
| 3 | | 1314.50000 | 187.00000 | |
| 4 | | 301.50000 | 79.00000 | |
| 5 | | 176.00000 | 316.00000 | |
| 6 | | 307.00000 | 0.00000 | |
| 7 | | 1188.00000 | 3215.00000 | |
| Clustering vector: | | | | |
| Belgium | Bulgaria | Czech Republic | Denmark | Germany |
| 5 | 5 | 5 | 6 | 3 |
| Estonia | Greece | Spain | France | Croatia |
| 1 | 1 | 2 | 7 | 1 |
| Italy | Latvia | Lithuania | Luxembourg | Hungary |
| 2 | 1 | 1 | 1 | 1 |
| Netherlands | Austria | Poland | Portugal | Romania |
| 4 | 6 | 3 | 6 | 4 |
| Slovenia | Slovakia | Sweden | | |
| 1 | 1 | 2 | | |

Cluster 1: Renewables – Nuclear

This cluster includes countries that are characterised by a primary energy structure dominated by renewable resources and significant nuclear contributions. This mix presents a strategic approach that prioritises a mix of low-carbon energy sources. The following countries belong to this category: Latvia, Greece, Croatia, Hungary, Estonia, Slovenia, Slovakia, Lithuania and Luxembourg. It should be noted that Estonia also continues to rely on oil shale, remaining a unique case.

Cluster 2: Renewables-Nuclear-Oil and Petroleum Products

This cluster includes countries that have a primary energy structure dominated by renewables and nuclear fuels, but there is also a significant share of energy from oil and petroleum products. Sweden, Italy and Spain are part of this cluster.

Cluster 3: Solid Fossil Fuel-Renewables

This cluster includes countries that rely on solid fossil fuels as their primary energy source, but have a significant share of renewable energy. Germany and Poland are part of this cluster.

Cluster 4: Natural Gas – Renewables

This cluster includes countries with a primary energy structure dominated by natural gas and renewable energy. These countries also use nuclear fuel and oil, and petroleum products as primary energy sources, but to a lesser extent. Romania and the Netherlands belong to this category.

Cluster 5: Nuclear - Solid Fossil Fuel – Renewables

This cluster includes countries that rely on nuclear fuel, solid fossil fuel, and renewable energy. The Czech Republic, Belgium, and Bulgaria belong to this category.

Cluster 6: Renewables

This cluster includes countries that have a primary energy structure dominated by renewable sources. Such a structure underlines the commitment of these countries to low-CO2 energy production. The following countries belong to this cluster: Denmark, Portugal and Austria.

Cluster 7: Nuclear-Renewables

This cluster includes countries that show a strong dependence on nuclear fuel as a primary energy source, but also have a significant share of renewable energy. France is part of this category.

Analysing the cluster group from 1990 and 2022, several conclusions can be drawn:

- There is a diversification of primary energy sources and a decrease in the consumption of solid fossil fuels.
- Renewable energy sources have gained significant importance in many countries.
- Nuclear energy maintains a stable position. However, in Germany, decisions have been made to phase out nuclear energy.
- Natural gas has become more important in countries that have reduced their dependence on solid fossil fuels.

The increase in the importance of natural gas was due to its lower carbon emissions compared to those from solid fossil fuels. Also, the production costs of using natural gas as a primary energy source are much lower than those of using solid fossil fuels, especially in the context of the carbon taxes proposed by the European Union.

Cluster analysis of EU member countries according to the share of renewable sources in total electricity production from renewable sources and biofuels

Our goal is to assess changes in the use of renewable sources for electricity production in EU countries during the period 2015-2022.

To create clusters, we consider the following variables: the share of electricity production from hydroelectric power plants in total electricity production from renewable sources and biofuels; the share of electricity production from wind power plants in the total electricity production from renewable sources and biofuels; the share of electricity production from solar energy in total electricity production from renewable sources and biofuels; the share of electricity production from biofuels (primary solid biofuels, pure biofuels and other liquid biofuels) in total electricity production from renewable sources and biofuels; the share of electricity production from biogas in total electricity production from renewable sources and biofuels; the share of electricity production from municipal waste in the total electricity production from renewable sources and biofuels.

All data used for the study were taken from the IRENA 2024 database for the years 2015, 2019 and 2022 and Tables 2, 3 and 4 present the values of the variables.

Table 2: Share of electricity production of each renewable source in total renewable energy production in 2015

| Country | from hydro sources (%) | from wind sources (%) | from solar sources (%) | from biofuels (%) | from biogas (%) | from municipal waste (%) |
|----------------|------------------------|-----------------------|------------------------|-------------------|-----------------|--------------------------|
| Belgium | 8.63 | 33.93 | 18.61 | 27.71 | 5.84 | 5.29 |
| Bulgaria | 66.43 | 15.69 | 14.94 | 1.64 | 1.30 | 0.00 |
| Czech Republic | 28.47 | 5.31 | 20.99 | 20.20 | 24.21 | 0.81 |
| Denmark | 0.09 | 71.18 | 3.04 | 18.74 | 2.32 | 4.63 |
| Germany | 12.43 | 40.24 | 19.33 | 8.60 | 16.52 | 2.88 |
| Estonia | 1.66 | 44.03 | 0.37 | 47.29 | 3.08 | 3.57 |
| Greece | 41.27 | 31.01 | 26.17 | 0.01 | 1.54 | 0.00 |

| | | | | | | |
|-------------|-------|-------|-------|-------|-------|-------|
| Spain | 20.65 | 50.80 | 14.27 | 4.93 | 1.01 | 0.79 |
| France | 61.60 | 21.80 | 7.89 | 4.78 | 1.87 | 2.06 |
| Croatia | 85.42 | 10.37 | 0.74 | 1.16 | 2.31 | 0.00 |
| Italy | 43.12 | 13.63 | 21.08 | 10.27 | 7.54 | 2.15 |
| Latvia | 66.98 | 5.29 | 0.00 | 13.61 | 14.08 | 0.00 |
| Lithuania | 42.76 | 33.82 | 3.05 | 15.03 | 3.59 | 1.75 |
| Luxembourg | 6.81 | 20.16 | 4.10 | 54.35 | 8.52 | 6.05 |
| Hungary | 0.24 | 48.39 | 7.11 | 24.98 | 6.65 | 12.64 |
| Netherlands | 79.10 | 9.43 | 1.83 | 7.82 | 1.24 | 0.59 |
| Austria | 10.15 | 46.51 | 0.24 | 39.22 | 3.88 | 0.00 |
| Poland | 25.31 | 47.63 | 3.27 | 11.53 | 1.21 | 1.20 |
| Portugal | 25.69 | 26.96 | 7.56 | 1.77 | 0.23 | 0.00 |
| Romania | 29.74 | 0.14 | 6.29 | 3.10 | 3.03 | 0.00 |
| Slovenia | 41.75 | 0.10 | 8.38 | 18.56 | 8.96 | 0.36 |
| Slovakia | 15.93 | 15.92 | 0.09 | 10.49 | 0.01 | 1.71 |

Source: Own computation

Table 3: Share of electricity production of each renewable source in total renewable energy production in 2019

| Country | from hydro sources (%) | from wind sources (%) | from solar sources (%) | from biofuels (%) | from biogas (%) | from municipal waste (%) |
|----------------|------------------------|-----------------------|------------------------|-------------------|-----------------|--------------------------|
| Belgium | 5.56 | 45.96 | 20.04 | 19.91 | 4.46 | 4.07 |
| Bulgaria | 42.38 | 16.50 | 17.75 | 19.92 | 2.89 | 0.55 |
| Czech Republic | 28.03 | 6.18 | 20.44 | 22.10 | 22.32 | 0.93 |
| Denmark | 0.07 | 67.19 | 4.01 | 22.12 | 2.60 | 4.01 |
| Germany | 10.19 | 49.98 | 17.62 | 6.82 | 13.08 | 2.31 |
| Estonia | 0.86 | 31.13 | 3.35 | 59.99 | 1.77 | 2.90 |
| Greece | 25.09 | 44.99 | 27.43 | 0.15 | 2.34 | 0.00 |
| Spain | 19.92 | 55.10 | 14.96 | 4.62 | 0.90 | 0.76 |
| France | 51.62 | 29.11 | 10.20 | 5.08 | 2.17 | 1.82 |
| Croatia | 70.96 | 17.55 | 0.99 | 5.71 | 4.80 | 0.00 |
| Italy | 41.56 | 17.44 | 20.46 | 9.74 | 7.14 | 2.04 |
| Latvia | 66.04 | 4.82 | 0.09 | 18.01 | 11.03 | 0.00 |
| Lithuania | 30.39 | 48.06 | 2.92 | 12.15 | 4.94 | 1.54 |
| Luxembourg | 4.55 | 15.16 | 31.13 | 39.63 | 6.67 | 2.85 |
| Hungary | 0.15 | 46.31 | 21.73 | 19.83 | 3.60 | 8.38 |
| Netherlands | 75.73 | 12.76 | 2.92 | 6.93 | 1.05 | 0.61 |
| Austria | 9.22 | 58.01 | 2.73 | 25.28 | 4.36 | 0.40 |
| Poland | 26.42 | 49.87 | 4.90 | 11.31 | 0.96 | 1.27 |
| Portugal | 27.00 | 27.49 | 7.22 | 1.83 | 0.22 | 0.00 |
| Romania | 26.83 | 0.12 | 6.01 | 3.10 | 1.87 | 0.00 |
| Slovenia | 38.06 | 0.09 | 8.87 | 17.44 | 8.04 | 0.44 |
| Slovakia | 16.58 | 20.06 | 0.69 | 13.16 | 0.02 | 1.79 |

Source: Own computation

Table 4: Share of electricity production of each renewable source in total renewable energy production in 2022

| Country | from hydro sources (%) | from wind sources (%) | from solar sources (%) | from biofuels (%) | from biogas (%) | from municipal waste (%) |
|----------------|------------------------|-----------------------|------------------------|-------------------|-----------------|--------------------------|
| Belgium | 6.14 | 46.06 | 25.64 | 14.63 | 3.78 | 3.76 |
| Bulgaria | 39.64 | 15.50 | 21.65 | 21.23 | 1.98 | 0.00 |
| Czech Republic | 25.94 | 5.39 | 22.09 | 23.46 | 22.02 | 1.09 |
| Denmark | 0.05 | 64.42 | 7.46 | 22.68 | 1.94 | 3.45 |
| Germany | 8.98 | 47.57 | 22.98 | 6.06 | 12.28 | 2.12 |
| Estonia | 0.79 | 23.05 | 20.57 | 53.97 | 0.21 | 1.41 |
| Greece | 17.71 | 48.17 | 31.60 | 0.23 | 2.29 | 0.00 |
| Spain | 15.94 | 49.69 | 28.31 | 4.60 | 0.78 | 0.68 |
| France | 42.21 | 31.43 | 16.53 | 5.62 | 2.47 | 1.75 |
| Croatia | 61.98 | 23.77 | 1.69 | 8.01 | 4.55 | 0.00 |
| Italy | 30.15 | 20.40 | 28.00 | 9.73 | 7.81 | 2.31 |
| Latvia | 72.69 | 5.02 | 1.08 | 14.59 | 6.61 | 0.00 |
| Lithuania | 27.30 | 40.43 | 9.14 | 14.71 | 4.25 | 4.17 |
| Luxembourg | 2.29 | 7.83 | 60.76 | 23.41 | 4.04 | 1.67 |
| Hungary | 0.08 | 42.35 | 33.80 | 17.70 | 1.67 | 4.40 |
| Netherlands | 70.92 | 13.10 | 6.86 | 7.41 | 1.07 | 0.64 |
| Austria | 6.26 | 51.42 | 21.60 | 16.31 | 3.62 | 0.79 |
| Poland | 27.88 | 45.09 | 11.98 | 13.12 | 0.89 | 1.05 |
| Portugal | 28.23 | 29.64 | 8.42 | 2.36 | 0.38 | 0.00 |
| Romania | 32.98 | 0.15 | 15.88 | 4.15 | 2.46 | 0.00 |
| Slovenia | 43.49 | 0.07 | 11.16 | 18.88 | 6.72 | 0.86 |
| Slovakia | 13.87 | 28.13 | 1.69 | 11.07 | 0.01 | 1.49 |

Source: Own computation

The R language was used to solve the algorithm.

The country groups obtained from the cluster analysis of the share of electricity production of each renewable source in the total renewable energy production for the years 2015, 2019 and 2022 are characterized as follows:

For the year 2015:

```

Cluster means:
  hydro      wind      solar biofuels  biogas municipal.waste
1 33.591250 15.86125 11.701250  9.92875 6.138750  0.847500
2 71.906000 12.51600  5.080000  5.80200 4.160000  0.530000
3  9.552222 44.76333  7.815556 26.37222 5.447778  4.116667

```

```

Clustering vector:
  Belgium      Bulgaria Czech Republic      Denmark      Germany
                3                2                1                3                3
  Estonia      Greece                Spain      France      Croatia
                3                1                3                2                2
  Italy      Latvia      Lithuania      Luxembourg      Hungary
                1                2                1                3                3
  Netherlands      Austria      Poland      Portugal      Romania
                2                3                3                1                1
  Slovenia      Slovakia
                1                1

```

Cluster 1: Hydro

This cluster includes countries that rely on the renewable production of electricity from hydro sources. The following countries belong to this cluster: Romania, Portugal, Slovenia, Slovakia, Italy, Lithuania, Greece, and the Czech Republic.

Cluster 2: Hydro – Wind

The cluster includes countries that have renewable production of electricity, mainly from hydro and wind sources. Bulgaria, France, Croatia, Latvia, and the Netherlands belong to this cluster.

Cluster 3: Wind - Biofuels

The cluster includes countries that have a structure of renewable production of electricity, mainly from wind sources and biofuels. The following countries belong to this cluster: Belgium, Denmark, Germany, Estonia, Spain, Luxembourg, Hungary, Austria, and Poland.

For the year 2019:

```

Cluster means:
  hydro      wind      solar biofuels  biogas municipal.waste
1 66.087500 16.06000  3.55000  8.93250 4.762500  0.6075000
2  3.401667 43.96000 13.83167 31.12667 3.910000  3.7683333
3 22.402000 49.60000 13.56600  7.01000 4.444000  1.1760000
4 31.491429 12.55429 11.63429 12.47000 6.071429  0.8214286

```

```

Clustering vector:
  Belgium      Bulgaria Czech Republic      Denmark      Germany
                2                4                4                2                3
  Estonia      Greece                Spain      France      Croatia
                2                3                3                1                1
  Italy      Latvia      Lithuania      Luxembourg      Hungary
                4                1                3                2                2
  Netherlands      Austria      Poland      Portugal      Romania
                1                2                3                4                4
  Slovenia      Slovakia
                4                4

```

Cluster 1: Hydro – Wind

This cluster includes countries that rely on the renewable production of electricity from hydro sources and wind sources. The countries that belong to this category are: France, Croatia, Latvia, Netherlands.

Cluster 2: Wind – Biofuels

The cluster includes countries that have a structure of renewable production of electricity, mainly from wind sources and biofuels. The countries are: Estonia, Belgium, Denmark, Luxembourg, Hungary, Austria.

Cluster 3: Wind- Hydro – Solar

This cluster includes countries that rely on the renewable production of electricity from wind sources, hydro sources and solar sources. The countries that belong to this category are: Germany, Greece, Spain, Lithuania, and Poland.

Cluster 4: Hydro

This cluster includes countries that rely on the renewable production of electricity from hydro sources. The following countries belong to this cluster: Bulgaria, Romania, Portugal, Czech Republic, Italy, Slovenia, and Slovakia.

For the year 2022:

```

Cluster means:
  hydro      wind      solar biofuels  biogas municipal.waste
1 28.273333 32.520000 12.62667  9.43500  2.635000    1.795000
2  9.673333 12.090000 34.47333 33.61333  8.756667    1.390000
3  7.880000 49.954286 24.48429 11.74429  3.765714    2.171429
4 53.616667  9.601667  9.72000 12.37833  3.898333    0.250000

Clustering vector:
  Belgium      Bulgaria Czech Republic      Denmark      Germany
                3          4          2          3          3
  Estonia      Greece      Spain      France      Croatia
                2          3          3          1          4
  Italy      Latvia      Lithuania      Luxembourg      Hungary
                1          4          1          2          3
  Netherlands      Austria      Poland      Portugal      Romania
                4          3          1          1          4
  Slovenia      Slovakia
                4          1

```

Cluster 1: Hydro -Wind

This cluster includes countries that rely on the renewable production of electricity from hydro sources and wind sources. The country that belong to this category are: France, Italy, Lithuania, Poland, and Portugal.

Cluster 2: Solar - Biofuels

The cluster includes countries that have a structure of renewable production of electricity, mainly from solar sources and biofuels. The countries are: Czech Republic, Estonia, and Luxembourg.

Cluster 3: Wind

This cluster includes countries that rely on the renewable production of electricity from wind sources. The country that belong to this category are: Belgium, Denmark, Germany, Greece, Spain, Austria, and Hungary.

Cluster 4: Hydro

This cluster includes countries that rely on the renewable production of electricity from hydro sources. The following countries belong to this cluster: Bulgaria, Romania, Croatia, Latvia, the Netherlands, and Slovenia.

Conclusions

The purpose of the current paper is to evaluate the changes brought about in the production of electricity from the point of view of energy mixes. Thus, it was observed:

- Diversification of primary energy sources and a decrease in the consumption of solid fossil fuels;
- Renewable energy sources gained significant importance in many groups of countries;
- Nuclear energy maintains a stable position. However, in Germany, decisions were taken to gradually eliminate nuclear energy.

- Natural gas became more important in countries that reduced their dependence on solid fossil fuels. The increase in the importance of natural gas was due to its lower carbon emissions compared to those of solid fossil fuels.

To assess changes in the use of renewable sources for electricity production, clusters were formed among EU member countries based on their share of renewable sources in total renewable electricity production and biofuels. Thus, it was found that most countries have a significant share of renewable energy from hydro and wind sources in their electricity production from renewable sources.

The policy related to the use of renewable sources is a key element of the energy policy implemented by the EU.

However, without significant advances in energy storage technologies and grid infrastructure, excessive reliance on renewables could lead to instability in energy supply during peak demand or adverse weather conditions.

In conclusion, efficient and diversified primary energy production is crucial for ensuring a country's energy security, and energy policies should focus on increasing domestic production, diversifying sources, and investing in modern energy technologies.

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