Czech University of Life Sciences Prague

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Master's Thesis

Statistical analysis of renewable energy indicators in the European Union

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Thesis title

Statistical analysis of renewable energy indicators in the European Union

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Objectives of thesis

Renewable energy has become an essential topic in the energy sector in recent years due to its potential to reduce carbon emissions and provide sustainable energy sources.
Many countries worldwide strive to increase their renewable energy production to achieve climate change targets and contribute to the green economy.
The European Union has taken new measures toward energy consumption.
The main aim of the thesis is to assess the development of the EU's production and consumption of renewable energy through statistical analysis of their key indicators.

Methodology

The practical part will be based on multivariate statistical models, such as factor analysis, principal component analysis or cluster analysis. The primary data source for this thesis is EUROSTAT.

The proposed extent of the thesis

60 – 80 pages

Keywords

Renewable energy, production, consumption, economy, European Union, multivariate statistical analysis.

Recommended information sources

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Declaration

I declare that I have worked on my master's thesis titled " Statistical analysis of renewable energy indicators in the European Union" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 30.03.2024 ______________________________

Acknowledgement

I would like to express my sincere gratitude to the many people who supported and helped me during the past two years while I worked on this thesis.

First, I thank Prof. Ing. Tomáš Hlavsa, Ph.D., for his excellent guidance and continuous scientific support. I am extremely grateful for the opportunity you gave me to start a scientific career.

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Last but not least, I am grateful for the support I received from my family during the stressful times of long days of classes and exam periods. Moreover, financial support was tremendous and helped me continue my master's studies.

Statistical analysis of renewable energy indicators in the European Union

Abstract

Renewable energy has become an essential topic in the energy sector in recent years due to its potential to reduce carbon emissions and provide sustainable energy sources. Many countries worldwide strive to increase their renewable energy production to achieve climate change targets and contribute to the green economy. The European Union has taken new measures toward energy consumption. The main aim of the thesis is to assess the development of the EU's production and consumption of renewable energy through statistical analysis of their key indicators. The practical part was based on collection of data from the EUROSTAT databases. The total number of indicators used in our study is 14 variables which are categorized into three categories; indicators related to production (5), indicators related to consumption (5) and indicators related to economy (4). The data underwent multivariate statistical models, including exploratory data analysis in the first stage, principal component analysis (PCA) in the second stage and cluster analysis in the last stage. The exploratory data analysis showed the contribution of each country in individual indicators and visualized the countries in a sorted view. The principal component analysis avoided the dataset with high variability and reduced the indicator to ten components. Those ten components were utilized for cluster analysis which classified all 27 EU states into 8 clusters. Germany is the main contributor in renewable energy production with big investment followed by France. Sweden and Finland showed the best practice in utilizing energy produced in different sectors of industry and life. Luxembourg shows the least improvement toward a complete rely on the renewable energy. In conclusion, all analysis done through different stages showed a high degree of shifting from finite sources of energy, such as fossil fuels and oil to more renewable sources as wind and solar power. Therefore, most EU countries are performing well in the regard of clean and affordable energy sectors which is crucial for the current environmental issues that the whole world is facing as global warming.

Keywords: Renewable energy, production, consumption, economy, European Union, multivariate statistical analysis, Principal component analysis, Cluster Analysis, Data visualization, Exploratory data analysis, Data standardization.

Statistická analýza ukazatelů obnovitelné energie v Evropské unii

Abstrakt

Obnovitelná energie se v posledních letech stala zásadním tématem v energetickém sektoru díky svému potenciálu snižovat emise uhlíku a poskytovat udržitelné zdroje energie. Mnoho zemí na celém světě se snaží zvýšit svou výrobu energie z obnovitelných zdrojů, aby dosáhly cílů v oblasti změny klimatu a přispěly k zelené ekonomice. Evropská unie přijala nová opatření ke spotřebě energie. Hlavním cílem práce je zhodnotit vývoj výroby a spotřeby energie z obnovitelných zdrojů v EU prostřednictvím statistické analýzy jejich klíčových ukazatelů. Praktická část byla založena na sběru dat z databází EUROSTATU. Celkový počet indikátorů použitých v naší studii je 14 proměnných, které jsou kategorizovány do tří kategorií; ukazatele související s výrobou (5), ukazatele týkající se spotřeby (5) a ukazatele související s ekonomikou (4). Data prošla vícerozměrnými statistickými modely, včetně průzkumné analýzy dat v první fázi, analýzy hlavních komponent (PCA) ve druhé fázi a shlukové analýzy v poslední fázi. Průzkumná analýza dat ukázala příspěvek každé země v jednotlivých ukazatelích a vizualizovala země v seřazeném zobrazení. Analýza hlavních komponent se vyhnula souboru dat s vysokou variabilitou a redukovala indikátor na deset komponent. Těchto deset komponent bylo použito pro shlukovou analýzu, která klasifikovala všech 27 států EU do 8 shluků. Německo je hlavním přispěvatelem do výroby obnovitelné energie s velkými investicemi následované Francií. Švédsko a Finsko ukázaly osvědčené postupy při využívání energie vyrobené v různých odvětvích průmyslu a života. Lucembursko vykazuje nejmenší zlepšení směrem k úplnému spoléhání se na obnovitelné zdroje energie. Závěrem lze říci, že všechny analýzy provedené v různých fázích ukázaly vysoký stupeň přechodu od omezených zdrojů energie, jako jsou fosilní paliva a ropa, k obnovitelným zdrojům, jako je větrná a solární energie. Většina zemí EU si proto vede dobře, pokud jde o sektory čisté a cenově dostupné energie, což je zásadní pro současné ekologické problémy, kterým čelí celý svět jako globální oteplování.

Klíčová slova: Obnovitelná energie, výroba, spotřeba, ekonomika, Evropská unie, vícerozměrná statistická analýza, Analýza hlavních složek, Shluková analýza, Vizualizace dat, Průzkumná analýza dat, Standardizace dat.

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1. Introduction

Renewable energy sources (RES) provide a sustainable alternative to fossil fuels in the face of depleting reserves and climate change. They offer a clean and virtually limitless energy source by harnessing the sun, wind, water, and geothermal heat. Their eco-friendly attributes make RES the most favorable alternative to conventional sources. As a result, many nations and regions are implementing proactive strategies to increase their capacity for RES (Lian et al., 2019).

The European Union (EU) has taken significant measures to address the pressing issue of climate change by tackling the surge in emissions of climate-altering atmospheric pollutants, such as CO2 and CH4. The Renewable Energy Directive (RED II), negotiated in 2018, forms a crucial part of the EU's plan to achieve energy self-sufficiency and promote the growth of renewable energy sectors. The RED II directive has introduced several changes, including the new target of generating 27% of total energy from renewable sources across the EU by 2030, superseding the previous 20% by 2020 (Segreto et al., 2020).

The European Green Deal proposed during the UN COP25 climate summit in Madrid, Spain, in December 2019, is a highly ambitious strategy to tackle climate change. The deal represents the EU's commitment to reducing greenhouse gas emissions and transitioning towards a more sustainable future (Brodny et al., 2020).

Recently, there has been a crucial debate among policymakers and researchers regarding the complex relationship between RES and the various factors that influence its generation and usage in EU countries. The main goal of these discussions is to identify ways to improve the production and adoption of renewable energy across all EU member states (Saint Akadiri et al., 2019).

Assessing how each EU member state implements RED II and the European Green Deal is crucial. This will help determine which countries are progressing towards achieving their environmental goals and which ones need to step up their efforts. By evaluating these initiatives at the national level, we can better understand their impact on reducing greenhouse gas emissions and promoting renewable energy sources. This knowledge can inform policies and strategies supporting a more sustainable future for all.

2. Objectives and Methodology

2.1 Objectives

The aim is to understand the trends of production and consumption of renewable energy in EU countries with emphasis on various indicators attributed to RES.

2.2 Methodology

Collection of data relevant to the research interest is the main asset. The source of those data is the statistical office of the European Union (EUROSTAT). The benefit of using EUROSTAT is the grouping of data into individual indicators. The main workflow is the processing and statistical analysis of the obtained data. The statistical analysis is conducted using SAS software.

The workflow is summarized as follows.

Exploratory data analysis	- Selection of indicators - Information about the selected indicators - Collection of the latest available data of each indicator
Principle component analysis	- Reducing the total number of indicators collected and processed during the exploratory data analysis (known as components) - Statistical selection of the components that are most relevant for the cluster analysis step
Cluster analysis	- Divide EU states into clusters. - The clusters are different from each other. - Members of each cluster share high degree of similarity
Data visualization	- Graphical representation of datasets - Aims to o Understand complex information. o Identify pattern, trends and relationships

Table 1 Methodological sequence of analyzes (source: own processing)

2.2.1 Exploratory data analysis

The aim of this step is to select the indicators and check its suitability for further complex and deeper processing and statistical analysis. It would avoid execution of statistical calculation without understanding the collected data and deeper connections (Meloun and Militký, 2012).

Most of statistical methods have the following assumptions about the processed data.

1. Minimum range of selection
2. The selection is homogenous.
3. The data are normally distributed.
4. All data have the same probability to be included in the selection.
5. All individual data are independent.

According to the previous assumptions, data are explored to check it is suitability for the next statistics steps. Otherwise, their analysis would be difficult and require complex tests with specific options. Moreover, graphical representation of collected data, would help and enable comprehensive evaluation of statistical analysis (Haned et al., 2012).

2.2.2 Statistical methods of survey analysis

2.2.2.1 Quantile characteristics

It encompasses the division of the sorted data into four equal parts, known as quantiles. The first, lower, quartile divides the smallest 25% of data from the rest. The second, middle, quartile divides the data into two equally occupied parts. So, the second quartile is similar to the median. The third, upper, quartile, separates 75% of data from the top 25% (Kába and Svatošová, 2012).

Two more components of quantiles are deciles and percentiles. Deciles divide the data into ten equal parts while the percentiles divide them into 100 parts.

2.2.2.2 Arithmetic mean and median.

The arithmetic mean is the basic statistical component, and it is calculated by dividing the sum of all data by the total number of those values.

$\mu=n\sum i=1nxi$

where

μ represents the arithmetic mean

xi represents each individual value in the dataset

n is the total number of values in the dataset

The median is the middle value of the data ordered by value or size. It also represents the second quartile.

For an odd number of values:

$$Me=x2n+1$$

For an even number of values:

$$Me=2x2n+x2n+1$$

where

Me represents the median

$x2n+1$ represents the middle value in the ordered dataset if n is odd.

$x2n$ and x $n/2+1$ $x2n+1$ represent the two middle values in the ordered dataset if n is even.

2.2.2.3 Kurtosis

It represents the concentration of elements of dataset around a certain value. Therefore, it gives an idea of the shape of the frequency distribution, either kurtosis or flatness. It is measured using the kurtosis coefficient formula (Kába and Svatošová, 2012).

$$\text{Kurtosis}=n\cdot s4\sum i=1n(xi-\bar{x})4$$

Kurtosis represents the kurtosis coefficient

xi represents each individual value in the dataset.

$\bar{x}$ represents the mean of the dataset.

s represents the standard deviation of the dataset

n is the total number of values in the dataset

<u>According to the kurtosis coefficient:</u>

If $\bar{\gamma}>0$, the distribution is leptokurtic (spiked), indicating a concentration of data points around the mean with heavy tails.

If $\bar{\gamma}=0$ the distribution is mesokurtic (normally peaked), suggesting a normal distribution with moderate tails.

If $\bar{\gamma}<0$, the distribution is platykurtic (flat), indicating a dispersion of data points with lighter tails.

In graphical representation, for a normally peaked distribution, we expect to see a horizontal line with data points primarily clustered around this line, reflecting an ideal condition.

2.2.2.4 Skewness

It characterizes the symmetry of frequencies distribution. The commonly used characteristic is the degree of skewness which is the arithmetic mean of the third power of the deviations of individual values from the arithmetic mean, divided by the third power of the standard deviation (Kába and Svatošová, 2012).

$\text{Skewness}=s3n1\sum i=1n(xi-\bar{x})3$

where

Skewness represents the skewness coefficient.

xi represents each individual value in the dataset.

$\bar{x}$ represents the mean of the dataset.

s represents the standard deviation of the dataset.

n *is the total number of values in the dataset.*

2.2.2.5 Standard deviation

It shows the dispersion of individual values around the arithmetic mean. When it small, the individual data are mostly similar to each other. On the other hand, it represents a significant difference among values when it is big. It is calculated as the square root of the variance.

$s=n\sum i=1n(xi-\bar{x})2$

s is the standard deviation

x_i represents each individual value in the dataset.

$\bar{x}$ is the mean of the dataset.

n *is the total number of values in the dataset*

2.2.2.6 Coefficient of variation

It represents the percentage of standard deviation into the arithmetic mean. It has a great importance in relative of measure of variability when comparing the variability between datasets that differ in size or expressed in different units.

$CV = \mu\sigma \times 100\%$

where

CV = Coefficient of Variation

σ = Standard Deviation

μ = Mean

2.2.3 Data standardization

This step is crucial step when dealing with datasets with high variability and units for individual indicators. Therefore, this step is used here before principal component and cluster analysis Where it will avoid the abovementioned problems. The commonly used method of standardization is the normalization of each value to its Z-score which is done by subtracting the mean and dividing by the standard deviation (Meloun and Militký, 2012).

The advantages of Z-score normalization are:

Uniform scale: All variables are converted to 0 and standard deviation 1, providing a uniform scale for comparison.

Relevant comparisons: Positive values represent data points above the mean, while negative values represent data points below the average. This makes it easier to compare the variables.

Recalibration: After standardization, there is no difference in scale between variables, facilitating meaningful comparisons.

2.2.4 Principal component analysis

It involves the analysis of main components, abbreviated to AHK. It is done to deduct the number of indicators that were originally collected and used during the exploratory data analysis. An important aspect of AHK is the minimal loss of information and creating new components that summarizes the original components. Moreover, it expresses the percentage share of each component which is beneficial in the cluster analysis step.

Methodological procedure of principal component analysis:

- creating a data matrix
- calculation of the covariance matrix
- expression of characteristic numbers of their corresponding characteristic vectors covariance matrix
- creation of main components
- expression of the share of the total variance used up by individual components.

2.2.5 Cluster analysis

Cluster analysis is used in the analytical part as a way to classify states into individual clusters (groups) based on selected indicators. The countries within the clusters show degree of similarity according to which they were joined together. But individual clusters differ from each other.

"Cluster analysis is a collective name for a whole range of computing procedures, the goal of which is the decomposition of a given set into several relatively homogeneous one’s subsets - clusters, so that objects within individual clusters are as similar as possible (Žambochová, 2008).

Cluster analysis mainly uses the so-called agglomerative hierarchical procedures. They combine or split objects at every step. The agglomerative procedure means that at each step we first unify the individual objects, then the groupings themselves into ever larger units. The purpose of this procedure is to create a hierarchical tree that starts with one-element sets and ends with a union all objects into one cluster. Such a hierarchical tree is called a dendrogram.

2.2.6 A method of assessing similarity

The Euclidean distance between two points (or vectors) in an n-dimensional space is defined as the straight-line distance between them. Mathematically, for two vectors

X=(x1,x2,...,xn) and Y=(y1,y2,...,yn) the Euclidean distance d(X,Y) is calculated as:

d(X,Y)=(x1−y1)2+(x2−y2)2+...+(xn−yn)2

In the context of clustering, Euclidean distance is often used to assess the dissimilarity or similarity between observations (or data points) in a dataset. It can help identify which observations are closer to each other and thus likely to be more similar.

The advantage of this measure is its computational simplicity. However, it has some shortcomings. It assumes that the variables are uncorrelated, which is a practical assumption conditions difficult to fulfill.

2.2.7 Data visualization

Graphical representation of data and information. It involves creating visual representations of datasets to help users understand complex data, identify patterns, trends, and relationships. Implementing scatter plots to data visualization to display the relationship between two variables. They are particularly useful for identifying patterns, trends, correlations, and outliers in datasets. In a scatter plot, each data point represents a single observation, with one variable plotted along the x-axis and the other along the y-axis.

3. Literature review

3.1 Renewable energy

Transitioning towards a more sustainable and environmentally responsible energy landscape requires the use of renewable energy. Unlike finite fossil fuels, renewable energy sources are derived from naturally occurring processes and can be harnessed without depleting finite resources. Such sources include solar, wind, hydropower, geothermal, and biomass. Renewable energy is not only appealing due to its ability to reduce greenhouse gas emissions and combat climate change, but also due to its potential to improve energy security, boost economic growth, and provide access to clean energy for underserved populations (Qazi et al., 2019; Strielkowski et al., 2021).

3.1.1 Types of renewable energy sources (RES)

Solar Energy: it is a highly versatile and widely embraced form of renewable energy. It is produced by harnessing the sun's rays through photovoltaic cells or solar panels, which can be utilized in numerous ways. These include mounting them on rooftops, implementing them in large-scale solar farms, and even incorporating them into portable devices. With its decentralized power supply, solar energy promises to improve our energy prospects and propel us toward a more sustainable world (Rabaia et al., 2021).

Wind Power: Renewable energy is rapidly gaining popularity, and wind power is a key contributor. By harnessing the kinetic energy of moving air through wind turbines, electricity can be generated sustainably. In many regions, wind farms have become a common sight, playing a significant role in the production of renewable energy. When combined with solar energy, wind power holds great promise in advancing our energy prospects and pushing us towards a more sustainable future (Díaz-González et al., 2012).

Hydropower: Hydropower has long been recognized as a reliable source of renewable energy. By utilizing the energy of flowing water, electricity can be generated in dams or rivers. This consistent power production has played a significant role in advancing sustainable energy practices. Hydropower holds immense potential in propelling us towards a more sustainable future when paired with other renewable energy sources like wind and solar (Moran et al., 2018).

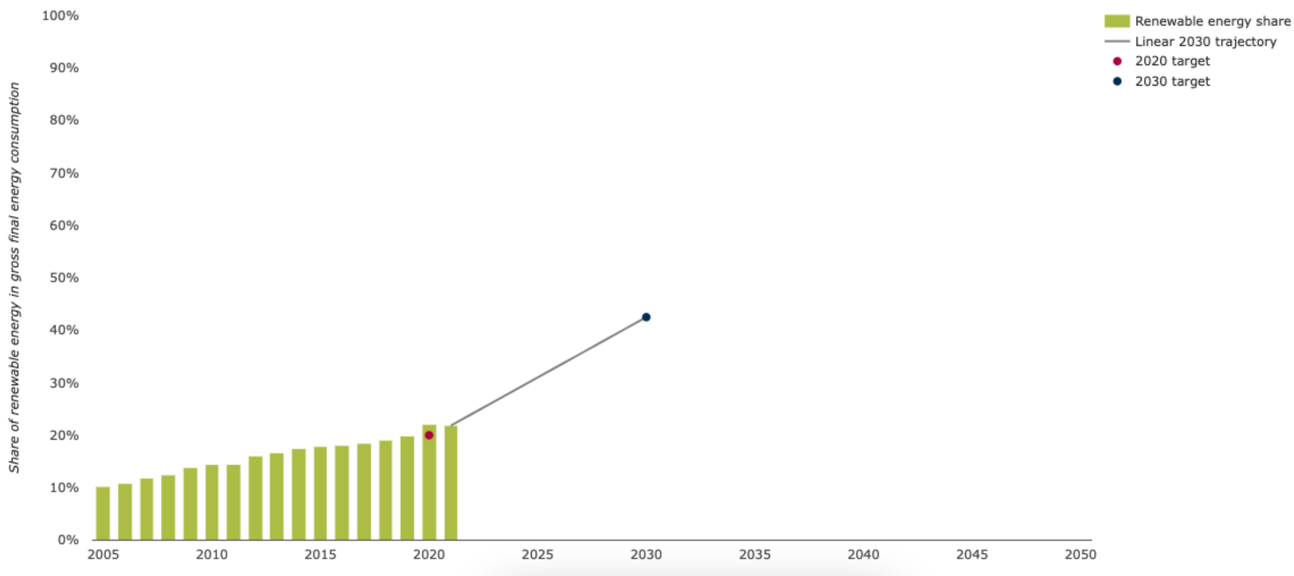
Geothermal Energy: Geothermal energy is a captivating source of power that allows us to tap into the Earth's internal heat. This type of energy is derived by accessing geothermal reservoirs and using steam or hot water to generate heat and electricity. One of the most alluring aspects of geothermal energy is its reliability and consistency, making it an excellent source for heating and electricity production. The potential for geothermal energy is boundless, and it is intriguing to ponder how it will continue to advance (Lund and Toth, 2021).

Biomass Energy: Biomass energy has emerged as a promising avenue for achieving renewable energy goals because it harnesses organic materials such as wood, agricultural residues, and municipal waste. This form of energy offers the potential to be converted into biofuels or burned directly for heat and electricity, thereby enabling sustainable and eco-friendly energy generation. Moreover, biomass energy fosters waste reduction and augments local economies by generating employment opportunities in the forestry and agricultural sectors. Given its manifold advantages, biomass energy is a judicious alternative for individuals seeking to lessen their carbon footprint and promote a cleaner, greener tomorrow (Field et al., 2008).

3.1.2 Environmental and economic benefits

The utilization of renewable energy sources has gained momentum due to its many benefits. One of the most prominent advantages is its potential to generate energy without causing detrimental greenhouse gas emissions, effectively mitigating air pollution and combating climate change. Furthermore, transitioning to clean energy has the potential to reduce dependence on fossil fuels, thereby creating a more secure energy future and reducing susceptibility to price fluctuations. In addition, the renewable energy sector has emerged as a significant catalyst for job creation and economic growth, attracting substantial investments in research, development, and infrastructure. With the advancement of technology, renewables are increasingly becoming competitive with fossil fuels, rendering them a prudent and economically viable option for energy production (Olabi and Abdelkareem, 2022).

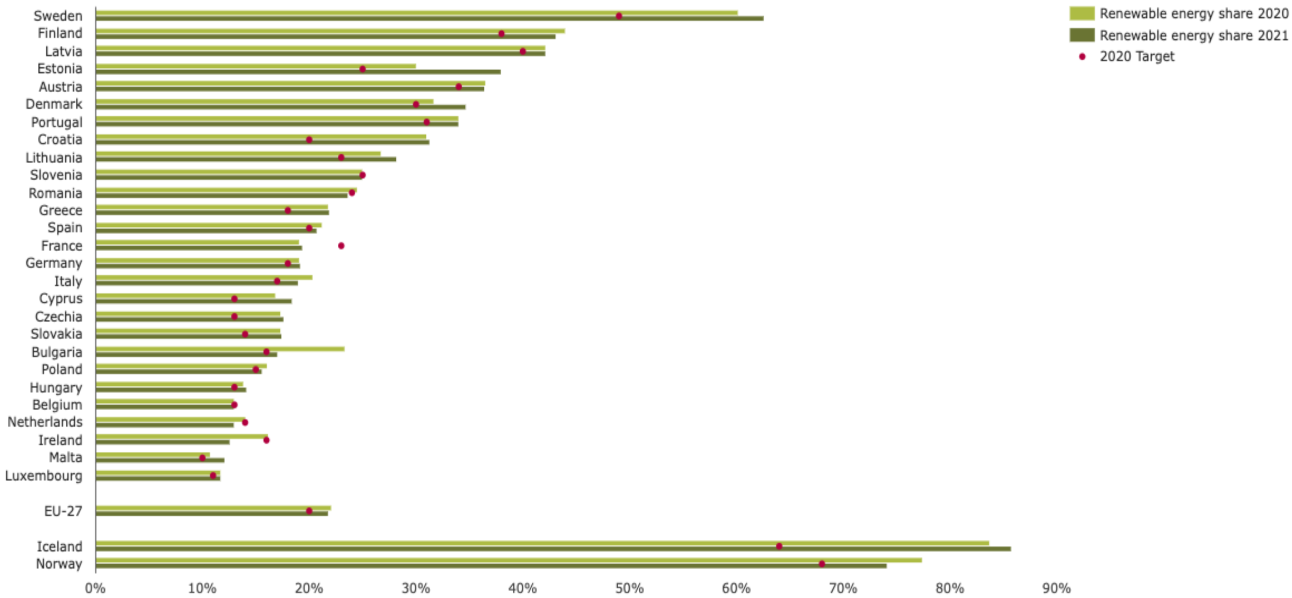
3.1.3 Renewable energy in EU countries



Picture 1 Progress towards renewable energy source targets.

Source: (*Share of energy consumption from renewable sources in Europe (8th EAP)* 2023)

The European Union's achievement of meeting its target of having 20% of its gross final energy consumption derived from renewable sources by 2020 is a significant milestone towards a more sustainable future. Furthermore, the recent political agreement to increase the binding 2030 target from 32% to 42.5% is a commendable step forward in the battle against climate change. This progress indicates the EU's dedication to reducing its carbon footprint and promoting renewable energy sources (European Environment Agency, 2023).



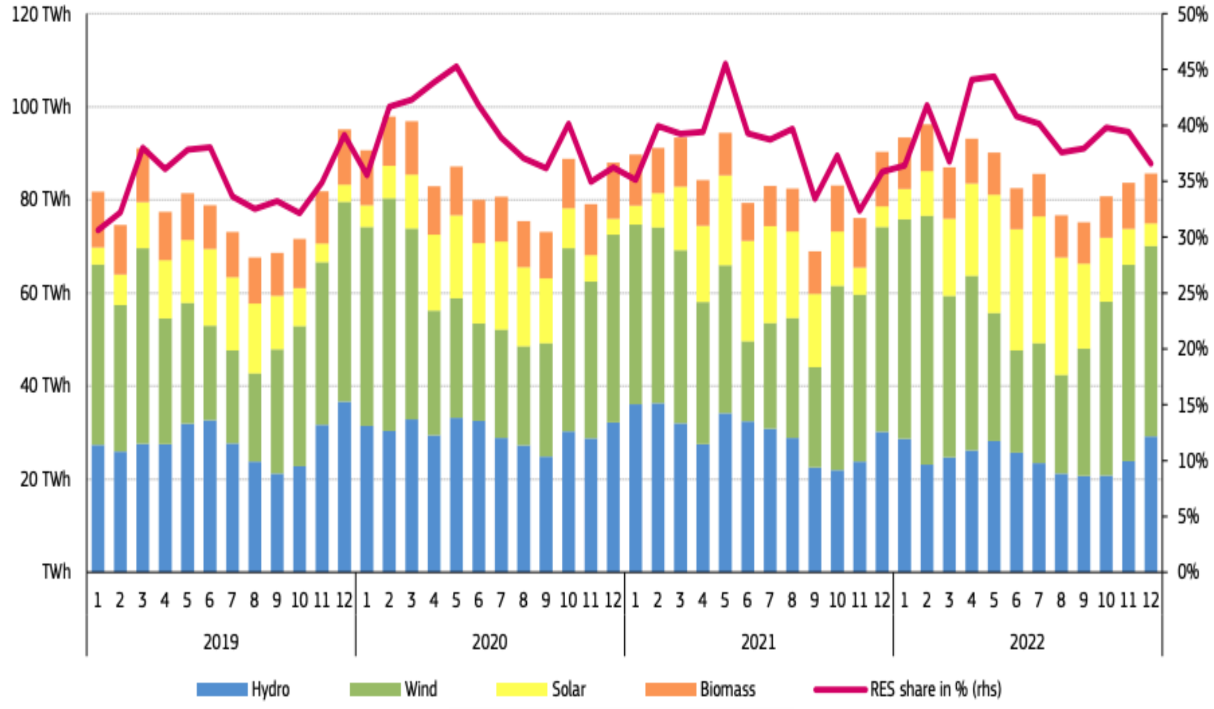
Picture 2 Share of energy from renewable sources, by country.

Source: (*Share of energy consumption from renewable sources in Europe (8th EAP)* 2023)

The data presented in figure 2 reveals that Sweden, Finland, and Latvia were the EU Member States with the highest proportion of RES in 2021. These countries have a well-established hydropower industry and a strong reliance on solid biofuels. Conversely, Luxembourg and Malta exhibited the lowest adoption rates of renewables, constituting less than 12% of their total energy consumption (European Environment Agency, 2023).

Over the long term, Denmark, Estonia, and Sweden have experienced the most substantial growth in RES shares, increasing by more than 18 percentage points since 2005. However, Romania and Slovenia have observed a rise of less than 6 percentage points between 2005 and 2021.

Notably, 15 of the 27 EU Member States have witnessed an increase in their renewable energy shares between 2020 and 2021. Estonia and Denmark have performed exceptionally well, having elevated their RES share by over 3 percentage points in 2021. Conversely, Bulgaria and Ireland have registered a decline of more than 3 percentage points compared to the previous year.



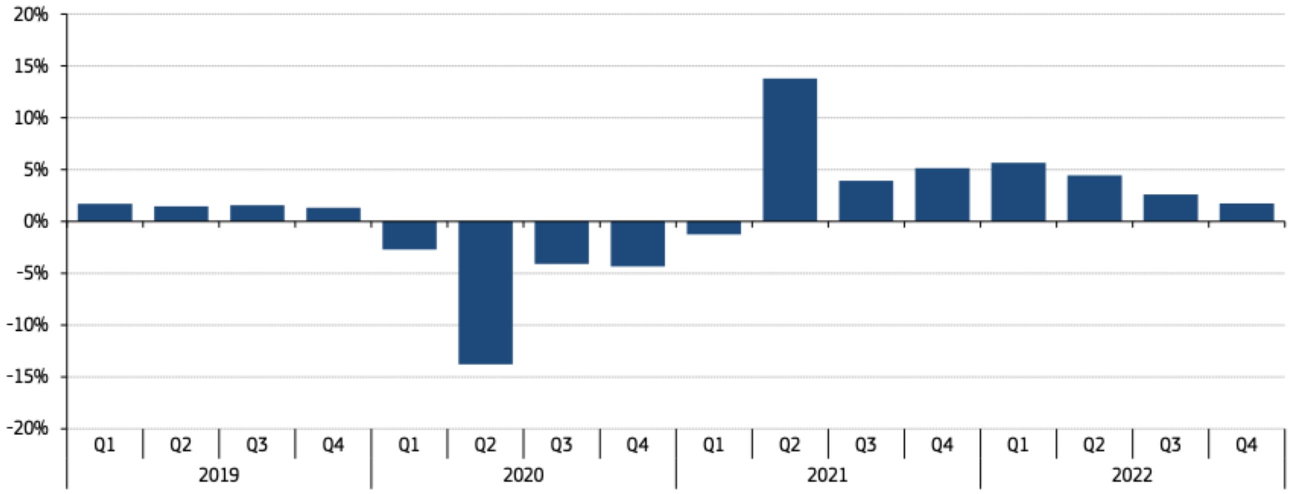
Picture 3 Monthly renewable generation in the EU and the share of renewables in the power mix.

Source: (*Quarterly report On European electricity markets Market Observatory for Energy DG Energy* 2023)

The graph in figure 3 depicts the progressive monthly generation of renewable energy sources in the EU and how they contribute to the overall electricity generation mix. As per the data, the share of renewable sources in the mix stood at 39% in Q4 2022, a significant increase from the 35% share observed in Q4 2021. Despite the lower levels of hydro and biomass output, the penetration of renewable energy sources increased in Q4 2022, owing to the rise in solar and wind generation levels. Notably, the generation of wind and solar energy surpassed that of gas-fired energy in 2022 (European Commission, 2023).

3.2 Economy

3.2.1 Growth domestic product (GDP)



Picture 4 EU GDP annual change (%)

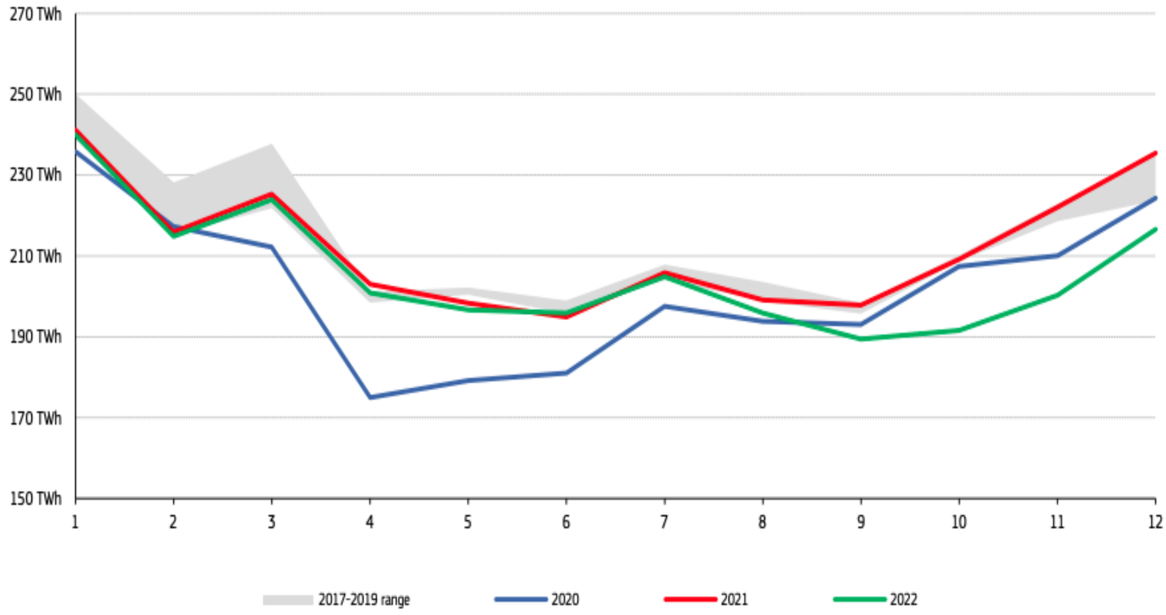
Source: (*Quarterly report On European electricity markets Market Observatory for Energy DG Energy* 2023)

The European Union (EU) has shown impressive economic growth, as seen in figure 4. According to the latest data from Eurostat in March 2022, the seasonally adjusted GDP in the EU rose by 1.7% year-on-year between October and December 2022, following a 2.6% increase in Q3 2022. Additionally, the GDP in the EU grew by 3.5% in 2022, following a 5.4% increase in 2021 (European Commission, 2023).

Although the economy showed signs of improvement, the recovery in the first half of 2022 slowed down during the year's second half. This was largely due to the pressure caused by high energy costs and rising inflation rates. By December of that same year, the EU's annual inflation rate had reached 10.4%, with energy costs accounting for 2.79 percentage points. Additionally, the high cost of electricity resulted in reduced consumption in energy-intensive industries, which meant that the increase in economic activity did not lead to a corresponding increase in electricity usage.

Despite facing challenges, the EU still experienced annual growth in 23 members compared to Q4 2021. Among these, Ireland reported the highest annual rates at (+13.1%), followed by Greece (+5.2%) and Romania (+4.7%). In contrast, Estonia (-4.4%) and Luxembourg (-2.2%) experienced the highest year-on-year decreases.

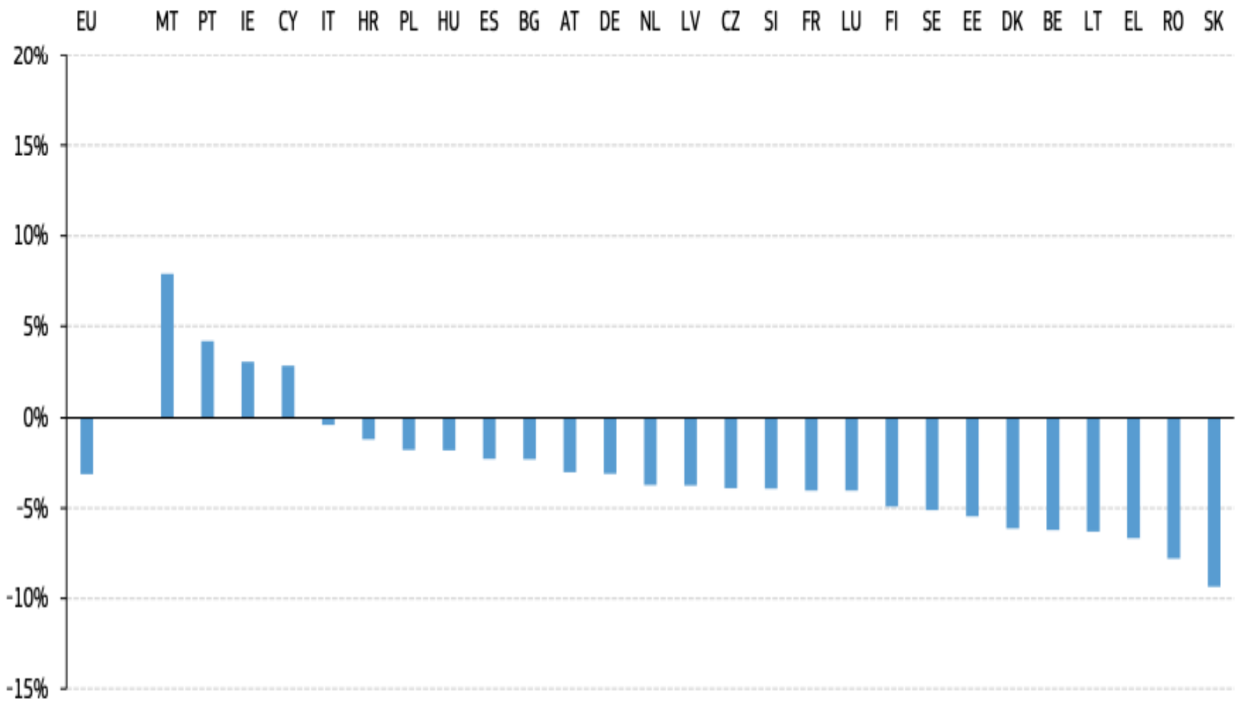
3.2.2 Electricity consumption



Picture 5 Monthly EU electricity consumption

Source: (*Quarterly report On European electricity markets Market Observatory for Energy DG Energy* 2023)

The report in figure 5 outlines the changes in electricity consumption between 2021 and 2022. The EU experienced a decline in consumption due to unprecedented prices in 2022. This led to decreased household energy demand and decreased demand from industries. Large industrial consumers were the most affected by high energy prices, resulting in a significant drop in consumption. Twenty-three members saw a decrease in consumption, with Slovakia (-9%), Romania (-8%), and Greece (-7%) experiencing the most significant drops. However, Malta (+8%) and Portugal (+4%) saw increased consumption due to cooling needs during the warm summer weather. Compared to the previous year, EU-wide consumption fell by 3% (European Commission, 2023).

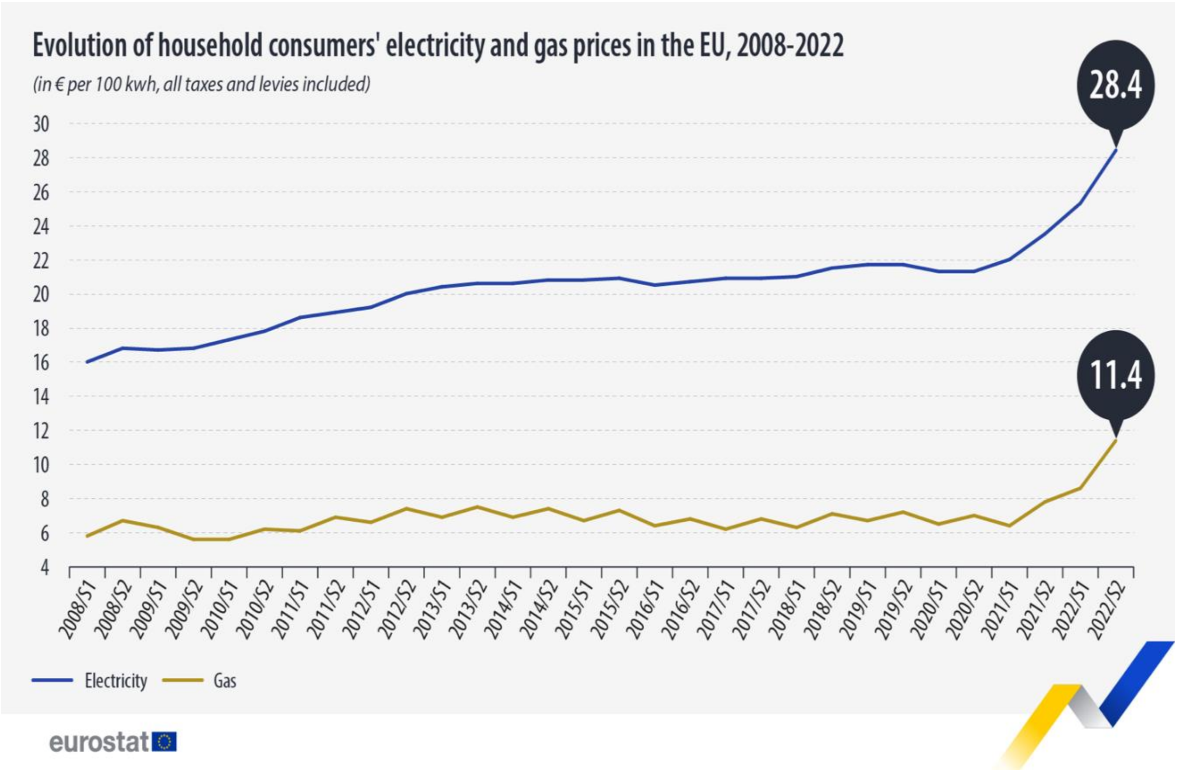


Picture 6 Annual changes in electricity consumption in 2022 by Member State

Source: (*Quarterly report On European electricity markets Market Observatory for Energy DG Energy* 2023)

Figure 6 showcases a report highlighting the variations in electricity consumption between Q4 of 2022 and Q4 of 2021. It is crucial to acknowledge that while the EU average displays an overall shift, each Member State experienced unique changes during this period. Ireland and Malta were the only countries that witnessed a year-on-year increase in consumption, with moderate growth of 4% and 2%, respectively. In contrast, twenty-five Member States reported a decline in consumption, with Slovakia, Romania, France, and Belgium leading the way with a decrease of 18%, 13%, and 12%, respectively. Even major economies like Germany and the Netherlands experienced reduced power consumption, which decreased by 9% and 7%, respectively. The mild winter of 2022/2023 also contributed to the overall decrease in demand (European Commission, 2023).

3.2.3 Electricity and gas prices



Picture 7 Electricity and gas prices for household consumers 2008-2022.

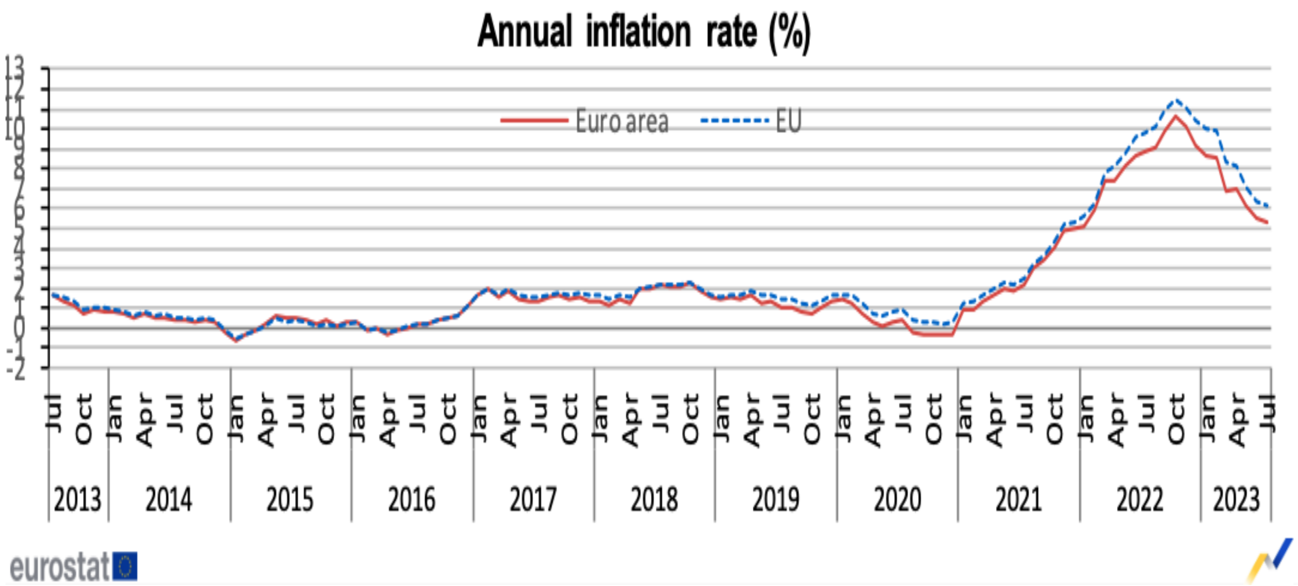
Source: (*Electricity & gas hit record prices in 2022 - Products Eurostat News - Eurostat* 2023)

During the latter half of 2022, the EU's cost of household electricity and gas skyrocketed to the highest on Eurostat's record. Electricity prices surged from €23.5 to €28.4 per 100 kWh, while gas prices increased from €7.8 to €11.4 per 100 kWh. Fortunately, there are indications of stabilization after an extensive price hike that began before the Russian invasion of Ukraine and continued until the second semester of 2022 (EUROSTAT, 2023a).

In response to the energy crisis, EU governments have implemented several measures to alleviate the situation, including reducing taxes and fees, providing tax waivers, capping prices, and allocating vouchers to final consumers. Some countries have also applied regulated prices.

Moreover, the share of taxes in the electricity and gas bills dropped significantly from 36% to 16% (-18.3%) and 27% to 14% (-15.8%), respectively. All EU countries have taken steps to help consumers by providing governmental allowances and subsidies or reducing taxes and levies to mitigate high-energy costs. While these measures have lowered consumer energy prices, they have also burdened governmental accounts.

3.2.4 Inflation rate



Picture 8 Annual inflation rates (%) 2013-2023

Source: (*Annual inflation down to 5.3% in the euro area Down to 6.1% in the EU* 2023)

In July 2023, the annual inflation rate for the euro area decreased from 5.5% to 5.3% compared to the previous month. The inflation rate was 8.9% the previous year. Similarly, the European Union's annual inflation rate decreased from 6.4% to 6.1% in July 2023. The countries with the lowest annual rates of inflation were Belgium (1.7%), Luxembourg (2.0%), and Spain (2.1%), while the highest annual rates of inflation were reported in Hungary (17.5%), Slovakia, and Poland (10.3%). Among the Member States, nineteen experienced a decrease in annual inflation, one remained stable, and seven reported an increase. Services contributed the most to the annual inflation rate of the euro area in July (+2.47 percentage points), followed by food, alcohol, and tobacco (+2.20 pp), non-energy industrial goods (+1.26 pp), and energy (-0.62 pp) (EUROSTAT, 2023b).

3.3 Renewable energy in Czech Republic

International Energy Agency published a report about different sectors of the energy in Czech Republic (International Energy Agency, 2021). The following points are summary of the renewable energy section in the report.

The Czech Republic has experienced significant growth in renewable energy production, with the share of renewables in TFEC rising from 11% in 2010 to 16% in 2019. The government has set a modest target of 13% of gross final consumption by 2020, which was surpassed in 2013. However, the Czech Republic has one of the lowest shares of renewables in electricity and transport among IEA countries.

The Czech Republic has several support schemes and measures to promote the development of renewable energy sources. Since 2017, around CZK 43 billion has been paid annually for operational support of renewable energy sources. The government is proposing an amendment to Act No. 165/2012, which aims to relaunch operational support for renewable energies except solar PV and other supported energy sources.

In 2018, 92% of renewables in TFEC were produced from bioenergy. The mid-term potential for renewable development mainly relies on bioenergy, which is expected to account for two-thirds of the total renewable energy in 2030.

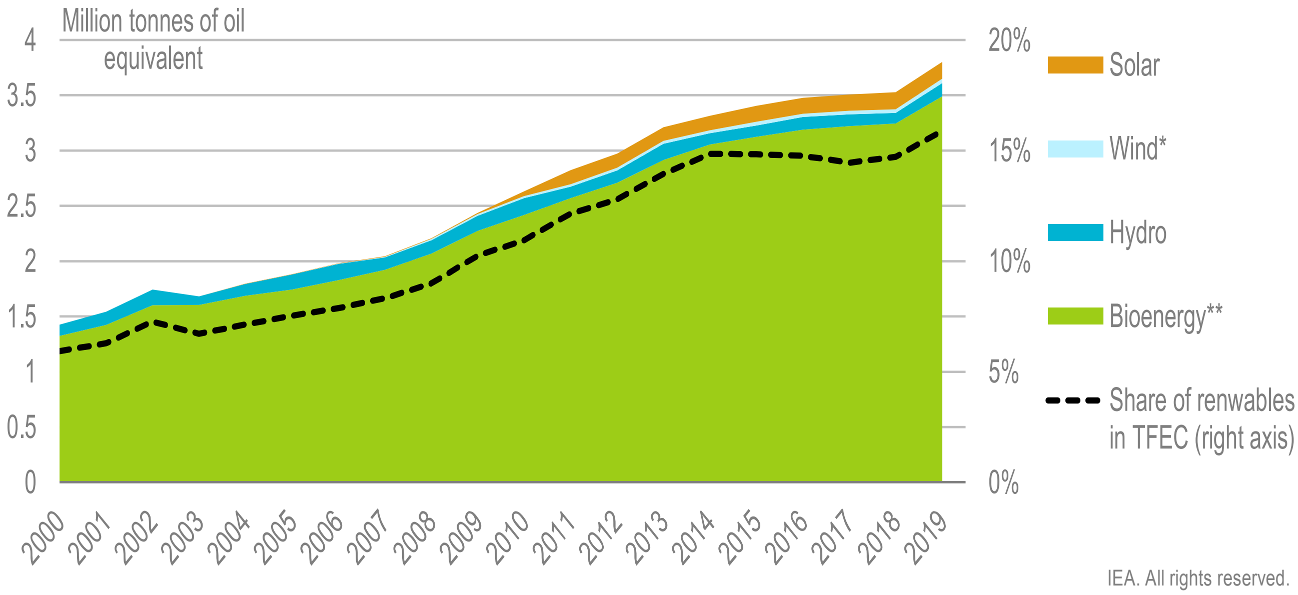
In 2018, the Czech Republic had a 20.6% share of renewables in the heating and cooling sector. The government expects the share to increase to 30.7% by 2030.

The renewable energy target for the transport sector was 10.8% by 2020, up from a target of 6% in 2014. In 2019, the share of renewables in transport was 5%.

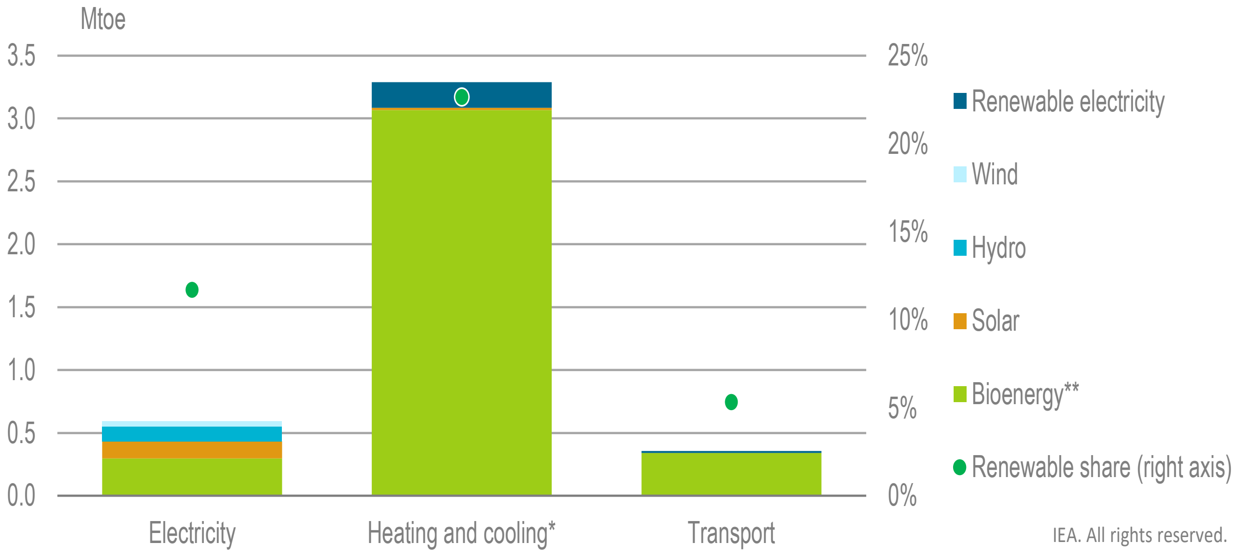
The use of renewable and decarbonized gases in the Czech Republic is low. The government should prepare and initiate legislation for promoting higher shares of low-carbon fuels and renewable and decarbonized gases such as hydrogen, synthetic methane, and biomethane to achieve climate targets cost-effectively.

The government expects a notable increase in renewable electricity production. In 2020, 10.3 TWh of electricity was generated from renewable sources, and the government estimates that up to 22 TWh of renewable electricity can be integrated into the system without causing stability problems. However, the IEA considers the 22 TWh limit a rather low projection.

Following graphs shows the status of renewable energy in Czech Republic (International Energy Agency, 2021)



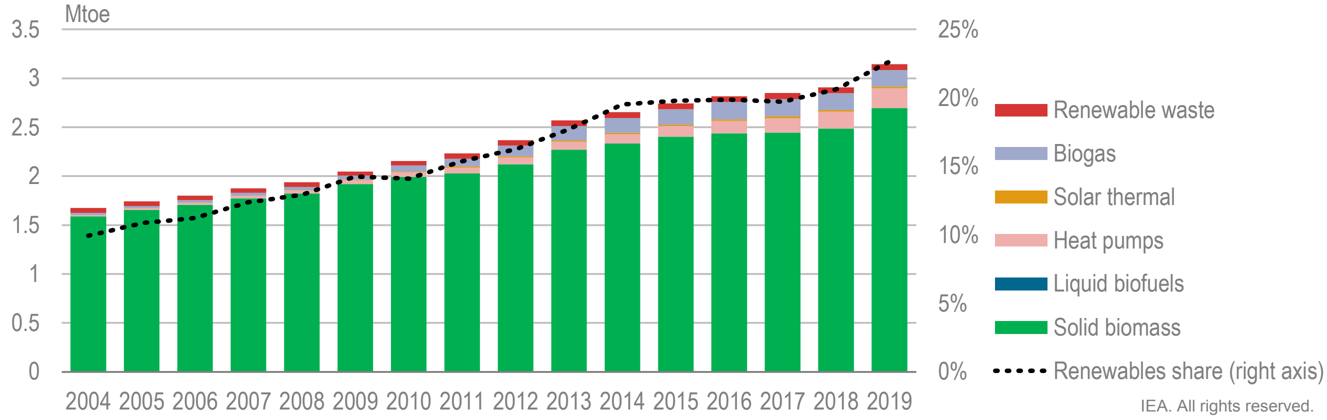
Picture 9 Renewable energy in total final energy consumption 2000-2019 (IEA, 2021)



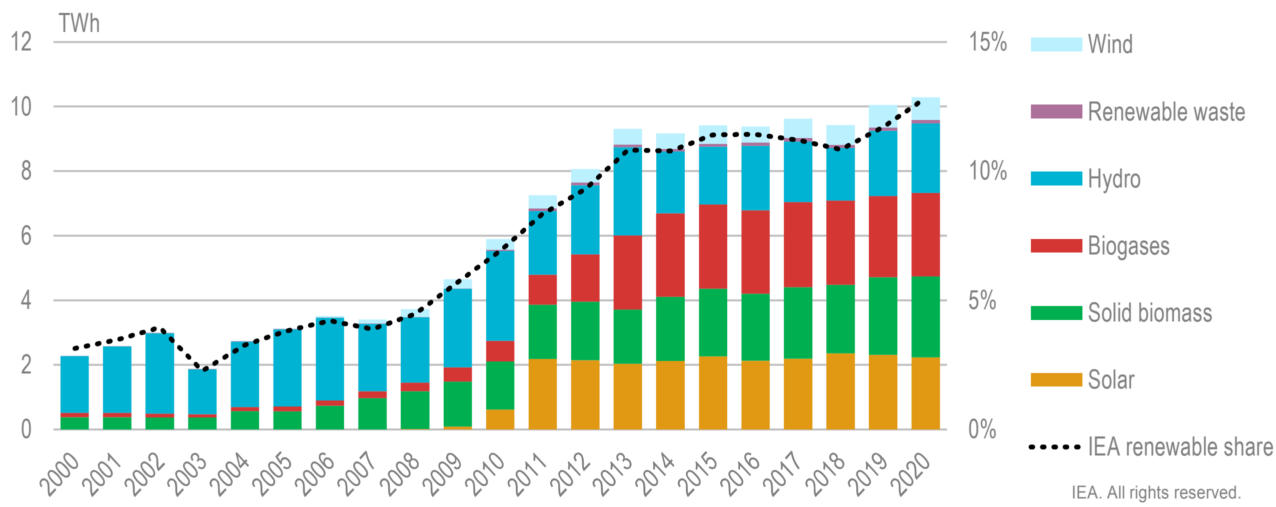
Picture 10 Renewable energy in electricity, heating, cooling, and transport in 2019 (IEA, 2021)

Renewable share by sector (% of gross final consumption)			Targets
	2019	**2020**	**2030**
Gross final consumption	16.2%	13%	22%
Transport	7.8%	10.8%	14%
Electricity	14.1%	13.5%	17%
Heating and cooling	22.7%	15.5%	1 percentage point annually to 2030

Picture 11 Status of renewable energy targets in 2019 and targets for 2020 and 2030 (IEA, 2021)



Picture 12 Renewable energy in heating and cooling 2004-2019 (IEA, 2021)



Picture 13 Renewable energy in electricity generation 2000-2019 (IEA, 2021)

3.4 Previous studies

Three peer-reviewed paper were used for the discussion of the analysis results came out from the practical part.

3.4.1 Marinou Cristian 2018

The first study that is relevant to our research interest is (Cristian, 2018). It aimed to do cluster analysis for EU member countries from the point of view of the use of renewable energy reflecting from the values of three specific indicators. The analysis results in the discovery and verification of the structure clusters, including the definition of indicators that statistically significantly differentiate the obtained clusters.

Among the selected indicators (%) are the following:

- I1 – Share of renewable energy in gross final energy consumption.
- I2 – share of renewable energy in transport.
- I3 – share of renewable energy in electricity.

Even before the cluster analysis, the author evaluates the clustering tendency to determine whether the analyzed data forms a cluster structure. The Hopkins test, including the graphic output of the matrix distance between analyzed objects, was used for these evaluations.

3.4.2 Mihaela Simionescu 2020

The second article I want to refer to is (Simionescu et al., 2020). This paper does not examine the correlation between RES and economic growth. However, it concentrates on the real gross domestic product (GDP) and the implementation of national goals in renewable energy. The authors use panel data models for a group of EU-28 countries between 2007 and 2017. The models provide evidence of a low and positive relationship between the impact of GDP per inhabitant and the share of RES in final consumption.

The empirical approach is based on two primary methods: (a) various panel data models that include a study of panel causality and (b) cluster analysis aimed at revealing groups of countries grouped according to their share of renewable energy in final consumption and their economic level development expressed in GDP per capita. The authors use some traditional panel data models to achieve these methods, including a fixed-effects model, a random-effects model, and a general estimator-based model equation.

3.4.3 Silvia Megyesiova 2023

The third study to be used for discussion is (Megyesiova et al., 2023). The study analyzed the sustainable indicators for affordable and clean energy in the European Union (EU) in 2010 and 2020 using univariate and multivariate statistical approaches. Univariate statistical methods were used to describe the indicators, while multivariate techniques were employed to uncover the multidimensionality of the Sustainable Development Goal 7 (SDG 7) indicators.

The study utilized cluster analysis and principal component analysis to identify differences and compare changes in grouping countries into clusters. In cluster analysis, EU countries were grouped based on similarities in their SDG 7 indicators, while principal component analysis aimed to reduce the dimensionality of the dataset. The study also used correlation analysis to detect statistically significant linear relationships between the indicators. The methodology involved selecting variables from the Eurostat database and using additional variables such as average temperature and gross value added in industry to complete the indicators' collection. The study aimed to identify the relationships between the selected indicators and the strengths and weaknesses of the countries in achieving sustainable and affordable energy consumption and production.

4. Practical Part

Three groups of appropriate indicators were selected for the complex analysis of the renewable energy sources, their production and consumption, and categorized accordingly.

First group of indicators includes data related to production.

- Primary energy production from RES (TOE)
- Fossil fuel energy production (TOE)
- Natural gas energy production (TOE)
- Oil production (TOE)
- Nuclear power generation (TOE)

Second group of indicators comprises data related to consumption.

- Primary energy consumption (TOE)
- Share of RES in gross final energy consumption (%)
- Share of energy from renewable sources in gross electricity consumption (%)
- Share of energy from renewable sources in transport (%)
- Share of energy from renewable sources for heating and cooling (%)

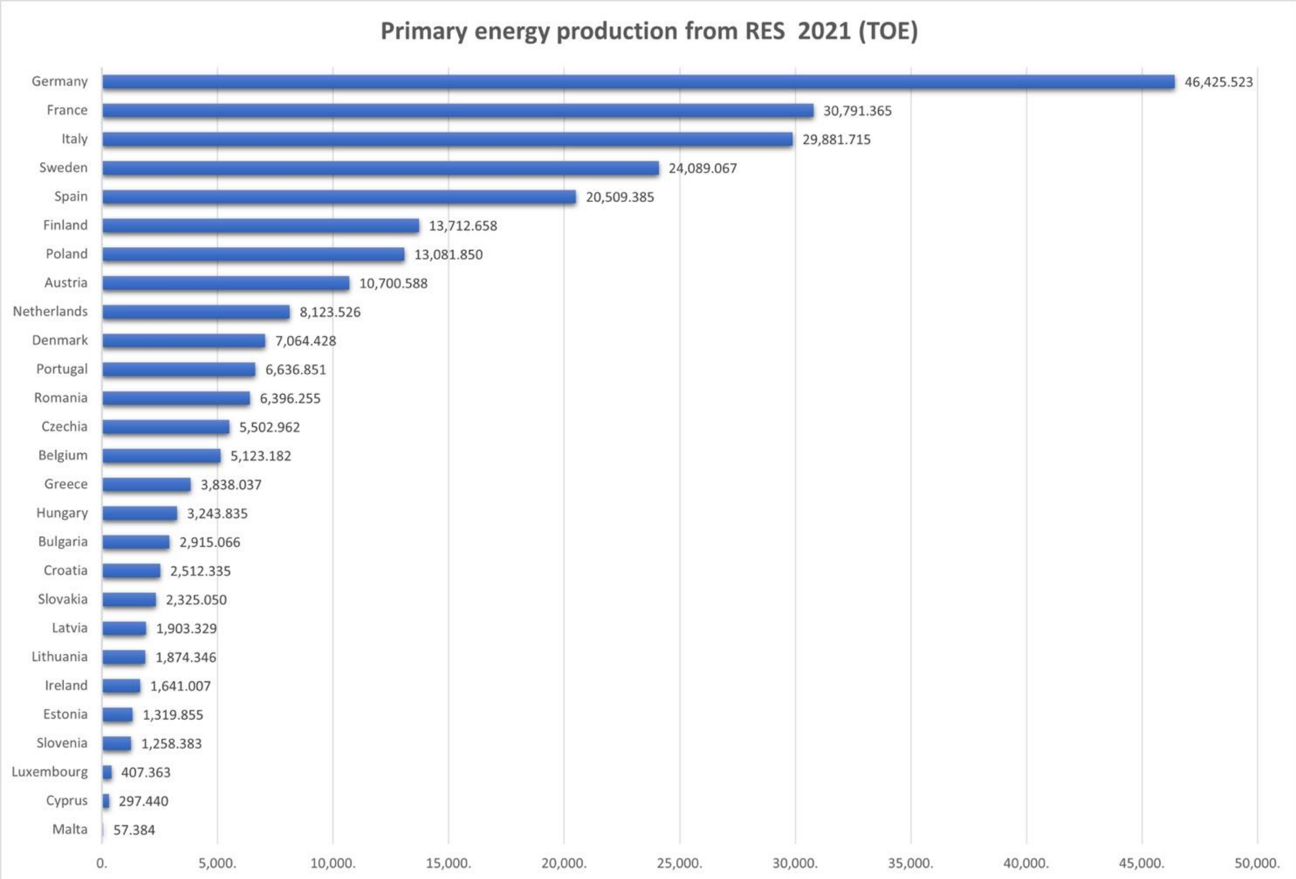
Third group of indicators contains data related to economy.

- The average price of electricity (EUR/Kwh)
- Energy dependence (%)
- GDP per capita (PPS)
- Energy inflation rate (%).

4.1 Exploratory data analysis

4.1.1 Data related to production.

4.1.1.1 Primary energy production from RES (TOE)



Graph 1 Primary energy production from RES

Source: (Eurostat data files)

This indicator shows each EU country's performance in producing energy from renewable energy sources (RES). As shown in Figure 9, Germany secures the first spot with 46,425.523 TOE units, followed by France and Italy in the second and third spots with 30,791.365 and 29,881.715 TOE units, respectively. Also, this figure represents the continuous commitment of Germany to RES and its substantial capacity for clean energy generation.

The Czech Republic falls somewhere in the middle with 5,502.962 TOE units. This data represents the Czech Republic's efforts to increase its renewable energy capacity.

On the other hand, Malta, Cyprus, and Luxembourg are the lowest three countries in energy production from RES. They can be attributed to needing to be bigger in land size and population number, which limit their capacity for production.

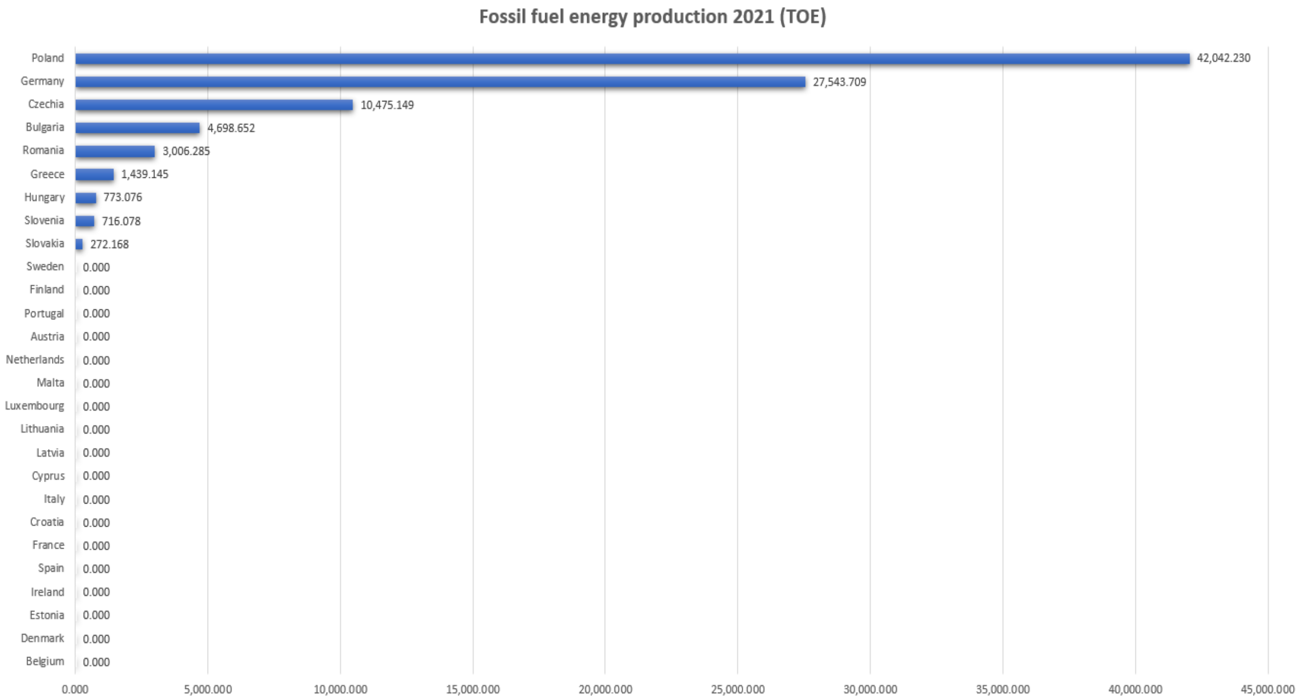
Analysis Variable : Primary energy production RES 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
27	9319.73	11505.96	57.3840000	46425.52	5123.18	123.4580258	1.8653109	3.2511406	1874.35	13081.85	11207.50

Table 2 Output of MEANS procedure - Primary energy production from RES (TOE)

Source: (own study)

The output data shows the huge variability in production units between individual states with a 123.458 coefficient of variation. The mean is 9,319, but it is of low importance due to high variability. The Skewness of data is 1.865, which means right-sided skewness and frequency distribution are skewed to the left of the mean. High variability is obvious in the quartiles as well. The lower quartile (Q1) is 1,874.35, the middle quartile (median) is 5,123.18, and the upper quartile is 13,081.85 with a quartile range (IQR) of 11,207.50.

4.1.1.2 Fossil fuel energy production (TOE)



Graph 2 Fossil fuel energy production.

Source: (Eurostat data files)

This indicator includes data about energy production from fossil fuels. Poland, Germany, and the Czech Republic secured the first three spots with 42,042.230, 27,542.709 and 10,475.149, respectively. Interestingly, Poland and Germany dominate this indicator with huge differences in their contribution compared to other countries. More than half of the EU countries are not using fossil fuels for energy production.

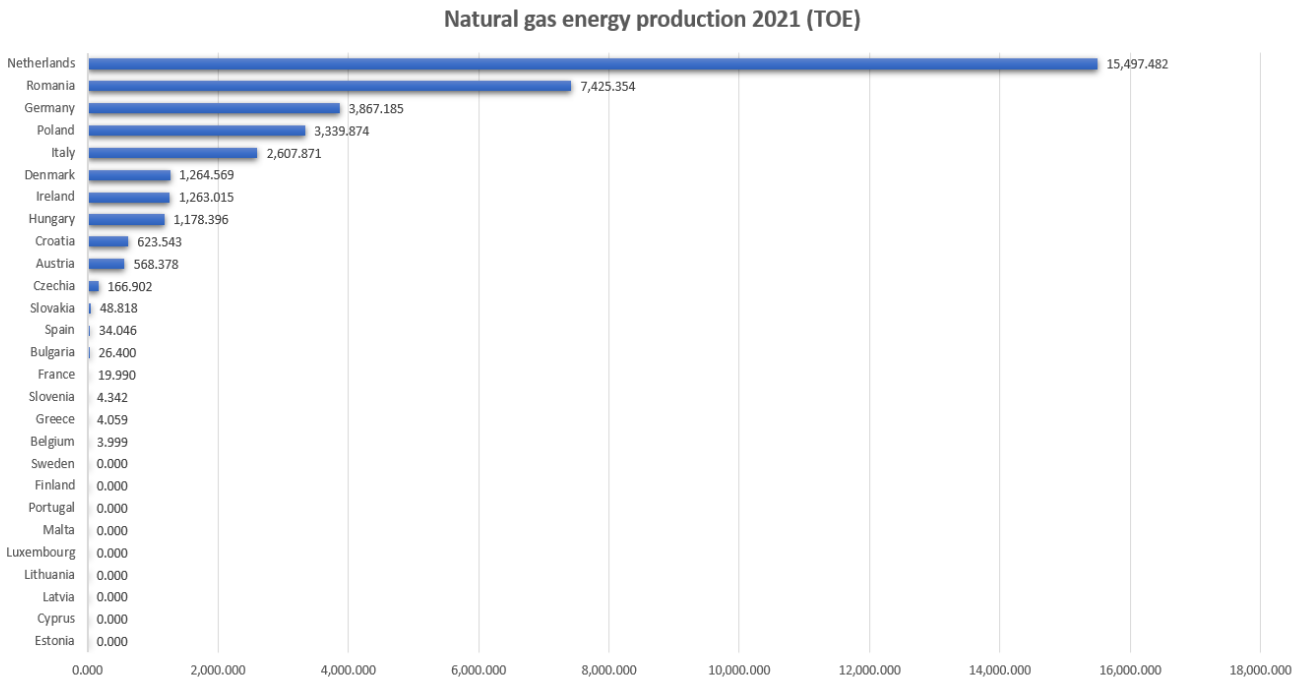
Analysis Variable : Fossil fuel energy production 2021										
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile
27	3369.13	9535.01	0	42042.23	0	283.0110872	3.4292738	11.7665377	0	773.0760000

Table 3 Output of MEANS procedure - Fossil fuel energy production (TOE)

Source: (own study)

The coefficient of variation is 283.011%, representing a high degree of inconsistency in the data set. The skewness is 3.43, meaning the frequency distribution is skewed to the left of the mean. Quartiles, mean, and standard deviation are statistically insignificant with the variability of the table.

4.1.1.3 Natural gas energy production (TOE)



Graph 3 Natural gas energy production.

Source: (Eurostat data files)

This indicator provides information about production of energy from natural gas. Netherlands, Romania and Germany are the top three countries with 15,497.482, 7,425.354 and 3,867.185 TOE respectively. Similar to fossil fuels, two countries, Netherlands and Romania, are dominating this sector. Nine countries do not utilize the natural gas for energy production. Czech Republic is in the middle of the chart with 166.902 TOE production.

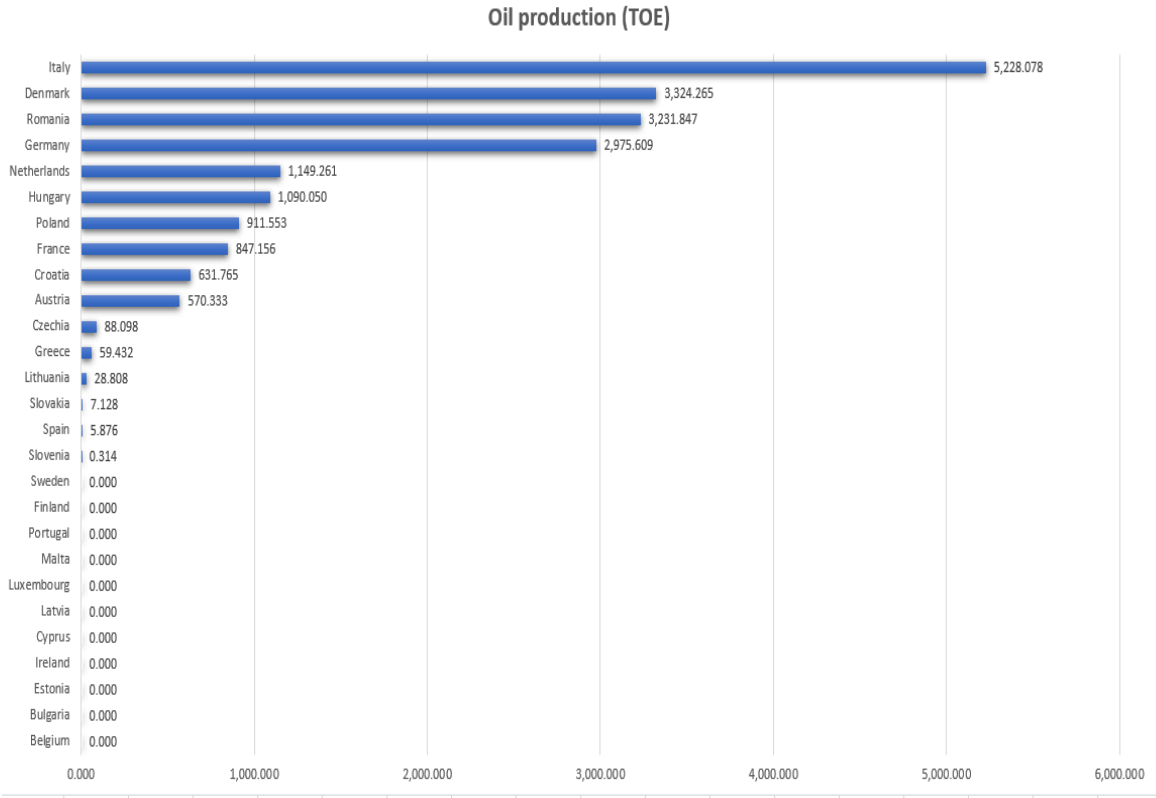
Analysis Variable : Natural gas energy production 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Variance	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile
27	1405.34	3282.95	0	15497.48	26.4000000	10777748.83	233.6049975	3.5149168	13.6698689	0	1263.02

Table 4 Output of MEANS procedure - Natural gas energy production (TOE)

Source: (own study)

The data shows clear variation between countries with 233.60 coefficient of variation. The skewness and kurtosis are 3.51 and 13.67 respectively. This suggests a positive right-sided distribution of the data and high variability in data.

4.1.1.4. Oil energy production (TOE)



Graph 4 oil energy production.

Source: (Eurostat data files)

This parameter shows the production of energy from oil. Italy, Denmark and Romania are on the top of the list with 5,228.078, 3.324.265, 3,231.847 respectively. Czech Republic is in the middle spot with 88.098 TOE. Estonia, Latvia and Slovenia are the least contributing countries with 187.97, 1,702.44 and 2,277.99 respectively.

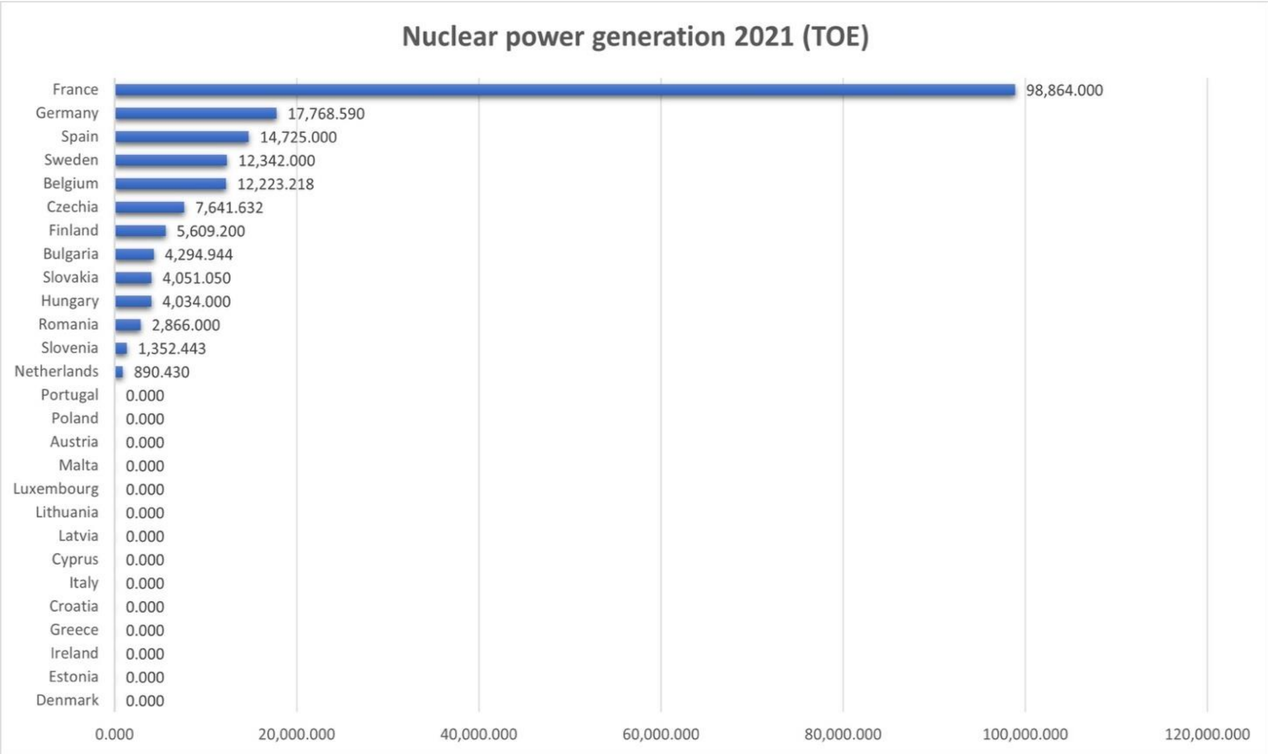
Analysis Variable : Oil production 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Lower Quartile	Upper Quartile	Quartile Range	Skewness	Kurtosis
27	18546.17	24825.14	187.9700000	99165.83	8094.50	133.8559119	2975.53	28887.01	25911.48	1.9658577	3.5088804

Table 5 Output of MEANS procedure - Oil energy production (TOE)

Source: (own study)

Coefficient of variation and kurtosis are 133.85 and 3.5 which represent high data variability. Skewness is 1.96 shows right-sided distribution of the datasets. Means, standard deviation and quartiles represents high data variability.

4.1.1.5 Nuclear power energy production (TOE)



Graph 5 nuclear power energy production.

Source: (Eurostat data files)

This indicator represents the countries that use nuclear power for energy production. In this regard, about half of EU countries use this power for energy production. The biggest producer is France with 98,864.00 TOE. Czech Republic is in the upper quartile and reserves the sixth spot with 7,641.00 TOE.

Analysis Variable : Nuclear power generation 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Range	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile
27	6913.43	19084.55	0	98864.00	0	98864.00	276.0504844	4.6274500	22.7545736	0	5609.20

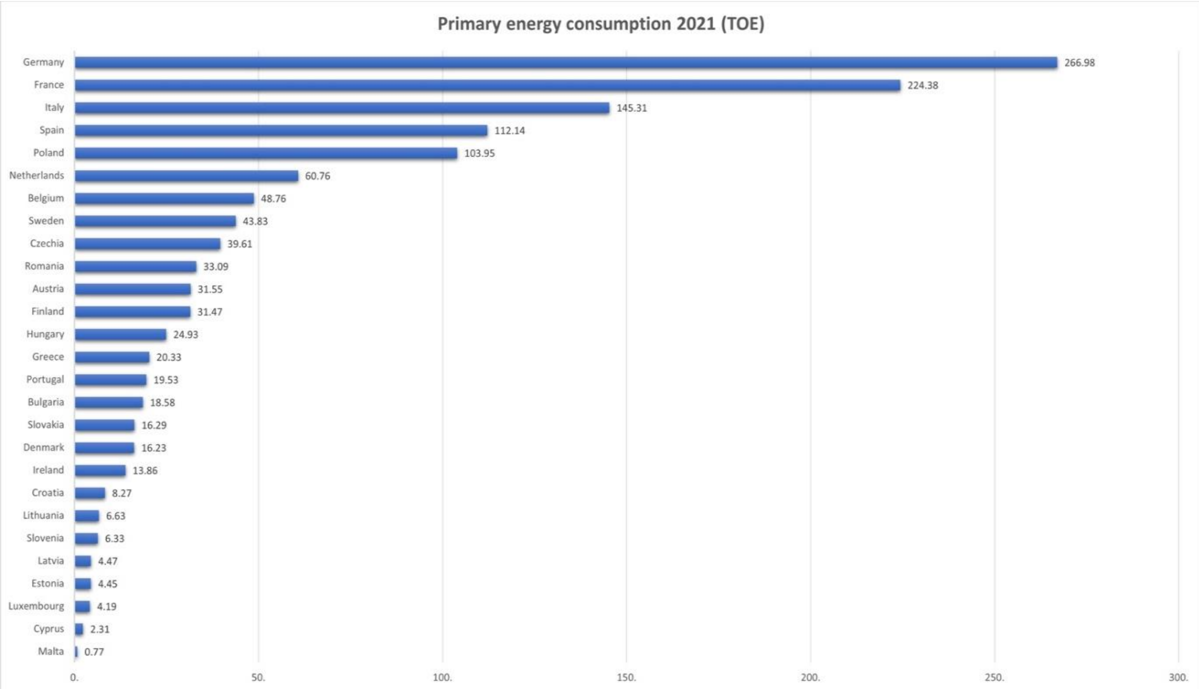
Table 6 Output of MEANS procedure - nuclear power energy production (TOE)

Source: (own study)

The skewness is 4.63 suggests a positive data set with heavy tails. The coefficient of variation is high at 276.05. The minimum value was 0 and recorded in 14 countries. Means, quartiles and standard deviation have no statistical significance.

4.1.2 Data related to consumption.

4.1.2.1 Primary energy consumption (TOE)



Graph 6 primary energy consumption.

Source: (Eurostat data files)

This parameter represents the total energy consumption by end users and services as households, agriculture and industry. Germany is at the top with 266.98 TOE and followed by France and Italy with 224.38 and 145.31 respectively. Czech Republic is located at 9th place with 39.61 TOE. Malta, Cyprus and Luxembourg are the lowest with 0.77, 2.31 and 4.19 TOE respectively.

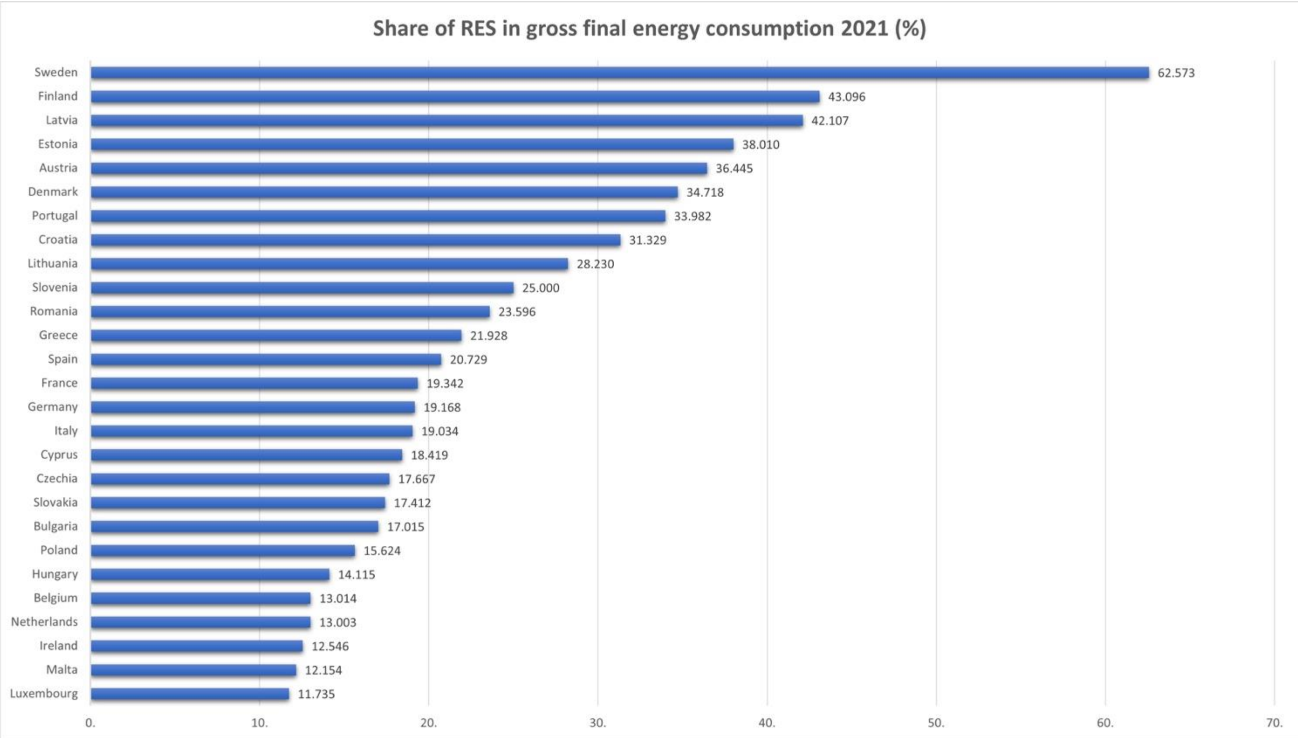
Analysis Variable : Primary energy consumption 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
27	48.4814815	67.3671017	0.7700000	266.9800000	20.3300000	138.9542970	2.2180440	4.5882840	6.6300000	48.7600000	42.1300000

Table 7 Output of MEANS procedure - Primary energy consumption (TOE)

Source: (own study)

The skewness is 2.21 represents right-sided distribution of data. Coefficient of variation is 138.95 shows high variability in dataset. Moreover, the means, quartiles and standard deviation are statistically insignificant.

4.1.2.2 Share of RES in gross final energy consumption (%)



Graph 7 Share of RES in gross final energy consumption (%)

Source: (Eurostat data files)

This indicator shows how countries utilizes RES and their share percentage in total energy consumption. Sweden, Finland and Latvia secure the top three spots with 62.57, 43.09 and 42.10 respectively. Share of RES in Czech Republic is 17.66%.

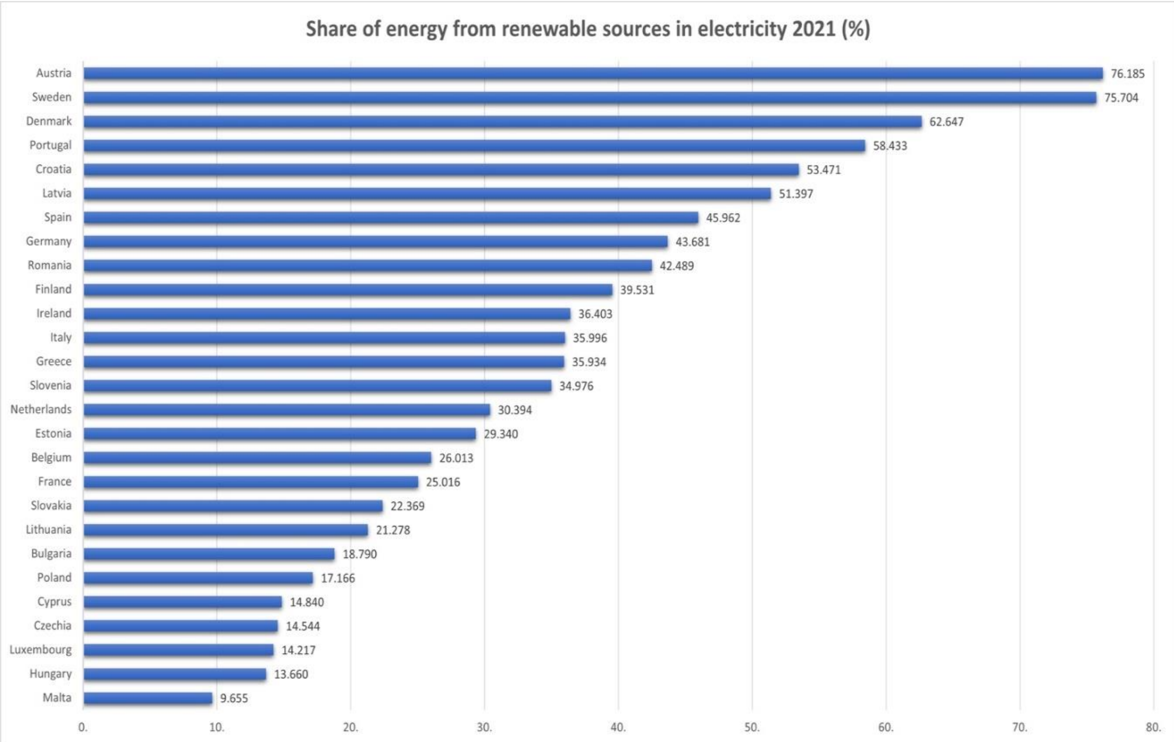
Analysis Variable : 2021 Share of RES in gross final energy consumption											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
27	24.5181852	12.2336007	11.7350000	62.5730000	19.3420000	49.8960287	1.3829966	2.0772037	15.6240000	33.9820000	18.3580000

Table 8 Output of MEANS procedure - Share of RES in gross final energy consumption (%)

Source: (own study)

High coefficient of variation represents variability. Skewness of 1.38 represents right-sided distribution of the dataset. Standard variation and quartiles support data variability and dispersion.

4.1.2.3 Share of RES in gross electricity consumption



Graph 8 Share of RES in gross electricity consumption (%)

Source: (Eurostat data files)

This indicator gives information about the usage of RES for electricity consumption. Austria, Sweden and Denmark are the top 3 countries with 76.185, 75.704 and 62.64 % respectively. Czech Republic is at the second half of the chart with 14.54 %.

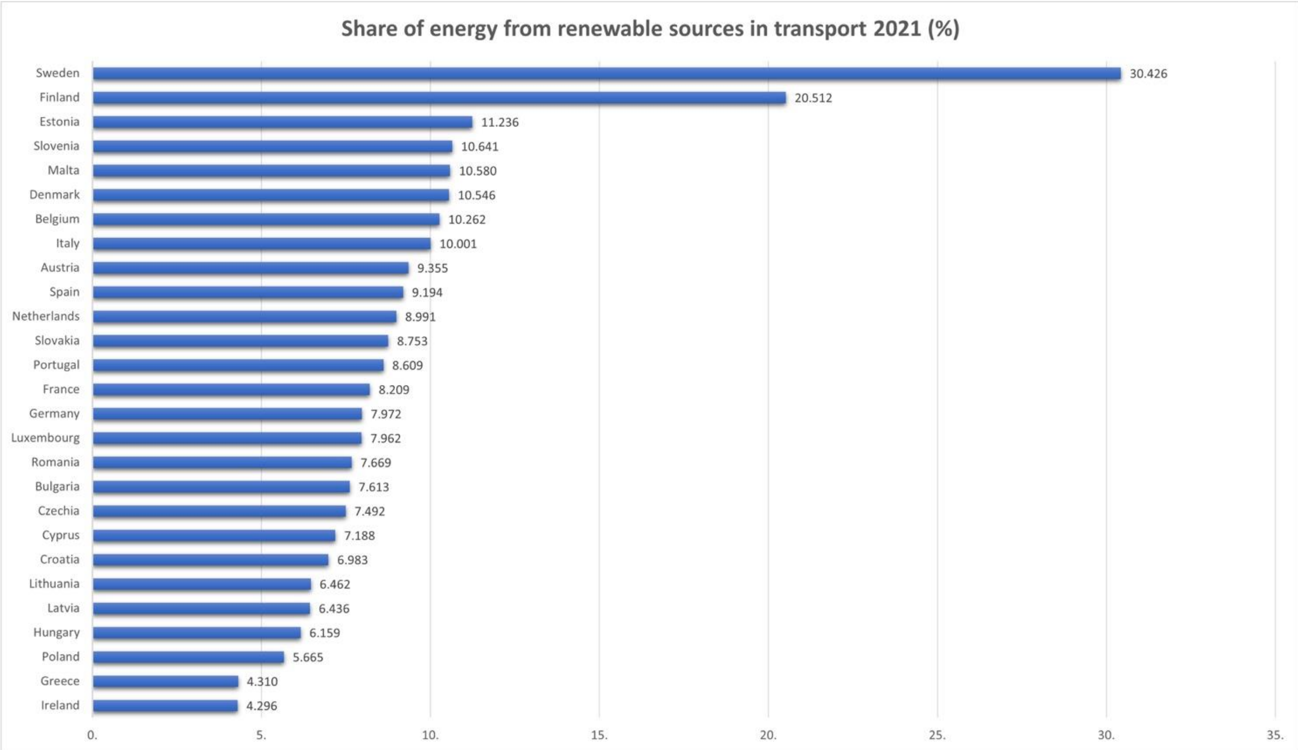
Analysis Variable : 2021 Share of energy from RS in gross EC											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
29	40.1168276	25.8261750	9.6550000	113.6700000	35.9340000	64.3774111	1.2971100	1.5234826	21.2780000	51.3970000	30.1190000

Table 9 Output of MEANS procedure - Share of RES in gross electricity consumption.

Source: (own study)

The skewness is 1.29 which indicates right-sided data distribution. Means, quartiles and standard deviation represent some data variability.

4.1.2.4 Share of energy from renewable sources in transport (%)



Graph 9 Share of energy from renewable sources in transport (%)

Source: (Eurostat data files)

This indicator shows the usage of RES energy in transport. Sweden and Finland dominate this indicator with 30.42 and 20.51 % respectively. The percentage in Czech Republic 7.49 %. Ireland, Greece and Poland are the least countries with 4.29, 4.31 and 5.665 % respectively.

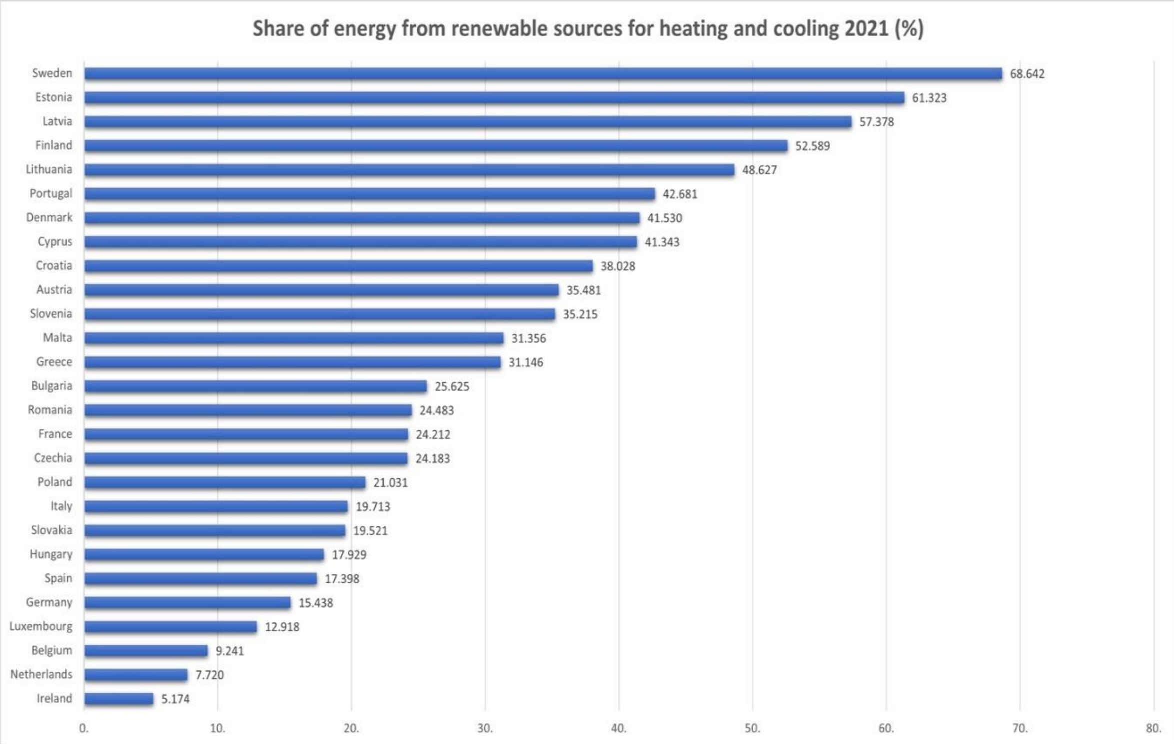
Analysis Variable : 2021 Share of energy from renewable sources in transport											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
27	9.3897037	5.1719072	4.2960000	30.4260000	8.2090000	55.0806219	3.0769246	11.0496472	6.9830000	10.2620000	3.2790000

Table 10 Output of MEANS procedure - Share of energy from renewable sources in transport (%)

Source: (own study)

The output presents a skewness of 3.07 which indicate a right-sided distribution of data. Coefficient of variation, mean, standard deviation and quartiles show moderate variability in the dataset.

4.1.2.5 Share of energy from renewable sources for heating and cooling (%)



Graph 10 Share of energy from renewable sources for heating and cooling (%)

Source: (Eurostat data files)

This indicator shows the usage of RES energy in heating and cooling. One more time, Sweden secures the top spot in this indicator with 68.64 %, while Estonia and Latvia came 2nd and 3rd with 61.32 and 57.37 % respectively, Interestingly, most countries are performing well in this sector compared to the share of RES in transport. This also applies to Czech Republic with 24.18 %, however it has a room to grow.

Analysis Variable : Share of energy heating cooling 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
27	30.7379630	16.8462346	5.1740000	68.6420000	25.6250000	54.8059565	0.5709480	-0.3687618	17.9290000	41.5300000	23.6010000

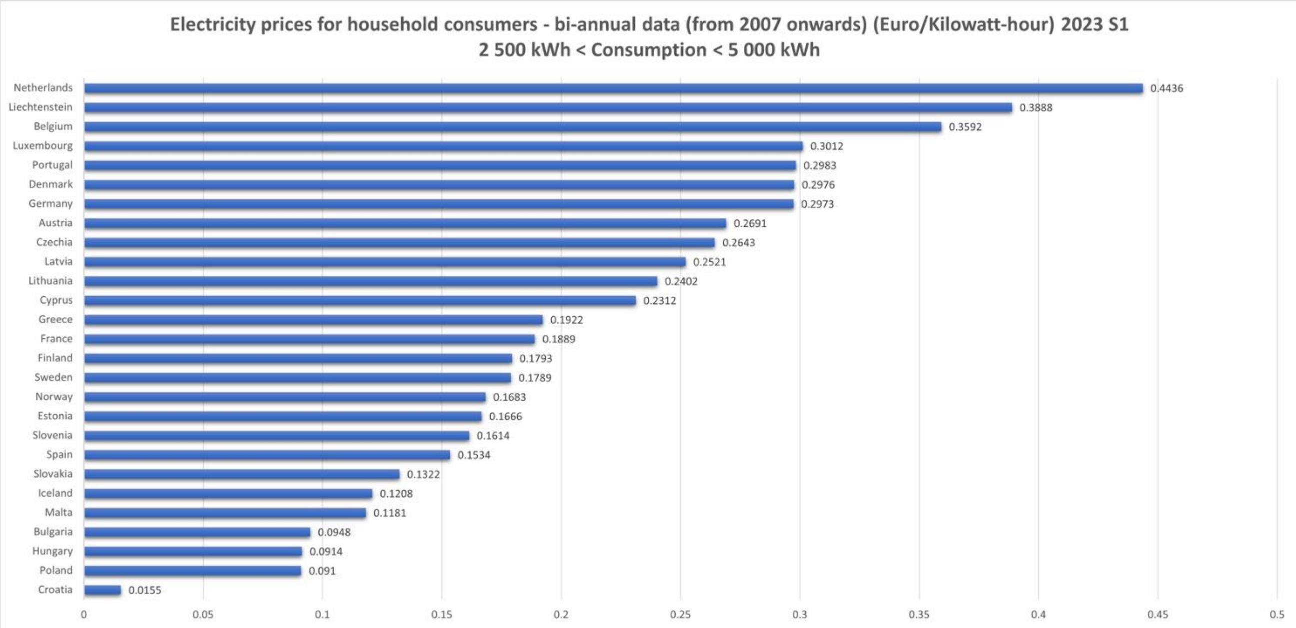
Table 11 Output of MEANS procedure - Share of energy from renewable sources for heating and cooling (%)

Source: (own study)

Skewness of 0.57 represents positive right-sided data distribution. Moderate variability is confirmed with 54.80 coefficient of variation in addition to mean, quartiles and standard deviation.

4.1.3 Data related to economy.

4.1.3.1 The average price of electricity (EUR/kWh)



Graph 11 Average price of electricity.

Source: (Eurostat data files)

This indicator explains the price of energy kWh for household consumers in EU countries. Netherlands, Luxembourg, and Belgium are the most expensive with 0.44, 0.38 and 0.35 EUR. Croatia, Poland and Hungary are the cheapest countries with 0.01, 0.09 and 0.09 EUR. The price in Czech Republic is 0.26 EUR which is higher than the mean (0.21).

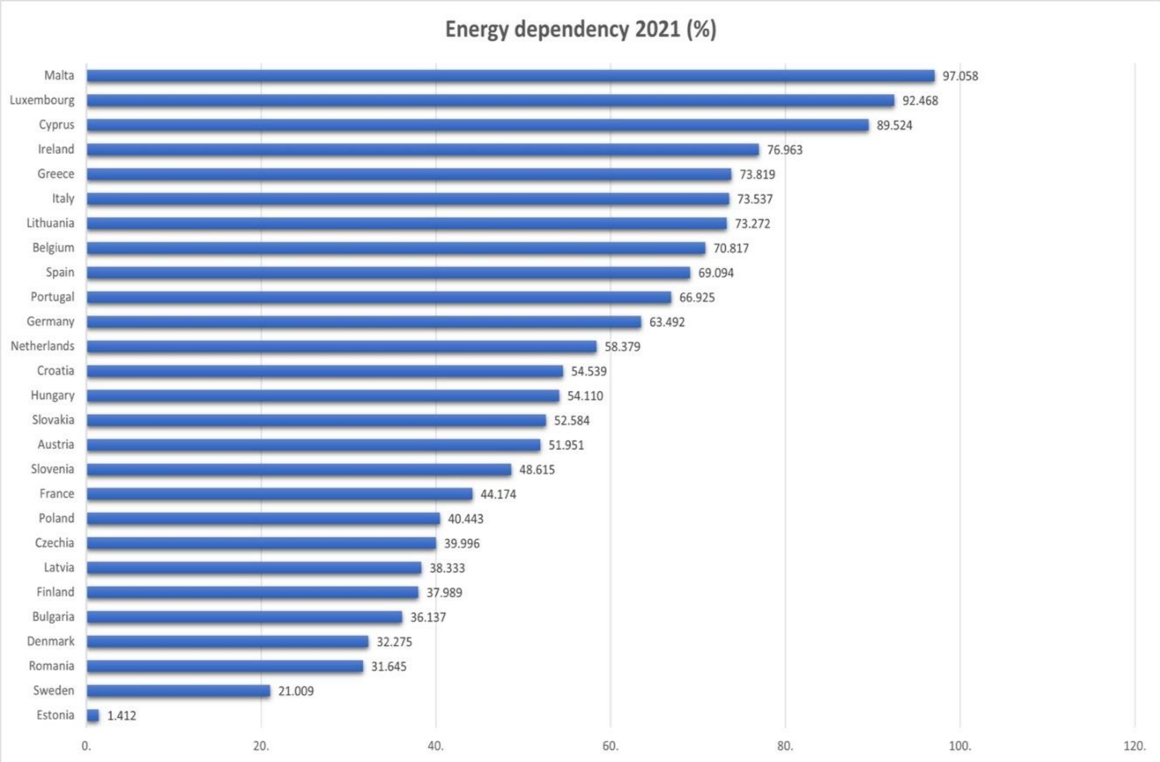
Analysis Variable : Total												
N	Mean	Std Dev	Minimum	Maximum	Median	Variance	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile	Quartile Range
27	0.2109519	0.1006521	0.0155000	0.4436000	0.1889000	0.0101309	47.7133257	0.3900067	-0.1073764	0.1322000	0.2973000	0.1651000

Table 12 Output of MEANS procedure - Data related to economy.

Source: (own study)

The data variability is moderate in this indicator as shown in quartiles, mean and standard deviation. The mean is 0.21 but cannot be used as a relative value due to recent inflation in energy prices.

4.1.3.2 Energy dependence (%)



Graph 12 Energy dependance.

Source: (Eurostat data files)

This parameter describes how countries rely on importing energy to cover its energy requirements. It is calculated using the formula (share of net imports / gross domestic energy consumption). The mean is 55.20% which shows that more than half of the energy in Europe is dependent on imports. Malta, Luxembourg and Cyprus are the most dependent countries with 97.05, 92.46 and 89.52 % respectively. Estonia, Sweden and Romania are the least dependent with 1.41, 21.009 and 31.645 % respectively. Czech Republic shows low dependance with 39.99 % which is lower than the mean (55.20).

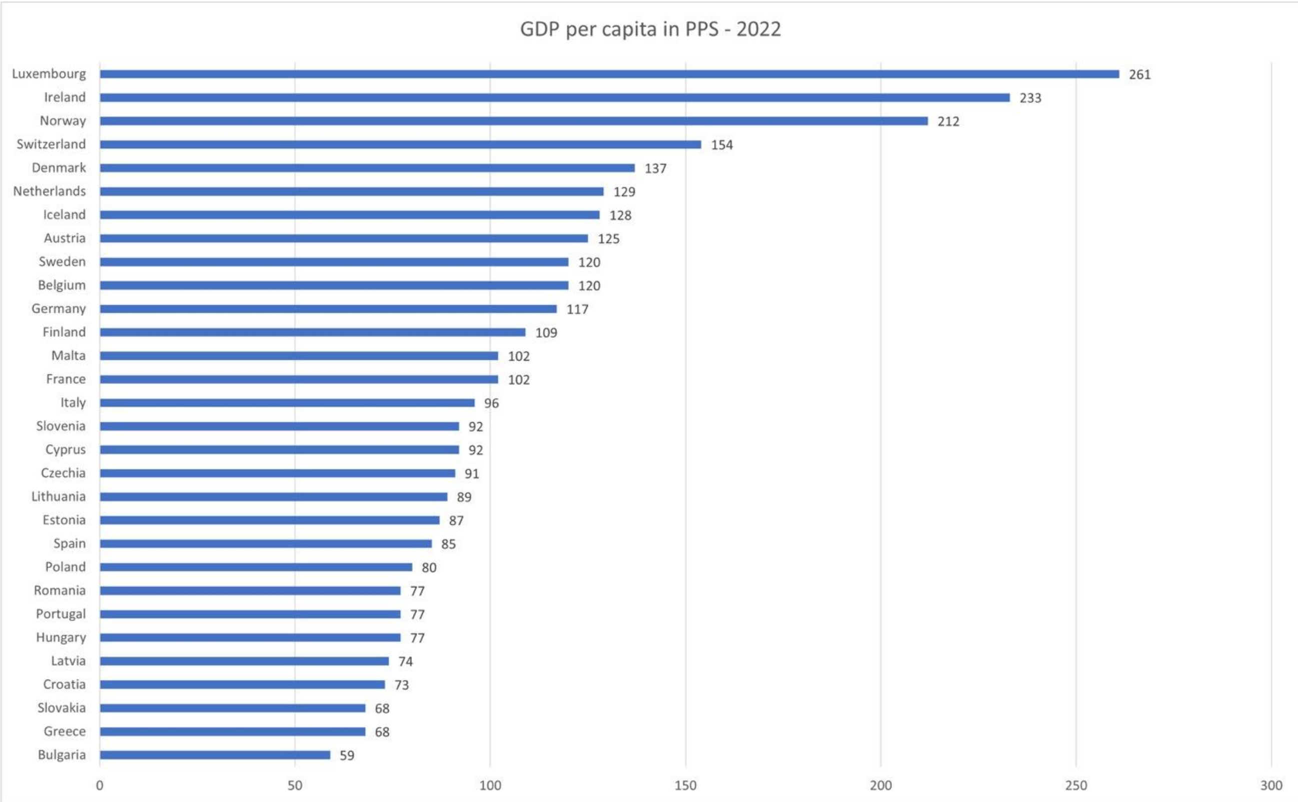
Analysis Variable : Energy dependence 2021											
N	Mean	Std Dev	Minimum	Maximum	Median	Variance	Range	Skewness	Kurtosis	Lower Quartile	Upper Quartile
27	55.2059259	22.5107771	1.4120000	97.0580000	54.1100000	506.7350866	95.6460000	-0.1569351	-0.0183823	38.3330000	73.2720000

Table 13 Output of MEANS procedure - Energy dependance.

Source: (own study)

The data shows high degree of variability and extreme values are recorded at the top and bottom of the chart in Malta and Estonia. Mean, standard deviation and quartiles confirm the high variability. Skewness of -0.15 indicates negative. Left-sided distribution of the data.

4.1.3.3 GDP per capita (PPS)



Graph 13 GDP per capita

Source: (Eurostat data files)

This indicator represents the purchase power of the individuals and the economic activity. It is expressed in purchasing power standards (PPS) and interpreted relative to the EU average which is 111. The highest GDP is recorded in Luxembourg, Ireland and Denmark with 261, 233 and 137 PPS respectively. Luxembourg and Ireland are more than twice the EU average. Czech Republic GDP is 91 which is just below the average. Bulgaria, Greece and Slovakia are the lowest countries with 59, 68 and 68 PPS respectively.

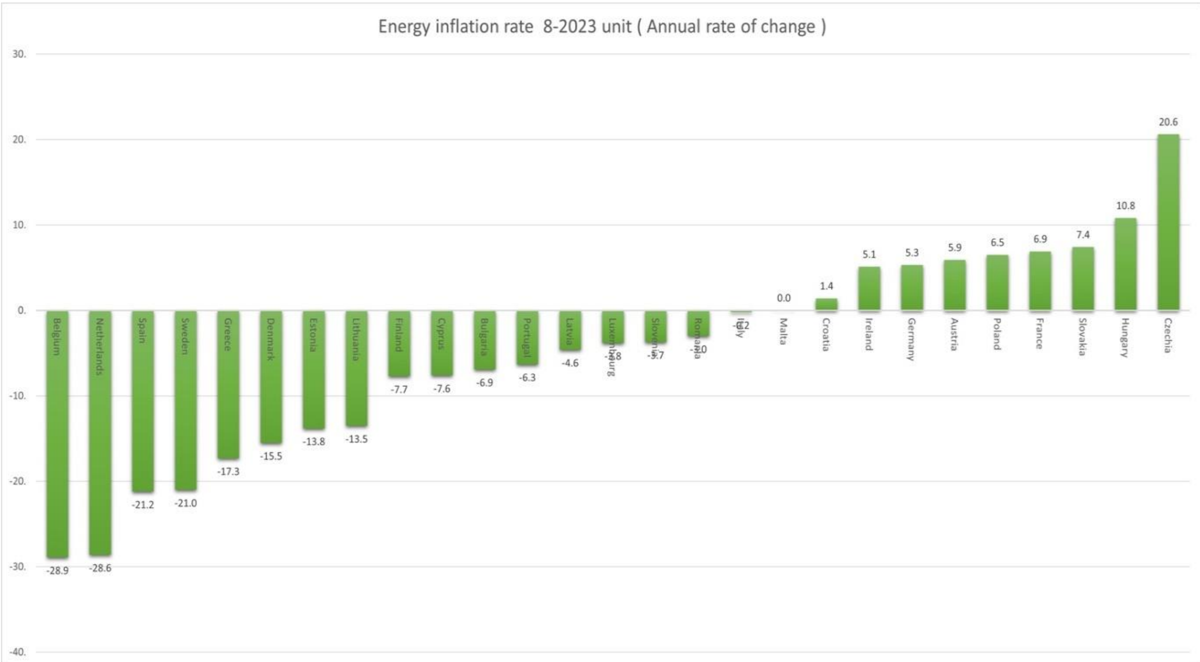
Analysis Variable : 2022 GDP per capita in PPS - 2022											
N	Mean	Std Dev	Minimum	Maximum	Median	Variance	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile
30	111.1333333	48.4267903	59.0000000	261.0000000	94.0000000	2345.15	43.5753962	1.8493467	3.2763225	77.0000000	125.0000000

Table 14 Output of MEANS procedure - GDP per capita

Source: (own study)

The dataset shows right-sided distribution as expressed with 1.84 skewness. Mean, standard deviation and quartiles represent less variability in the dataset.

4.1.3.4 Energy inflation rate (%)



Graph 14 energy inflation rate.

Source: (Eurostat data files)

This indicator shows the annual change in energy prices compared to the previous year. It shows that about 16 countries successfully managed to decrease the price after its surge in 2022. Belgium, Netherland and Spain are the top performers. On the other hand, Czechia Republic, Hungary and Slovakia are the least performers.

Analysis Variable : 2023-08 Energy inflation rate 2023-08											
N	Mean	Std Dev	Minimum	Maximum	Median	Range	Coeff of Variation	Skewness	Kurtosis	Lower Quartile	Upper Quartile
27	-4.9518519	12.1417072	-28.9000000	20.6000000	-3.8000000	49.5000000	-245.1952841	-0.2389301	-0.2340312	-13.8000000	5.3000000

Table 15 Output of MEANS procedure - energy inflation rate.

Source: (own study)

The outputs indicate that most countries managed the surge in prices as indicated in the mean -4.95. Coefficient of variation, quartiles and mean represent variation in the dataset. The chart is left-sided as indicated in the skewness -0.23.

4.2 Principal component analysis

It is used to minimize the total number of original variables, referred as components. The result of PCA comprises a summary of the information included in the original components with minimal loss of information. The proportion of each component is also determined using the AHK correlation matrix and described the total variance and intercorrelation of components.

Data of variables have different units of measurement and show high variability. Therefore, standardization was a necessity to be done before proceeding with principal component analysis. Standardization was done using STDIZE function in the SAS program. The results of standardization are shown in Table 1. The first column contains all 14 indicators, the second column comprises the average value, the third column lists the standard deviation, the fifth column shows the number of countries included in the analysis, while the fifth contain the label as explanation of indicator name.

Location and Scale Measures				
Location = mean Scale = standard deviation				
Name	**Location**	**Scale**	**N**	**Label**
electricity prices	0.210952	0.100652	27	electricity prices
Energy dependence	55.205926	22.510777	27	Energy dependence
Energy inflation rate	-4.951852	12.141707	27	Energy inflation rate
GDP per capita in PPS	105.185185	45.892045	27	GDP per capita in PPS
Fossil fuel energy production	3369.129333	9535.009554	27	Fossil fuel energy production
Natural gas energy production	1405.341593	3282.948192	27	Natural gas energy production
Nuclear power generation	6913.426185	19085	27	Nuclear power generation
Oil production	18546	24825	27	Oil production
Primary energy consumption	48.481481	67.367102	27	Primary energy consumption
Primary energy production from R	9319.732778	11506	27	Primary energy production from RES
Share of energy from renewable s	30.737963	16.846235	27	Share of energy from renewable sources for heating and cooling
Share of energy from renewable_1	35.188556	18.675832	27	Share of energy from renewable sources in electricity
Share of energy from renewable_3	9.389704	5.171907	27	Share of energy from renewable sources in transport
Share of RES in gross final ener	24.518185	12.233601	27	Share of RES in gross final energy consumption

Table 16 STDIZE procedure output

Source: (own study)

The standardized data underwent principal component analysis using the SAS program through PRINCOMP procedure and the command is as follows.

```
proc princomp data=WORK.IMPORT plots(only)=(scree);
var 'electricity prices'n 'Energy dependence'n 'Energy inflation rate'n
'GDP per capita in PPS'n 'Fossil fuel energy production'n
'Natural gas energy production'n 'Nuclear power generation'n
'Oil production'n 'Primary energy consumption'n
'Primary energy production from R'n 'Share of energy from renewable s'n
'Share of energy from renewable_1'n 'Share of energy from renewable_2'n
'Share of energy from renewable_3'n 'Share of RES in gross final ener'n;
run;
```

The main output is how each component contributes to the total variance. The proportion column shows the extent of contribution to the total variance expressed by individual component. The contribution of the first four components is 77.49%. The high data variability in each indicator leads to a challenge in the analysis. This challenge would cluster most EU states in one large cluster with minimal distance. Therefore, components related to alternative sources of energy, fossil fuels, natural gas, oil and nuclear power, were excluded. The share of the components combined were minimal, however their information was valuable to understand all possible sources of energy involved in each EU country and were used for the final cluster analysis.

Eigenvalues of the Correlation Matrix				
	Eigenvalue	Difference	Proportion	Cumulative
1	4.94531353	1.00879200	0.3297	0.3297
2	3.93652153	2.24438286	0.2624	0.5921
3	1.69213867	0.64219565	0.1128	0.7049
4	1.04994302	0.05774147	0.0700	0.7749
5	0.99220154	0.19137223	0.0661	0.8411
6	0.80082931	0.12117363	0.0534	0.8945
7	0.67965568	0.25659877	0.0453	0.9398
8	0.42305692	0.14126444	0.0282	0.9680
9	0.28179247	0.11738486	0.0188	0.9868
10	0.16440761	0.15056886	0.0110	0.9977
11	0.01383875	0.00270328	0.0009	0.9986
12	0.01113547	0.00259090	0.0007	0.9994
13	0.00854457	0.00792362	0.0006	1.0000
14	0.00062094	0.00062094	0.0000	1.0000

Table 17 Eigenvalues of the AHK correlation matrix

Source: (own study)

After excluding the first three indicators, a total of 10 revised indicators were implemented to understand and interpret interdependencies. Again, data were standardized before the new AHK analysis. The output of AHK is a correlation matrix that gauges the extent of interdependence among individual variables in the set. Also, the matrix facilitates the identification of direct and indirect dependencies between indicators. Notably, along the diagonal, values are equal to one, signifying maximum direct dependence. This robust analysis provides valuable insights into the structure and relationships within the dataset, paving the way for a nuanced understanding of the factors influencing energy source choices among EU countries.

Correlation Matrix															
		electricity prices	Energy dependence	GDP per capita in PPS	Oil production	Primary energy consumption	Primary energy production from R	Share of energy from renewable s	Share of energy from renewable_1	Share of energy from renewable_3	Share of RES in gross final ener	Energy inflation rate	Fossil fuel energy production	Natural gas energy production	Nuclear power generation
electricity prices	electricity prices	1.0000	0.0097	0.2566	0.2470	0.1658	0.1410	-.1339	0.0684	-.0238	-.0380	-.3331	0.0274	0.5027	-.0151
Energy dependence	Energy dependence	0.0097	1.0000	0.3419	0.1013	-.0003	-.0939	-.4811	-.3397	-.3813	-.5844	-.0016	-.1239	-.0537	-.1212
GDP per capita in PPS	GDP per capita in PPS	0.2566	0.3419	1.0000	-.0068	-.0367	-.0215	-.3260	0.0061	0.0445	-.1761	-.0269	-.1124	0.0640	-.0292
Oil production	Oil production	0.2470	0.1013	-.0068	1.0000	0.9692	0.8925	-.4284	0.0546	-.0501	-.2432	0.0106	0.4148	0.3104	0.5528
Primary energy consumption	Primary energy consumption	0.1658	-.0003	-.0367	0.9692	1.0000	0.9269	-.3454	0.0354	-.0163	-.1823	0.1738	0.4774	0.2110	0.6446
Primary energy production from R	Primary energy production from R	0.1410	-.0939	-.0215	0.8925	0.9269	1.0000	-.1139	0.2943	0.2881	0.1199	0.0770	0.3790	0.1485	0.5207
Share of energy from renewable s	Share of energy from renewable s	-.1339	-.4811	-.3260	-.4284	-.3454	-.1139	1.0000	0.4286	0.5388	0.8800	-.1972	-.2275	-.3842	-.1181
Share of energy from renewable_1	Share of energy from renewable_1	0.0684	-.3397	0.0061	0.0546	0.0354	0.2943	0.4286	1.0000	0.4292	0.7471	-.2369	-.1759	-.0026	-.0685
Share of energy from renewable_3	Share of energy from renewable_3	-.0238	-.3813	0.0445	-.0501	-.0163	0.2881	0.5388	0.4292	1.0000	0.7011	-.3355	-.1857	-.1042	0.0571
Share of RES in gross final ener	Share of RES in gross final ener	-.0380	-.5844	-.1761	-.2432	-.1823	0.1199	0.8800	0.7471	0.7011	1.0000	-.2461	-.2125	-.2446	-.0654
Energy inflation rate	Energy inflation rate	-.3331	-.0016	-.0269	0.0106	0.1738	0.0770	-.1972	-.2369	-.3355	-.2461	1.0000	0.3411	-.2213	0.1486
Fossil fuel energy production	Fossil fuel energy production	0.0274	-.1239	-.1124	0.4148	0.4774	0.3790	-.2275	-.1759	-.1857	-.2125	0.3411	1.0000	0.1772	-.0054
Natural gas energy production	Natural gas energy production	0.5027	-.0537	0.0640	0.3104	0.2110	0.1485	-.3842	-.0026	-.1042	-.2446	-.2213	0.1772	1.0000	-.0919
Nuclear power generation	Nuclear power generation	-.0151	-.1212	-.0292	0.5528	0.6446	0.5207	-.1181	-.0685	0.0571	-.0654	0.1486	-.0054	-.0919	1.0000

Table 18 correlation matrix

Source: (own study)

Another output of Principal component analysis is the eigenvalues of the correlation matrix. The proportion of first parameters increased by over 10% due to the deletion of the selected components from the previous analysis that included all 14 components.

Eigenvalues of the Partial Correlation Matrix				
	Eigenvalue	Difference	Proportion	Cumulative
1	3.54171249	0.44226227	0.3542	0.3542
2	3.09945023	1.85974070	0.3099	0.6641
3	1.23970953	0.35723168	0.1240	0.7881
4	0.88247785	0.29931075	0.0882	0.8763
5	0.58316709	0.18658871	0.0583	0.9347
6	0.39657838	0.18123786	0.0397	0.9743
7	0.21534052	0.19129825	0.0215	0.9958
8	0.02404227	0.00963233	0.0024	0.9982
9	0.01440993	0.01129823	0.0014	0.9997
10	0.00311171		0.0003	1.0000

Table 19 Eigenvalues of correlation matrix

Source: (own study)

The increment in proportion is also verified through scree plot and variance explained graphs. The total share of first three components became 69.41%. The share of the fourth component is 10.14% which brings the total share of the first four parameters to 79.55%. Those components will be included in further analysis due to their importance to the EU countries.

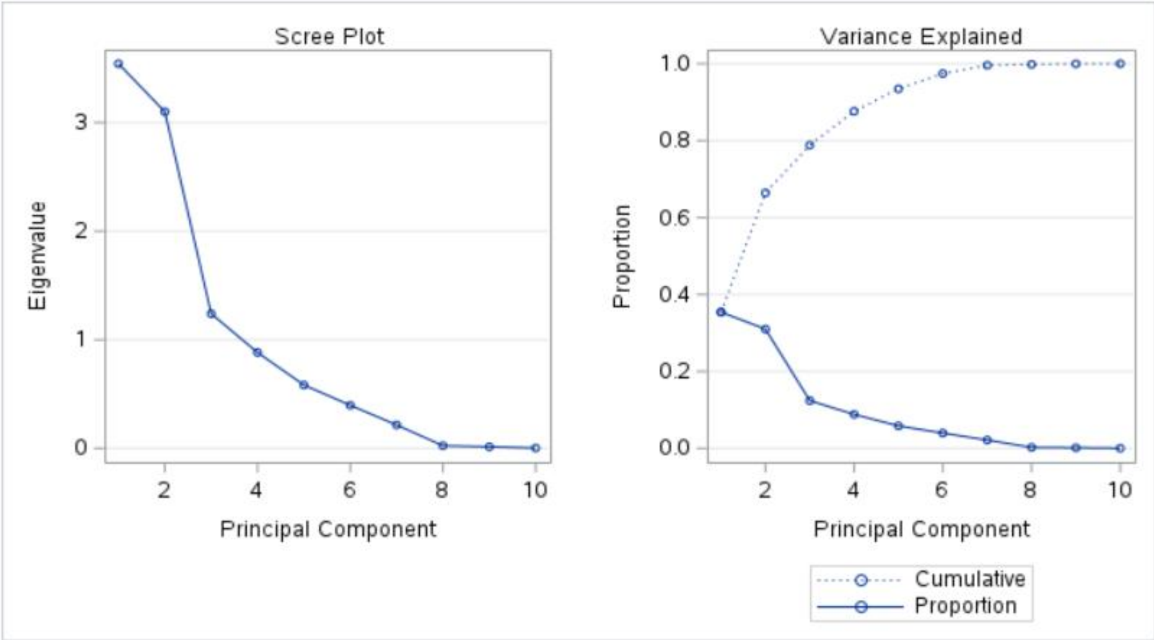


Table 20 visualization variance explained analysis.

Source: (own study)

Next step of analysis was the PRINCOMP of the remaining ten components among themselves. The degree of correlation between the components is presented in Table 5.

Eigenvectors											
		Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10
electricity prices	electricity prices	-.022176	0.101326	0.637112	-.693245	0.214213	-.038033	-.233783	-.016675	0.019583	-.009569
Energy dependence	Energy dependence	-.394224	0.210956	0.050193	0.141957	0.039129	0.832133	-.264681	-.011148	-.095000	0.065052
GDP per capita in PPS	GDP per capita in PPS	-.149697	0.114602	0.708266	0.468704	-.177822	-.065366	0.451906	0.043557	0.029767	-.015383
Oil production	Oil production	-.056225	0.548664	-.152608	-.101418	0.002102	-.079954	0.098811	0.728773	-.068227	-.332124
Primary energy consumption	Primary energy consumption	0.024745	0.552363	-.135540	-.096008	0.086962	-.080625	0.234422	-.143568	0.116191	0.750710
Primary energy production from R	Primary energy production from R	0.215317	0.509656	-.049854	0.070573	0.146716	-.001442	0.050490	-.619687	-.061597	-.523965
Share of energy from renewable s	Share of energy from renewable s	0.448562	-.164289	-.015289	-.185533	0.173220	0.496607	0.504215	0.114492	0.430359	-.089285
Share of energy from renewable_1	Share of energy from renewable_1	0.387095	0.189275	0.097459	0.014647	-.729254	0.074881	-.387022	0.018953	0.340661	0.031716
Share of energy from renewable_3	Share of energy from renewable_3	0.387991	0.054493	0.161398	0.468943	0.564804	-.073401	-.439848	0.205343	0.165990	0.113848
Share of RES in gross final ener	Share of RES in gross final ener	0.519581	-.020607	0.100004	-.023406	-.105114	0.176993	0.079496	0.079579	-.799340	0.158395

Table 21 analysis of ten components

Source: (own study)

4.3 Cluster analysis

This is the last step in the practical part. It aims to finding clusters of states that share some degree of similarity of indicators related to renewable energy sources. It summarizes all the analysis that have been done beforehand.

Data standardization was done before the cluster analysis. Later the CLUSTER procedure was performed using SAS as follows.

```
proc cluster data=Work._Temp_sdz method=ward plots outtree=work.Cluster_tree;
var 'R_electricity prices'n 'R_Energy dependence'n 'R_GDP per capita in PPS'n
'R_Oil production'n 'R_Primary energy consumption'n
'R_Primary energy production from'n 'R_Share of energy from renewable'n
'R_Share of energy from renewabl2'n 'R_Share of energy from renewabl3'n
'R_Share of RES in gross final en'n;
id name;
run;
```

The CLUSTER procedure determines similar states and combine them into single clusters. Ward’s method was used to connect clusters and it minimize the increment in residual variance as well as minimizing the loss of information. The output of CLUSTER procedure is in Table 6

Cluster History						
Number of Clusters	Clusters Joined		Freq	Semipartial R-Square	R-Square	Tie
26	France	Netherlands	2	0.0012	.999	
25	Hungary	Slovakia	2	0.0014	.997	
24	CL26	Slovenia	3	0.0024	.995	
23	Cyprus	Lithuania	2	0.0026	.992	
22	Croatia	Portugal	2	0.0027	.990	
21	Germany	Italy	2	0.0044	.985	
20	Bulgaria	CL25	3	0.0051	.980	
19	Denmark	Romania	2	0.0082	.972	
18	CL23	Greece	3	0.0093	.963	
17	CL24	Poland	4	0.0097	.953	
16	Czechia	CL19	3	0.0112	.942	
15	CL18	Malta	4	0.0125	.929	
14	Ireland	Luxembourg	2	0.0155	.914	
13	CL20	CL17	7	0.0183	.896	
12	CL16	Latvia	4	0.0185	.877	
11	Finland	Sweden	2	0.0189	.858	
10	CL12	Estonia	5	0.0229	.835	
9	Belgium	CL14	3	0.0252	.810	
8	CL21	Spain	3	0.0285	.782	
7	Austria	CL10	6	0.0307	.751	
6	CL13	CL15	11	0.0311	.720	
5	CL6	CL22	13	0.0467	.673	
4	CL7	CL11	8	0.0871	.586	
3	CL9	CL5	16	0.1269	.459	
2	CL4	CL3	24	0.2155	.243	
1	CL2	CL8	27	0.2434	.000	

Table 22 Clustering history

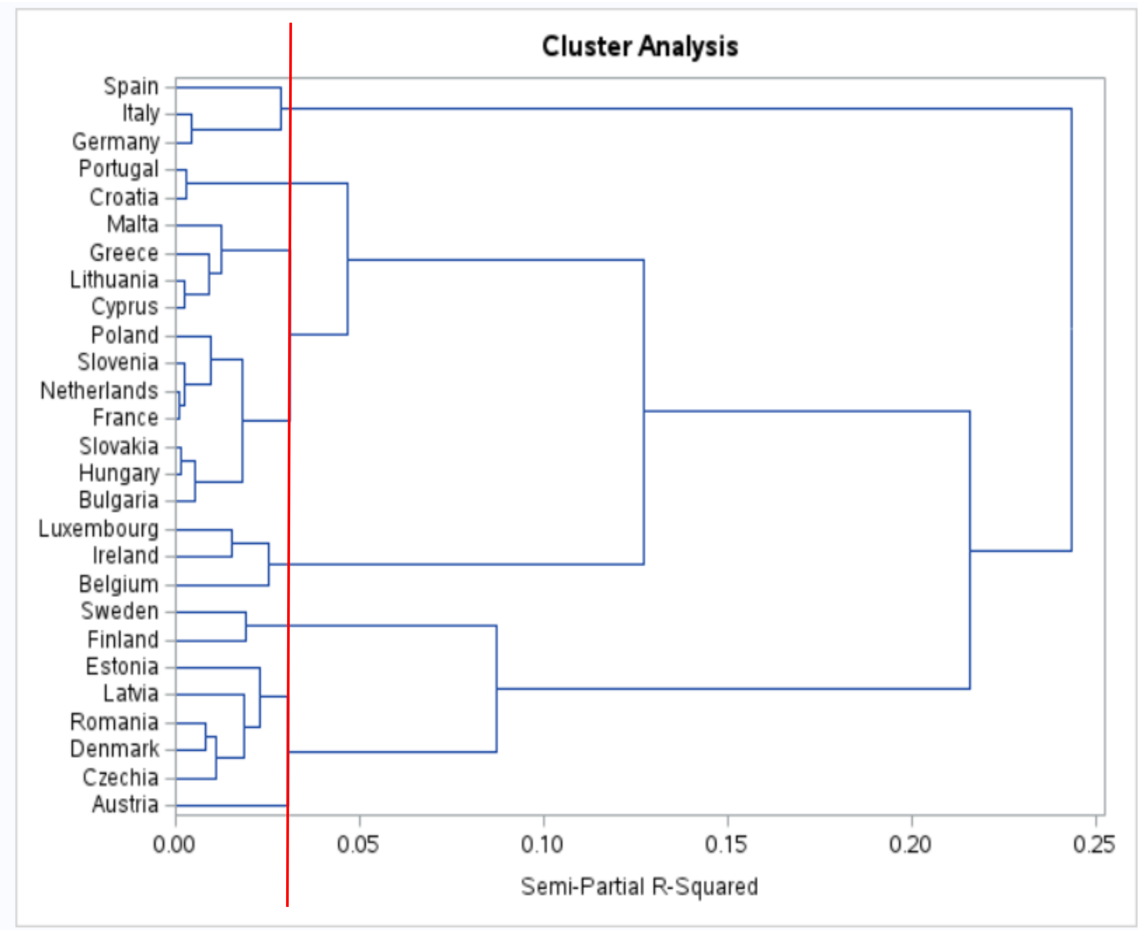
Source: (own study)

The Freq column shows how many times the variables comprising each result is made up of cluster. The contribution of newly contributed clusters is measured using Semipartial R-square. The R-square is low in within-cluster variability and high in between-cluster variability. Pseudo F statistics shows the degree of variability in between-cluster variability. The Pseudo t-squared shows the places where clustering has more clusters.

The dendrogram is created as follow

```
Proc tree data = tree out=new graphics horizontal;
ID state;
run;
```

The output of dendogram commans is shown in Figure 38



Graph 15 dendrogram by countries.

Source: (own study)

Red vertical line is implemented to mark the end of clustering and following clusters are described.

Cluster 1: It includes Spain, Italy and Germany. These three countries are big producers of energy. Germany, in particular, is the leader in renewable energy production. Germany invest huge amount in the energy production however, it is one of the most expensive states. Interestingly, the use of RES in own energy consumption represents a small portion in Germany. Italy and Spain share high consumption of total energy which is attributed to the big land and population. Moreover, Spain and Italy show high degree of energy dependence and expensive electricity.

Cluster 2: It includes Portugal and Croatia. Both countries are not big producers of renewable energy but the similarity between them is high share of renewable energy in energy consumption.

Cluster 3: Malta, Greece, Lithuania and Cyprus. They are small to medium-sized countries. Their size influences the production level and consumption in the area of renewable energy sources.

Cluster 4: Poland, Slovenia, Netherlands, France, Slovakia, Hungary and Bulgaria. This cluster show high degree of variability among the states included. Netherlands is the top producer of natural gas. France is the biggest producer of nuclear power. Poland is the leader in fossil fuels. Moreover, France is the second biggest producer of renewable energy. Slovenia, Slovakia, Hungary and Bulgaria are similar in being average in the production and utilization of renewable energy sources.

Cluster 5: Luxembourg, Ireland and Belgium. They are similar in high GDP. Additionaly, they do not show interest in RES. This can be attributed to being dependent on their natural sources and financial capability.

Cluster 6: Sweden and Finland. They both are high producers of renewable energy and usage in different aspects. Sweden is in the lead spot of final energy consumption and second in gross electricity consumption. Finland secures a top 3 position in transport and heating and cooling.

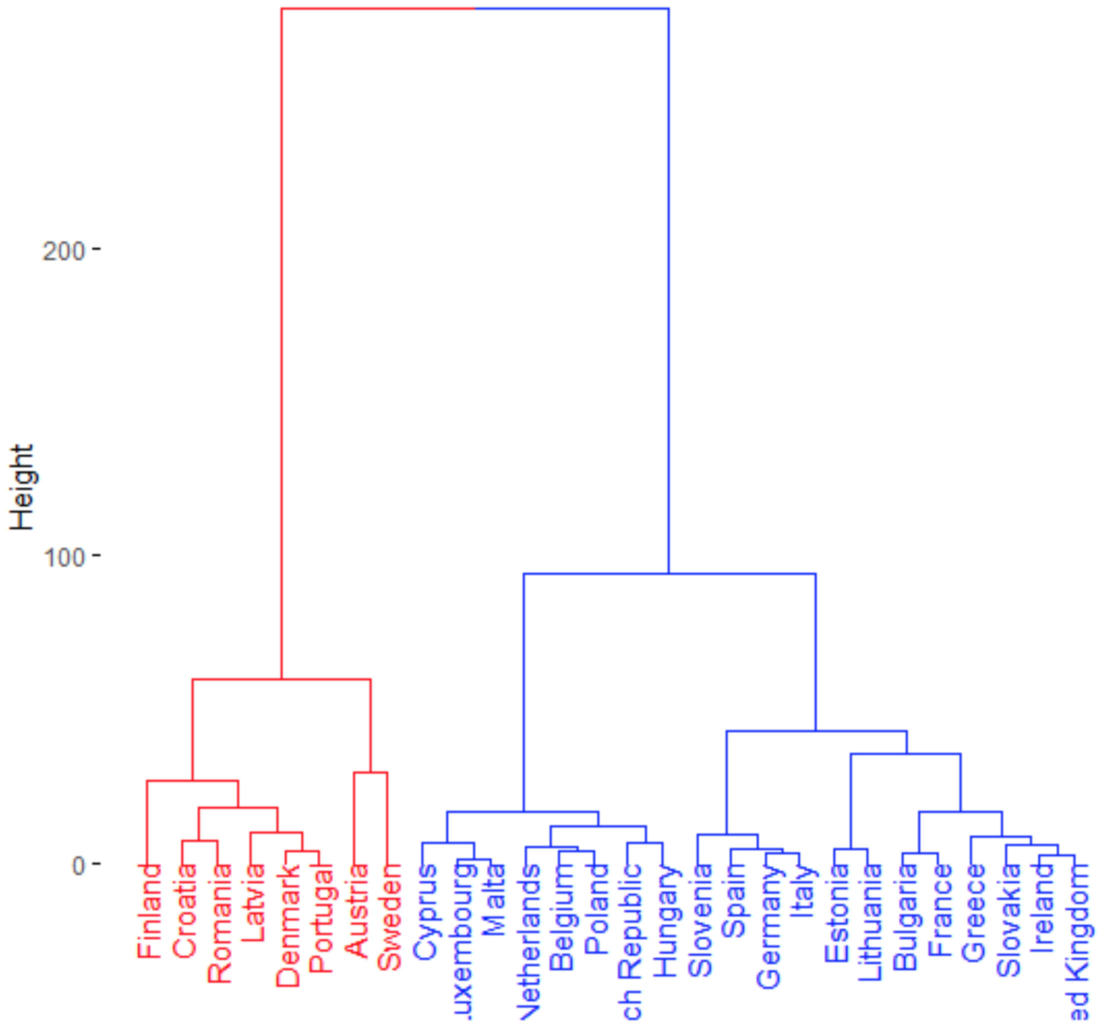
Cluster 7: Estonia, Latvia, Romania, Denmark, Czech Republic. Denmark is one of the most expensive electricity prices. Energy production in Denmark is mainly from its own natural gas and oil. Estonia and Latvia are one of the least RES producers. Estonia is one of the highest air polluters states. Estonia and Latvia are among the cheapest energy prices. Czech Republic is in the middle of RES table among EU states. Moreover, almost quarter of energy consumption comes from RES in Czech Republic.

Cluster 8: Austria. It is the only single state cluster. It is characterized by highest share of RES in electricity consumption. Austria is less dependent on fossil fuels, oil and natural gas. This makes it one of the least air polluters EU states.

5. Results and Discussion

5.1 Marinoiu Cristian (2018)

The study (Cristian, 2018) was conducted for data available in 2016. showed two clusters for all EU states. The indicators used in the analysis are only three and they are share of RES in the consumption of energy (I1), electricity (I2) and transport (I3). All indicators were included in our study. The red cluster contains 8 countries with high share if RES in energy consumption compared to the second cluster. Moreover, he found a statistically significant difference in the first two indicators, share of RES in energy and electricity. No significant difference observed in the third indicator, share of RES in transport.



Graph 16 Cluster analysis

5.2 Mihaela Simionescu (2020)

The authors (Simionescu et al., 2020) analysed data from 2007 and 2017. Here we compare our results to the analysis of 2017 due to high relevance and significance in the EU vision toward 2030 about RES. Two indicators were used in the study, and they are share of RES in electricity and GDP per capita. Both indicators were included in our study. Two clusters were created when including only the share of RES in electricity. Adding the GDP to the analysis resulted in three clusters.

Table 4. Clusters of countries according to the share of renewable energy in the final consumption in the EU-28 in 2017 (k-means method).

Clusters according to Share of Renewable Energy in Electricity in 2017		Clusters according to Share of Renewable Energy in Electricity and GDP per Capita in 2017		
Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3
Austria, Denmark, Estonia, Portugal, Romania, Croatia, Latvia, Sweden, Lithuania	Bulgaria, Belgium, Cyprus, Estonia, Finland, Greece, Hungary, France, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Poland, Slovakia, Slovenia, Spain, UK	Austria, Belgium, Denmark, Finland, France, Germany, Netherlands, UK, Sweden, Ireland	Luxembourg,	Bulgaria, Croatia, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Slovakia, Slovenia, Romania, Cyprus, Italy, Spain

Table 23 cluster of countries.

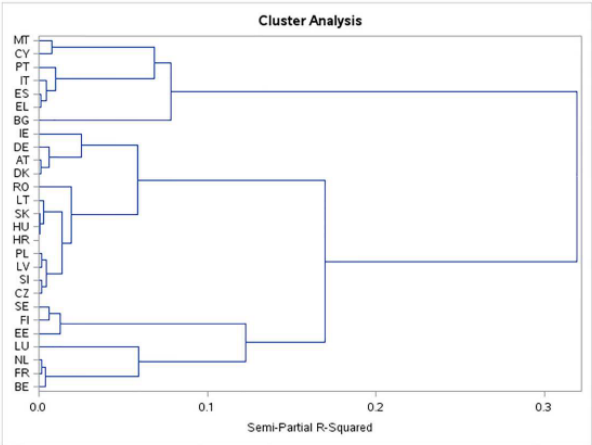
The left side of the table showing two clusters according to share of RES in electricity. Cluster 1 for high share and cluster 2 for low share. The clustering is highly consistent with our results except for Estonia which is not included in the high share cluster.

The right side of the table include the clusters after adding the GDP to the analysis. As a result, Luxembourg formed its own single-state cluster. This is also confirmed in our study with Luxembourg being the leader in GDP indicator. Moreover, Cluster 1 includes rich countries with high share of RES in electricity while, Cluster 3 is the opposite.

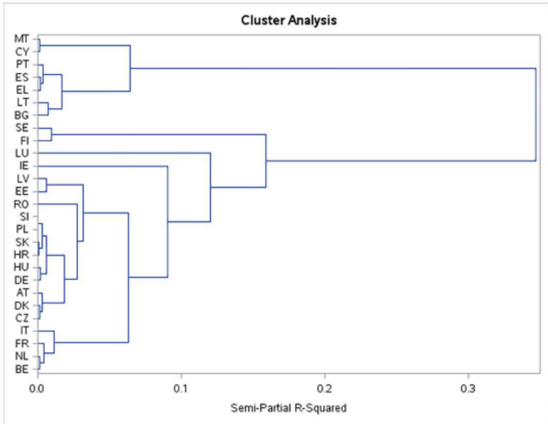
5.3 Silvia Megyesiova (2023)

The authors (Megyesiova et al., 2023) used eight indicators and they are; x1 primary energy consumption per capita, in tonnes of oil equivalent (TOE), x2 final energy consumption in households per capita, in kilograms of oil equivalent (KGOE), x3 energy productivity, in purchasing power standard (PPS) per kilogram of oil equivalent, x4 share of renewable energy in gross final energy consumption, percentage of total, x5 energy import dependency, percentage of total, x6 population unable to keep home adequately warm, percentage of total, x7 temperature ℃, average for the time span between 1991–2020, x8 GVA in industry (except construction), percent of total, average for the period 2010–2020. Four indicators are similar to those used in our study.

The cluster analysis was done for 2010 and 2020 separately. In 2010, the analysis depended on temperature and energy consumption and resulted in five clusters. On the other hand, in 2020, the analysis resulted in seven clusters according to the same principals used in 2010.



Graph 18 cluster analysis2010.



Graph 17 cluster analysis2020.

2010

2020

Using the temperature as indicator for RES improvement showed shifting of some countries in a good direction toward more clean and affordable energy production and consumption. In our study, the energy inflation rate was relevant to the period used in our study and showed the impact of higher energy prices from common sources on awareness about the advantages of RES.

6. Conclusions

The study was performed in three stages. First stage included selection of indicators related to different sector of RES and collection of their data from EUROSTAT. Moreover, exploratory analysis to understand the collected data in each country and how it is compared to other countries. The second step involves principal component analysis which mean reducing the original number of selected indicators to focus on those of high relevance on RES which aims to avoid the high variability in data. The third and last stage is cluster analysis which combine countries that have one or more sort of similarities in one cluster and differ from other clusters.

It is noticeable that Germany is the main contributor in RES followed by France. Moreover, Italy, Spain, Finland, and Sweden are big producer with above the average production and consumption. Belgium, Netherlands, Ireland and Luxembourg are of the least contributors despite being economically developed countries with high GDP.

In conclusion is that in recent years, there has been a noticeable shift away from using solid fossil fuels as the primary source of energy. This trend is particularly evident in countries where fossil fuels have traditionally been the main source of energy. Although solid fossil fuels are still a significant part of the energy mix, their share in overall energy consumption has significantly decreased over time. This shift is due to several factors, including increased awareness of the environmental impact of fossil fuels, advances in renewable energy technologies, and changing consumer preferences. As a result of this trend, we are likely to see a continued shift towards cleaner and more sustainable sources of energy in the coming years.

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8. List of pictures, tables, graphs and abbreviations

8.1 List of pictures

8.2 List of tables

8.3 List of graphs

8.4 List of abbreviations

RES	renewable energy sources
EU	European Union
Eurostat	European Statistical Office
GDP	Growth domestic product
CO2	carbon
kWh	kilowatt-hours
TOE	Tonnes of Oil Equivalent
IEA	International Electricity Agency