Analysis of Primary Energy Consumption, for the European Union Member States

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Abstract: The purpose of the article is to analyse the primary energy consumption of the EU member states and examine the relationship between renewable energy and non-renewable energy sources. The study is based on the production, import, export and gross energy consumption of the EU countries' primary energy carriers. The quantitative and percentage distribution of these variables was examined for the years 2010 and 2020. The correlation matrix of the countries was prepared on the basis of the data series of gross energy consumption from 2010 to 2020. Correlation values between renewable energy and non-renewable energy were collected from these result matrices. These values tabulated, made it possible to compare the countries in the correlation of renewable and non-renewable gross energy consumption. The results show that the EU countries have realized that in order to protect the climate, their energy strategy needed to be based on renewables. Renewable energies should replace the coal-fired power plants, that are the most responsible for greenhouse gas emissions. There are already significant changes in oil consumption of some EU countries, which is indicated by the spread of electric transport. Gas will remain the dominant fossil energy source in the future, due to the relatively low price and various technological advantages. Opinions on nuclear technology are divided, but the undeniable advantage is that specific greenhouse gas emissions, are extremely low.

Keywords: correlation; fossil energy; primary energy consumption; renewables

1 Introduction

In recent decades, world economic growth was significant due to the low cost of natural resources used for production and transportation. [1] With the growth of the world's population, energy consumption is significantly increasing mainly in the fast-growing Asian and African regions. In addition to the growing production and

the change in lifestyles - especially in developed countries – also the energy demand increases. [2] In addition, the world's energy use is expected to increase by about 50% between 2018-2050. [3] [4]

The improvement of energy efficiency reduces the growing demand for energy; however, renewable energy has become a key issue in partially replace fossil energy. [5] [6] The role of renewable energy is significant even if the renewables are often available in smaller quantities, the production cannot be regulated and some of them depend on the weather conditions. The gross domestic product, population, labor, as well as greenhouse gas emissions growth, have a positive relationship with energy consumption. [7]

2 World Energy Outlook

Due to the Russian-Ukrainian war, the world is in the middle of a global energy crisis of unprecedented depth. Global energy markets are feeling the strain of the war since Russia is a major player in global energy markets. The world's energy consumption increased by 16.5% during the period between 2010 and 2021, from 505799 PJ up to 589354 PJ. However, between 2019 and 2021 the consumption of fossil fuels was unchanged.

Oil, coal and gas are still dominant in the world's energy consumption. Among fossil fuels, crude oil consumption was still the most significant in 2021 (184213 PJ), followed by coal consumption (160104 PJ) and natural gas consumption (145349 PJ). The fossils account for 82.5 % of energy consumption in the year 2021. (Figure 1)

The importance of non-fossil fuels is much smaller in the world. Nuclear energy accounted only for 4.3% (25313 PJ), hydro energy for 6.8% (40260 PJ) and renewables for 5.8% (34115 PJ) in total energy consumption. [8]

However, the renewables consumption increased by 345% (from 7659 PJ up to 34115 PJ) between 2010 and 2021. The use of energy and its growth rate is very uneven on Earth. In the year 2021, the largest energy users are China (26.5%), the USA (15.6%), India (6.7%), Russia (5.3%) and Japan (3.0%)

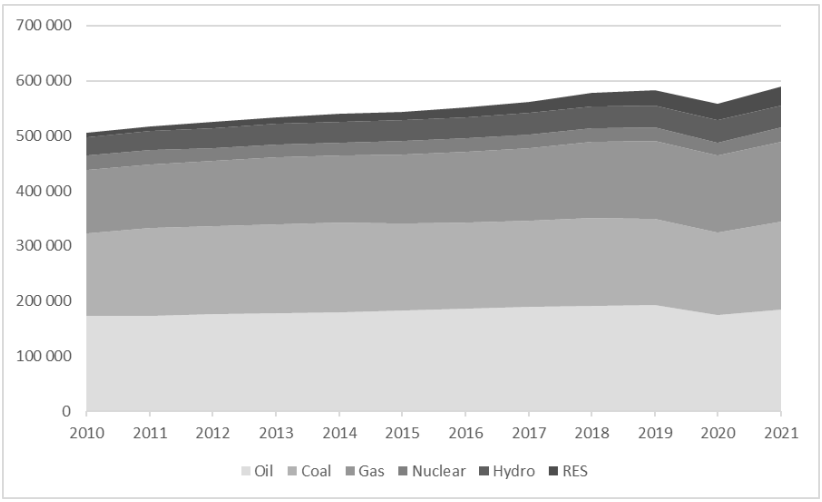

Figure 1
The development of the world's energy consumption, (PJ)

Primary energy grew by 31000 PJ in 2021, the largest increase in history and more than reversing the sharp decline that happened in 2020. However, between 2019 and 2021 renewable energy increased by 8000 PJ. According to forecasts, the primary energy intensity improves by 2.4% per year over the period to 2030. Growth in primary energy in the year 2021 was driven by emerging economies, which grew by 13000 PJ, with China expanding by 10000 PJ [9]. According to the forecast the primary energy supply will peak in 2036 at 643000 PJ, about 9% higher than at present, and then it will decline by around 3% by the year 2050.

3 Energy Situation in the European Union

The European Union has different energy sources as solid fossil fuels, natural gas, oil and petroleum, nuclear energy and renewable energy (such as hydro, wind and solar energy). The fossil-fuel share in primary energy consumption has decreased from over 90% to 70%, mainly due to reduced coal consumption for three decades, The primary energy production of the European Union amounted to 23994 PJ in 2021, which means a 17% drop compared to the year 2010. In the EU, coal accounted for 16%, oil for 4%, natural gas for 7%, renewables for 41% and nuclear energy for 32% of the primary energy production in 2021. The composition of primary energy production varies widely among the countries. Renewable energy is the only source of primary production in Malta and the main source in some EU countries with shares of over 95 % in Cyprus, Latvia and Portugal. Nuclear energy is the significant energy source from total national energy production in France (75%), Belgium (63%) and Slovakia (60%). Solid fuels are the dominant sources in

Poland (71%), Estonia (58%) and the Czech Republic (45%). Natural gas has an important role in energy production in the Netherlands with a share of 63% and in Ireland with 47%. Crude oil is the main source of primary production in Denmark (45%).

The energy available in the European Union comes from energy produced in the EU countries and from energy imported from third countries. As a result of the decline in domestic production, the EU had to rely increasingly on primary energy imports to meet the demand. The EU consumed 51249 PJ import energy, meanwhile, it exported 17262 PJ of energy in 2021. The EU is the world's largest energy importer, 58% of all energy was imported. There are several EU member states which depend, to a great extent, on specific suppliers, which makes them vulnerable.

Russia has been the largest importer of crude oil and natural gas for the EU as well as the main supplier of solid fuel. About 30% of crude oil, 43% of natural gas and 54% of solid fossil fuel (mostly coal) imports come from Russia. The Russia-Ukraine war in 2022 created a crucial economic crisis that led the European Union to take drastic economic sanctions against Russia considering that some countries such as Belgium, Hungary and Greece still rely heavily on energy imports from Russia.

The energy dependency rate of a country is the proportion of energy it imports divided by the county's total consumption. It is expressed as a percentage and it reflects how much an economy depends on other countries to meet its energy needs. In 2021, the EU produced about 42% of its own energy and 58% was imported. The import dependency of the EU member states is very wide-ranging. The import energy dependency of Malta, Cyprus and Luxembourg was over 90%, but Estonia's dependency rate stood only at 10% in 2021.

Gross inland energy consumption, sometimes it is abbreviated as gross inland consumption. The terms mean the overall supply of energy for all activities on the territory of the country, excluding international maritime bunkers. It measures the energy inputs to the economy. The gross energy consumption of the European Union decreased by 9.1% from 64464 PJ to 58578 PJ between 2010 and 2021. Fossil fuels are dominant in the European Union's gross energy consumption, the fossils account for 68.7% of energy consumption. Oil and petroleum represented 32.8% (19200 PJ), natural gas 24.3% (14242 PJ), and coal products 11.6% (6794 PJ) in consumption in 2021. The importance of non-fossil fuels is also significant in the European Union. Nuclear energy accounted for 13.3% (7815 PJ) in total energy consumption in the year 2021. (Figure 2).

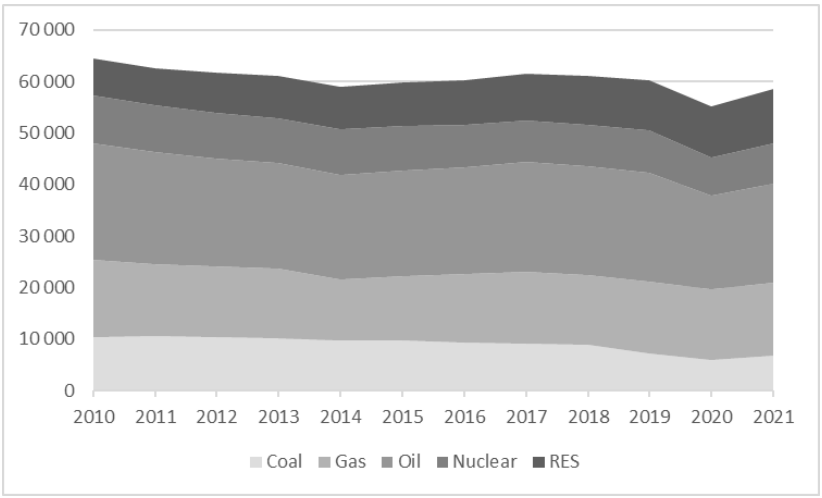

Figure 2
The development of the European Union's Gross Inland Consumption (PJ)

The EU's renewable energy consumption without hydropower reached 10526 PJ in 2021 with a share of 18% of the total. Biomass has the largest share with 44%, followed by hydropower (14%), wind power (12%), biogas (9%), biodiesel (5%), municipal waste (5%), solar PV (4%), geothermal energy (3%), solar energy (2%). In the EU, renewables represent 20.6% of electricity, 7.1% of transport and 18.1% of heating and cooling in 2021.

3.1 The Role of Renewables in the European Union's Energy Policy

The potential for renewable energy resources is enormous because they can exponentially exceed the world's energy demand; therefore, these types of resources will have a significant share in the future global energy portfolio. [10] In the future biomass can be considered the best option and has the largest potential, which meets these requirements and could insure fuel supply. [11] [12] A number of renewable energy technologies are available at different stages of the development cycle. Hydropower and bioenergy are the main sources of energy worldwide. Other options are technically proven and available on commercial terms, still occupying only a fraction of their potential markets. [13-15]

Hydropower, wind, solar and biomass energy are even more expensive than fossil-based power generation. However, due to steadily declining reserves of fossils and rising energy prices, it is increasingly worthwhile to switch to renewable energy sources. [16] [17] Renewable energy growth around the world continued to be driven by a combination of targeted public policy and advances in energy technologies. The policy support for renewable energy focused primarily on power

generation, with support for renewable technologies lagging in the heating and cooling as well as transport sectors. [18]

The utilization of renewable energy sources has an increasing role in the EU's climate and energy policy. By using more renewables to meet its energy needs, the European Union lowers its dependence on imported fossil fuels and makes its energy production more sustainable. Influenced by economic and environmental interests the European Union committed itself to increase the utilization of renewable energy sources at the end of the 1990s. The Energy Policy White Paper issued by the European Commission initiated a common Renewable Energy Strategy and set up an Action Plan in 1997. The indicative objective was a 12% share of the contribution by renewable sources of energy and the European Union's gross inland energy consumption by 2010. [19] Recognizing the growing dependence on imports, the European Commission defined the objectives of energy policy in the Green Paper in 2006. Three key energy policy objectives were identified: improved competitiveness, security of supply, and protection of the environment. [20] The Directive 2009/28/EC established an overall policy for the production and promotion of energy from renewable sources in the EU. The directive set a binding target of 20% final energy consumption from renewable sources by 2020 – to be achieved through the attainment of individual national targets. Each EU country must have shown what actions they would intend to take to meet their renewables targets (including sectorial targets for electricity, heating and cooling, and transport). The countries must also ensure that at least 10% of their transport fuels come from renewable sources by 2020. Table 1 shows where the EU countries are in terms of the evolution of the use of renewable energy in the final energy consumption. It should be noted that gross inland energy consumption, which is the subject of the study, should not be confused with final energy consumption.

Table 1

The development of the share of renewable energy in the final energy consumption and the 2020 targets

	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2020 target**
	%											**%**
EU27 from 2020	14.4	14.5	16.0	16.7	17.4	17.8	18.0	18.4	19.1	19.9	22.1	20.0
Belgium	6.0	6.3	7.1	7.7	8.0	8.1	8.7	9.1	9.5	9.9	13.0	13.0
Bulgaria	13.9	14.2	15.8	18.9	18.0	18.3	18.8	18.7	20.6	21.5	23.3	16.0
Czechia	10.5	10.9	12.8	13.9	15.1	15.1	14.9	14.8	15.1	16.2	17.3	13.0
Denmark	21.9	23.4	25.5	27.2	29.3	30.5	31.7	34.4	35.2	37.0	31.7	30.0
Germany	11.7	12.5	13.5	13.8	14.4	14.9	14.9	15.5	16.7	17.3	19.3	18.0
Estonia	24.6	25.5	25.6	25.4	26.1	29.0	29.2	29.5	30.0	31.7	30.1	25.0
Ireland	5.8	6.6	7.0	7.5	8.5	9.1	9.2	10.5	10.9	12.0	16.2	16.0
Greece*	10.1	11.2	13.7	15.3	15.7	15.7	15.4	17.3	18.0	19.6	21.7	18.0

Spain	13.8	13.2	14.2	15.1	15.9	16.2	17.0	17.1	17.0	17.9	21.2	20.0
France	12.7	10.8	13.2	13.9	14.4	14.8	15.5	15.8	16.4	17.2	19.1	23.0
Croatia	25.1	25.4	26.8	28.0	27.8	29.0	28.3	27.3	28.0	28.5	31.0	20.0
Italy	13.0	12.9	15.4	16.7	17.1	17.5	17.4	18.3	17.8	18.2	20.4	17.0
Cyprus	6.2	6.2	7.1	8.4	9.1	9.9	9.8	10.5	13.9	13.8	16.9	13.0
Latvia	30.4	33.5	35.7	37.0	38.6	37.5	37.1	39.0	40.0	40.9	42.1	40.0
Lithuania	19.6	19.9	21.4	22.7	23.6	25.7	25.6	26.0	24.7	25.5	26.8	23.0
Luxembourg	2.9	2.9	3.1	3.5	4.5	5.0	5.4	6.2	8.9	7.0	11.7	11.0
Hungary	12.7	14.0	15.5	16.2	14.6	14.5	14.4	13.6	12.5	12.6	13.9	13.0
Malta	1.0	1.8	2.9	3.8	4.7	5.1	6.2	7.2	7.9	8.2	10.7	10.0
Netherlands	3.9	4.5	4.7	4.7	5.4	5.7	5.8	6.5	7.4	8.9	14.0	14.0
Austria	31.2	31.6	32.7	32.7	33.6	33.5	33.4	33.1	33.8	33.8	36.5	34.0
Poland	9.3	10.3	11.0	11.5	11.6	11.9	11.4	11.1	14.9	15.4	16.1	15.0
Portugal	24.1	24.6	24.6	25.7	29.5	30.5	30.9	30.6	30.2	30.6	34.0	31.0
Romania	22.8	21.7	22.8	23.9	24.8	24.8	25.0	24.5	23.9	24.3	24.5	24.0
Slovenia	21.1	20.9	21.6	23.2	22.5	22.9	22.0	21.7	21.4	22.0	25.0	25.0
Slovakia	9.1	10.3	10.5	10.1	11.7	12.9	12.0	11.5	11.9	16.9	17.3	14.0
Finland	32.2	32.5	34.2	36.6	38.6	39.2	38.9	40.9	41.2	42.7	43.8	38.0
Sweden	46.1	47.6	49.4	50.2	51.2	52.2	52.6	53.4	53.9	55.8	60.1	49.0

*(provisional)
Source: Eurostat database (2021)

The European Council set even more ambitious goals by increasing commitments by 2030. The aim was to promote the EU to achieve a more competitive, secure and sustainable energy system. The EU countries agreed on a new renewable energy target of at least 27% of the EU's final energy consumption, a 40% cut in greenhouse gas emissions compared to 1990 levels.

The European Commission aimed to increase between 55% and 75% the proportion of renewables in gross final energy consumption by 2050. This along with energy efficiency is considered critical in any model that could be adopted. [21]

The development of renewable energy is important from the viewpoint of lowering the cost of imported energy, borne by Central European countries. In addition, it would help to achieve the aim of reducing CO2 emissions. [22] Many illusions are related to the widespread use of renewable energy resources. A further reduction of bioenergy consumption can be achieved by faster electrification of heat needs and increased energy efficiency compared to RePowerEU by 2030. In order to achieve the goal, solar energy capacity must be significantly increased by 2030. [23]

The EU policy on energy aims to ensure the security of energy supply in the member states, to promote energy efficiency and energy saving, as well as to increase the share of renewable energy. Solidarity among the member states is fundamental. However, each country is responsible for its own energy security. The spread of renewables may be impeded by the availability of fossil resources within a country.

[24] The factors that provide the framework for countries are as follows different international obligations, differences in planning/licensing cultures, public awareness concerning renewables and/or technical differences. [25] [26]

The climate policy of the EU, the high fossil fuel prices and efforts to reduce energy import dependency on Russia to reduce fossil fuel demand, despite increasing consumption of coal in the current crisis.

Having revised the Renewable Energy Directive 2018/2001/EU the member states established a new binding renewable energy target for 2030. They will ensure that the share of energy from renewable sources in the Union's gross final consumption of energy of at least 32%, with a clause for a possible upwards revision by 2023. In July 2022, the European Commission presented Europe's new 2030 climate targets. The goal is to increase the present target to at least 40% renewable energy sources in the energy mix by 2030.

The Russian-Ukrainian war that broke out in 2022 created a new energy situation. The European Commission published the REPowerEU plan to reduce the EU's dependence on Russian gas and oil before 2030. Part of the plan is to raise the energy efficiency target from 9% to 14% by 2030 and to increase the share of renewable energy sources in the EU's energy structure. The REPowerEU plan also supports the European Commission's request to increase in the directive to 45% by 2030. Figure 3 shows the evolution of renewable energy targets. [27]

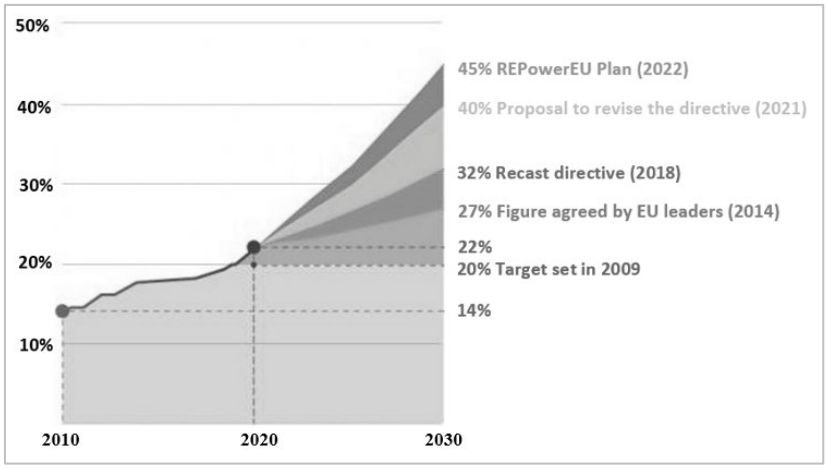

Figure 3
Evolution of renewable energy targets

Besides, the REPowerEU plan would increase total renewable energy capacity to 1236 GW by 2030, compared to the "Towards 55%!" with 1067 GW planned for 2030.

4 Material and Method

In energy statistics, the ability to separate primary and secondary energy is very important. In order to avoid double counting, it is essential to be able to separate new energy entering the system, (primary) and the energy that is transformed within the system (secondary). Primary energy can be defined as the energy that's extracted directly from natural resources, such as crude oil, hard coal and natural gas or is produced from primary commodities. Secondary energy is energy produced by converting the primary energy, such as electricity, refined automotive fuel or hydrogen. [28] Primary energy sources are very important for all sectors of the economy and global production and population have been rapidly growing. [29]

In the article, we analysed the gross inland energy consumption of the European Union countries. The gross inland energy consumption represents the quantity of energy necessary to satisfy the inland consumption of the geographical entity. In the narrow sense, it represents the sum of primary energy production and net import (import-export). In the broad sense, it is supplemented with recovered products, variations of stocks, bunkers and direct use. The diagram of energy flow can be illustrated by the Sankey diagram (Figure 4), where the direction of flow is shown by the arrows and the width of the arrows is shown proportionally to the flow quantity.

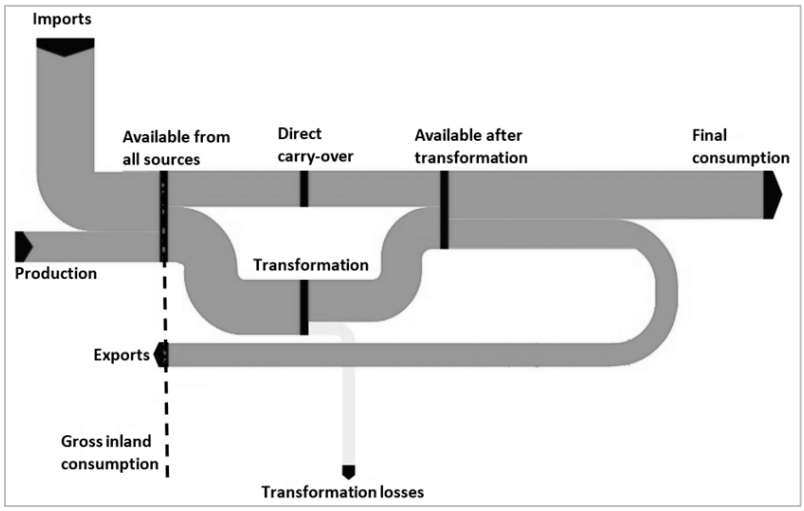

Figure 4
Simplified Sankey diagram for energy flow

The data of analysis come from the database of the European Commission Eurostat and the International Renewable Energy Agency (IRENA) regarding the period between 2010 and 2020. The main unit for energies is joules, or rather petajoules (PJ) according to the International System of Units (SI). In the article, we use the petajoule, as a unit of energy.

In the study, we used comparative time series analysis. The purpose of the article was to analyse the gross inland energy consumption of the EU countries and to examine the relationship between renewable energy and non-renewable energy sources. In the course of the analysis, we tried to determine which non-renewable energy carrier was replaced by the renewables in the EU member states. The replacement of energy sources with each other was analysed by correlation matrix and it was evaluated at 1% and 5% significance levels. The evaluation happened by using IBM SPSS Statistics 25.

To test the significance of the correlation coefficient, we formulate the hypothesis H0: $\rho = 0$. Our decision is based on a correlation coefficient (r) calculated in a sample with n elements. The rejection of H0 depends on the magnitude of the coefficient r and the magnitude of the degree of freedom f ($f = n-2$).

To calculate the significance, we use the t-distribution statistic. The formula is:

$$t = r \cdot \sqrt{\frac{n-2}{1-r^2}} \tag{1}$$

Using the statistical table of the result of the equation and the distribution of the t-distributed variable, we can determine whether our result is significant and, if so, to what extent.

If $|t| >$ table, we reject H0 and say that the population correlation coefficient is different from 0. So, if the absolute value of our obtained result is greater than the number in the table corresponding to the given degree of freedom and significance level (usually 0.95), then we can reject the null hypothesis with 95% certainty.

The positive sign of r refers to the linear proportionality of the renewable and the primary energy associated with it, while the negative sign refers to its inverse proportionality. In this case, the inverse relationship is used to analyse the replacement between renewable and non-renewable energies. The closer to one the absolute value of r is, the stronger the relationship.

5 Results

5.1 Primary Production of EU-27

Among the EU member states France has been the leader in primary energy production for a long time. France's primary energy production amounted to 5065 PJ, which was an 11% decrease from 2010. Nuclear was the main source of energy production, accounting for 76% of total primary production, while renewables had a share of 23% in 2020. France was followed in the ranking by Germany. Between 2010 and 2020, Germany's primary energy production decreased by 27% to reach 3923 PJ. Renewables was accounting for around 50%

of total primary production in 2020, however, this rate was only 25% in 2010. Coal was the second highest contributor with 25%, while nuclear had an 18% share and oil had a 3% share**.** Poland was the third member state in the ranking. Poland's primary energy production was 2381 PJ in 2020, which represents a 15% decrease compared to 2010. Poland is Europe's largest coal producer. Black and brown coal were the main sources of energy production, accounting for 70% of total primary production, while the share of renewables was 23% in 2020. The Netherlands is also an important primary energy producer in the EU. However, Dutch primary energy production fell dramatically. The country's primary energy production was 2947 PJ in 2010, then it decreased to 1105 PJ by 2020. Gas remained the main source of energy production, accounting for 65% of the total in 2020. The share of renewables was 27% in the primary energy production mix. (Figure 5) The values of some countries are significantly higher than the values of the other countries, so for better visualization, they are shown separately on the right side of the figure.

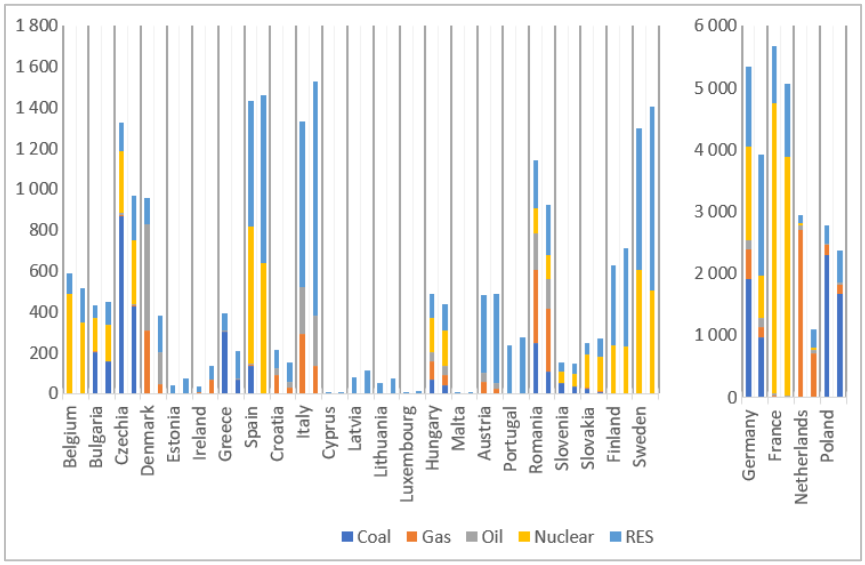

Figure 5
Primary energy production of EU-27 in 2010 and 2020 (PJ)

5.2 Energy Imports of the EU-27

Germany has been one of the largest energy importers in the European Union. Germany's import energy consumption was 10,231 PJ in 2010, then it decreased by 14% to 8809 PJ for the year 2020. Oil was dominant in energy imports in Germany with a share of 57%, while gas had a share of 32% and the share of coal was 10%. The country's import energy dependency was 63.7%. The Netherlands was the second largest importer among the member states. Between 2010 and 2020 the

Dutch total energy imports decreased by 5.5% and reached 6873 PJ. In the case of the Netherlands, oil was by far the largest imported energy product with a share of 81%. Besides, the Dutch gas import was significant (16% of the total energy imports). The import energy dependency of the Netherlands was 63.7%. Italy was also a very important energy importer in the EU. Italy's import energy consumption was 7336 PJ in 2010 and 5347 PJ in 2020, it means a 27% drop during the 10-year period. In Italy's import energy mix the share of oil was 52%, while gas had a share of 43%. In international comparison, Italy's 73.5% import energy dependency rate was high. France's energy imports decreased significantly between 2010 and 2020, from 6745 PJ to 5212 PJ. The two dominant import products of France were oil (62.3%) and gas (32.4%) in 2020. The French import energy dependence can be considered low (44%) among EU countries. Spain also should be mentioned as an important energy importer of the EU. In 2020, Spain's import energy consumption amounted to 4506 PJ, while in 2010 the energy imports were 5087 PJ. The Spanish import energy mix is based on oil with a share of 70% and the share of gas was 26% in 2020. The import energy dependence of Spain reached 67% for year 2020. (Figure 6)

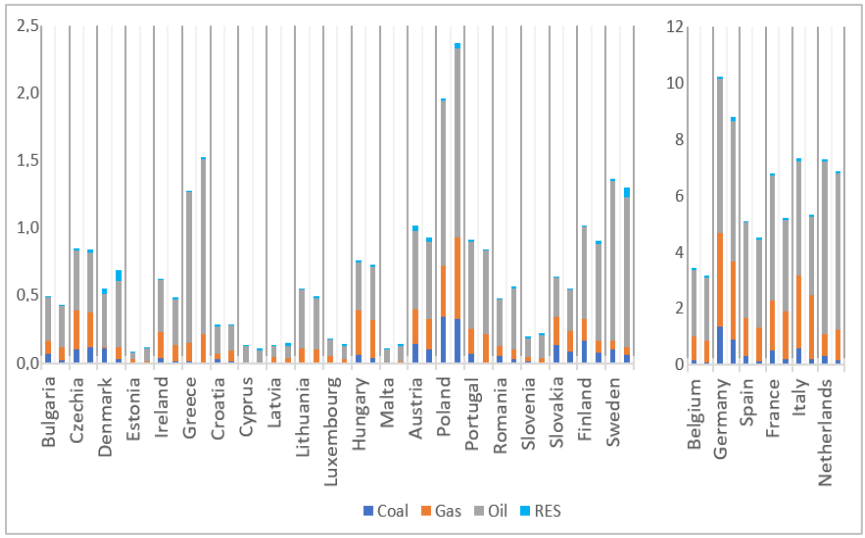

Figure 6
Energy imports of EU-27 in 2010 and 2020 (PJ)

5.3 Energy Exports of the EU-27

As can be seen in Figure 7 the Netherlands was by far the largest energy exporter among the EU member states. The Netherlands's energy export amounted to 6095 PJ in 2010, then it decreased by 26.5% to 4478 PJ in 2020. Oil was by far the largest exported energy product of the Dutch with a share of 87%. Oil was followed

by gas accounting for 11% of energy exports. Belgium was one of the countries, in the European Union, that could increase energy exports. Belgium increased its energy exports from 1160 PJ to 1278 PJ during the period 2010-2020. Oil accounted for 89% and gas for 10% of total exports in 2020. Spain was the third largest exporter among the EU member states in 2020. In addition, Spain's energy exports nearly doubled between 2010 (591 PJ) and 2020 (1159 PJ). Oil was by far the most important energy product with a share of 84%, followed by Res with 7% and coal with 4.5%. Germany has been one of the significant energy exporters in the EU. The German energy exports amounted to 1110 PJ in 2020, compared to 1612 PJ in 2010. In the German export energy mix, oil represents 83%, while the 11.5% share of renewables can be considered significant. Italy's energy export was 1278 PJ in 2010 but fell to 1033 PJ in 2020. Italian energy exports were concentrated on oil, with oil accounting for 96% of the total. France should also be mentioned as a major energy exporter. French energy exports also decreased from 1092 PJ to 878 PJ during the period 2010-2020. In France's energy exports, oil and gas were dominant, with a share of 62% and 35% respectively. (Figure 7)

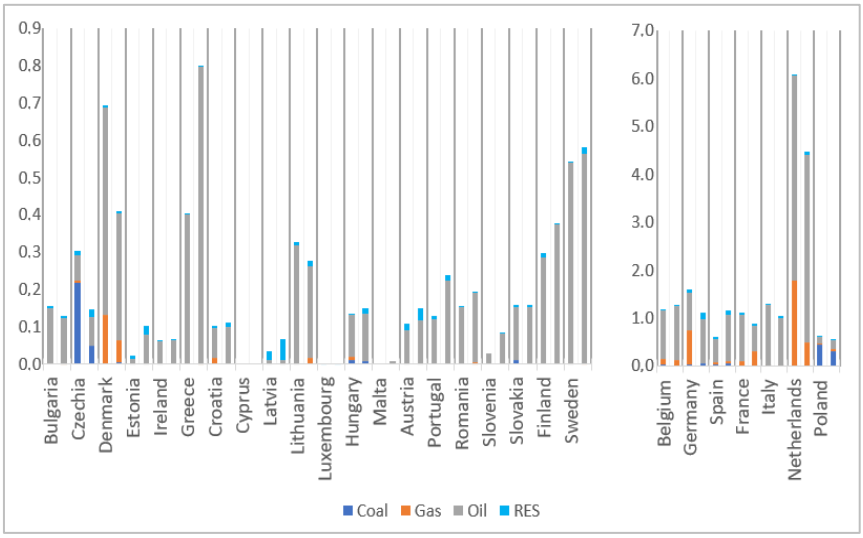

Figure 7
Energy exports of EU-27 in 2010 and 2020 (PJ)

5.4 Gross Inland Energy Consumption of the EU-27

Germany has been the largest economy in the European Union and also the most significant energy consumer. Germany reduced its gross energy consumption by 16% during the period 2010-2020 and reached 11818 PJ. Germany's energy consumption has been based on fossil energy. Oil accounted for 35%, gas for 26% and coal for 16% of total energy consumption in 2020. However, renewable energy

use increased significantly between 2010 and 2020 from 9% to 17%. German nuclear energy consumption fell from 11% to 6% during the 10-year period. France also reduced its energy consumption by 17% from 1350 PJ to 9449 PJ over the ten years (compared to the 2010 level). In French energy consumption, nuclear energy dominated with a share of 41% in 2020. Oil represented 29%, gas had a 16% share and renewable energy had a 13% share in gross energy consumption. France was followed by Italy in the energy consumption ranking. Italy's inland energy consumption was 5763 Mtoe in 2020, compared to 7202 PJ in 2010. In the energy consumption of Italy, the share of gas was 42%, while oil had a share of 33%. The share of renewables reached 21% by 2020, compared with 13% in 2010. Spain was the fourth largest energy consumer among the EU member states. The gross energy consumption of Spain fell to 4646 PJ in 2020 from 5464 PJ in 2010. Spain's energy consumption is based on oil, which accounts for 41% of the total. Natural gas accounted for 25%, the nuclear energy for 14% of total energy consumption. In the case of Spain, the share of renewables in gross energy consumption also increased significantly and reached 17% by 2020. Unlike the previous countries, Poland did not reduce its energy consumption between 2010 and 2020. Poland's energy consumption remained at the level of 4217 PJ by 2020. Coal was dominant in the gross inland energy consumption with a share of 41%, 29% came from oil, 17% from natural gas and 13% from renewable energy. (Figure 8)

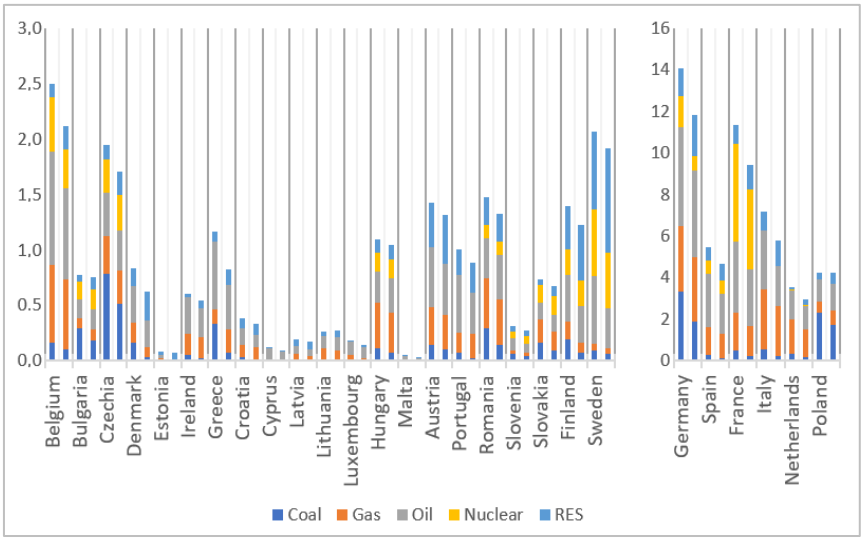

Figure 8

Gross Inland Energy Consumption of EU-27 in 2010 and 2020 (PJ)

5.5 Evaluation of the Relationship between Non-Renewable Energy and Renewable Energy based on Correlation Analysis

The study covered the years 2010-2020 (n = 11). The calculation of the r values of the correlation matrix f = 9 degrees of freedom (f = n-2), in addition to the student t table value, was determined at the 5% and 1% two-tailed significance levels, based on the following formulae:

$$r_{1,2} = \pm\sqrt[2]{\frac{t^2}{t^2+f^2}} \tag{2}$$

$$t_{0,95}(f = 9) = 2.262 \rightarrow r_{1,2} = \pm 0.6020 \tag{3}$$

$$t_{0,99}(f = 9) = 3.250 \rightarrow r_{1,2} = \pm 0.7348 \tag{4}$$

Based on equations, the positive correlation at the 5% significance level occurs at values r > 0.6020, and the negative correlation at r < -0.6020. At the 1% significance levels, these values are r > 0.7348 and r < -0.7348, respectively.

Table 2 shows the correlation values between the countries' renewable and non-renewable gross energy consumption.

Table 2
Correlation values between the countries' renewable and non-renewable gross energy consumption

	Coal	Gas	Oil	Nuclear
1. Belgium	-0.9074**	0.0398	-0.6948**	-0.4100
2. Bulgaria	-0.8837**	0.1980	0.7504**	0.5874*
3. Czechia	-0.9290**	-0.2352	0.0922	-0.0098
4. Denmark	-0.9526**	-0.8913**	-0.6287*	
5. Germany	-0.7824**	0.2804	-0.5375*	-0.9378**
6. Estonia	-0.8394**	-0.8024**	-0.9581**	
7. Ireland	-0.8229**	0.4163	-0.1077	
8. Greece	-0.9132**	0.5851*	-0.7941**	
9. Spain	-0.4559	-0.3626	-0.6798**	-0.5304*
10. France	-0.6973**	-0.1607	-0.7851**	-0.7768**
11. Croatia	-0.5074	-0.1418	-0.4529	
12. Italy	-0.8555**	-0.4503	-0.8608**	
13. Cyprus	0.5240*		-0.4196	
14. Latvia	-0.7542**	-0.7073**	0.5131	
15. Lithuania	-0.7793**	-0.8841**	0.8933**	
16. Luxembourg	-0.9055**	-0.8627**	-0.4356	
17. Hungary	-0.0964	-0.4409	-0.4604	-0.1828
18. Malta		0.9433**	-0.9385**	

19. Netherlands	-0.7152**	-0.2523	-0.7663**	0.1656
20. Austria	-0.6369*	-0.3127	-0.3354	
21. Poland	-0.8525**	0.9242**	0.7296**	
22. Portugal	-0.3962	0.3464	-0.3692	
23. Romania	-0.7641**	-0.7920**	0.4011	-0.7568**
24. Slovenia	-0.2652	-0.3189	-0.3725	-0.0445
25. Slovakia	-0.9361**	-0.4263	0.4288	0.1440
26. Finland	-0.8551**	-0.8427**	-0.6851**	-0.4109
27. Sweden	-0.8538**	-0.2412	-0.9099**	-0.2993

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 2 shows that coal is negatively correlated with renewable energy at 1% significance in gross energy consumption in the case of Denmark (-0.9526), Slovakia (-0.9361), Czechia (-0.9290), Greece (-0.9132), Belgium (-0.9074), Luxembourg (-0.9055), Bulgaria (-0.8837), Italy (-0.8555), Finland (-0.8551), Sweden (-0.8538), Poland (-0.8525), Estonia (-0.8394), Ireland (-0.8229), Germany (-0.7824), Lithuania (-0.7793), Romania (-0.7641) and Latvia (-0.7542). Coal is negatively correlated with renewable energy at 5% significance in gross energy consumption in the case of the Netherlands (-0.7152), France (-0.6973) and Austria (-0.6369). The gas is negatively correlated with renewable energy at a 1% significance, in gross energy consumption, in the case of Denmark (-0.8913), Lithuania (-0.8841), Luxembourg (-0.8627), Finland (-0.8427), Estonia (-0.8024), Romania (-0.7920). The gas is negatively correlated with renewable energy at 5% significance in gross energy consumption in the case of Latvia (-0.7073). Gas is positively correlated with renewable energy at a 1% significance in gross energy consumption in the case of Malta (0.9433) and Poland (0.9242). Oil is negatively correlated with renewable energy at 1% significance in gross energy consumption in the case of Estonia (-0.9581), Malta (-0.9385), Sweden (-0.9099), Italy (-0.8608), Greece (-0.7941), France (-0.7851) and Netherlands (-0.7663). Oil is negatively correlated with renewable energy at 5% significance in gross energy consumption in the case of Belgium (-0.6948), Finland (-0.6851), Spain (-0.6798) and Denmark (-0.6287). Oil is positively correlated with renewable energy at a 1% significance in gross energy consumption in the case of Lithuania (0.8933) and Bulgaria (0.7504). Oil is positively correlated with renewable energy at a 5% significance in gross energy consumption in the case of Poland (0.7296). Nuclear energy is negatively correlated with renewable energy at 1% significance in gross energy consumption in the case of Germany (-0.9378), France (-0.7768) and Romania (-0.7568).

The correlation analysis shows which fossil energy carrier(s) each country focuses on replacing, when using renewable energy. Most countries are trying to replace coal. This is the fossil energy carrier that typically produces the most carbon dioxide emissions. Efforts must be made to replace coal as quickly as possible, even at the

cost of temporarily consuming additional gas. With the parallel use of gas and renewable energy sources, the European Union can achieve the largest emission reduction in the fastest way possible. By 2050, EU can achieve the goal of climate neutrality, while producing the lowest possible aggregate emissions, during the transition period. [30]

Conclusions

The structure of energy production of the EU member states was different due to the differences in natural endowments. The increasingly strict climate protection commitments and the countries' energy independence efforts are all moving the energy consumption mixes of the EU countries, in the direction of renewable energy. This are clearly shown by the changes in the composition of the countries' energy production, import, export and energy consumption between 2010 and 2020. Apart from a few countries, the changes all point in the direction of increased renewable energy use. This is clearly demonstrated by the growth of renewable energies and the increasing weight of their share in the countries' energy consumption mix. Correlation analysis shows that renewable energies replaced fossil energies. In most EU countries coal was replaced by renewable energies. Coal is the most climate-burdening fossil energy carrier with the highest specific carbon dioxide emissions. The replacement of gas and oil is a much slower process than that of coal, since gas is an important element for heating and electricity production, while oil plays a major role in transportation. In the case of nuclear energy, the negative correlation value was due to rapidly growing renewable energies. E.g., in Germany, the shutdown of nuclear power plant blocks, as a result of the Fukushima disaster, was also a contribution.

Decarbonisation is an important part of the EU's climate policy. One way to reduce carbon dioxide emissions is to reduce energy consumption. The gross energy consumption of the European Union decreased by 9.1%, from 64464 PJ to 58578 PJ, between 2010 and 2021. It is important to note that further increasing the efficient use of energy significantly contributes to the reduction of energy consumption. Another option for reducing carbon dioxide emissions is to increase the share of renewables, which the EU has set at 20% by 2020 compared to 12% in 2010. This target value differs from country to country depending on the resources and geopolitical situation.

EU member states are divided in terms of how they want to achieve climate goals. One group of countries is anti-nuclear, led by Germany and the other group is in favour of nuclear energy, led by France. It is important to point out that the EC's proposal presented at the end of January 2022, which can classify energy production using natural gas and nuclear energy as sustainable, is favourable for both groups. According to the EC's proposal, all of this would last until the security of supply can be ensured by using renewable energy sources. Europe is extremely polarized when it comes to energy, however, practically every country is counting on either natural gas or nuclear energy, or both, for the medium term. [31]

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