Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

Renewable Energy Consumption and Economic Growth in European Union Countries

Master's Thesis

Study Program: Electrical Engineering, Power Engineering and Management

Field of Study: Management of Power Engineering and Electrotechnics

Scientific Adviser: Doc. Ing. Julius Bemš, PhD

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MASTER‘S THESIS ASSIGNMENT

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Renewable Energy Consumption and Economic Growth in European Union Countries

Guidelines:

1. Describe energy sources and consumption in EU countries
2. Research on renewable energy sources and share in EU countries in the time period
3. Evaluation and analysis of renewable energy consumption and economic growth
4. Interpretation of model, conclusion and suggestions

Bibliography / sources:

1. CVIJOVIĆ, JELENA, TIJANA OBRADOVIĆ and SNEŽANA KNEŽEVIĆ. A literature survey on relationship between renewable energy consumption and economic growth. Ekonomika poljoprivrede [online]. 2020, vol. 67, no. 3, pp. 991-1010. Available at: doi:10.5937/ekopolj2003991c
2. BALTAGI, BADI H. Econometric analysis of panel data. Chichester: Wiley, 2016.
3. ITO, KATSUYA. CO2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. International Economics [online]. 2017, vol. 151, pp. 1-6. Available at: doi:10.1016/j.inteco.2017.02.001

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Study Program: Electrical Engineering, Power Engineering and Management

Topic: Renewable Energy Consumption and Economic Growth in European Union Countries

Details:

- Describe energy sources and consumption in EU countries
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- Modeling of analysis and suggestions

Literature:

- CVIJOVIĆ, JELENA, TIJANA OBRADOVIĆ and SNEŽANA KNEŽEVIĆ. A literature survey on relationship between renewable energy consumption and economic growth. Ekonomika poljoprivrede [online]. 2020, vol. 67, no. 3, pp. 991-1010. Available at: doi:10.5937/ekopolj2003991c
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Abstract

This study analyzes the relationship between the use of renewable energy and economic growth in the case of the European Union countries. Based on panel data regression analysis, it aims to demonstrate the positive impact of renewable energy consumption on GDP per capita. In general, energy belongs to the most critical factors of the economy. It plays a vital role in the economic development of countries. Energy also represents one of the main components in production, and it is directly related to economic growth. States need to develop policies regarding their own energy resources. They tend towards renewable energy resources for reducing their energy dependence. An increase in energy consumption and demand direct countries to alternative energy sources. Due to climate change and greenhouse gas emissions, renewable energy sources are considered alternatives to fossil energy sources. In recent years economists have frequently discussed the substitution of non-renewable energy sources by renewable ones. The reason is the general concern over future source scarcity. In addition, the effects of these two energy sources on the economy and the environment have been studied.

First, this thesis outlines the types of energy sources and their use cases worldwide. More specifically, it focuses on renewable energy sources, it defines them and indicates the ratio and the importance of renewable energy resources in total energy sources. It presents modern technologies that are actively used today. In addition, it summarizes the history and explains the theories of economic growth models. Subsequently, the thesis discusses energy economics and policies in Europe and the world. In particular, the energy supply of the European Union and the importance given to renewable energies in this regard were analyzed, considering renewable energy policies, supports, and targets as well as the future of renewable energy and its role in the economy.

The panel data regression analysis is based on the data provided by the World Development Indicators database of the World Bank. Renewable energy consumption, fossil energy consumption, CO2 emission per capita, and GDP per capita data of European Union countries between 1996 and 2015 were selected from the database to create panel data for this research. The panel data regression analysis was performed using the generalized method of moments (GMM) estimator. As a result, the thesis concluded that all three independent variables positively affect GDP. The impact of fossil energy consumption on GDP is greater than the impact of renewable energy consumption. The reason is that the share of fossil energy consumption in total energy consumption is still higher than the share of renewable energy consumption. Yet, given the ongoing climate change, the promotion of renewable energy in the EU is necessary for an economically and environmentally sustainable future.

Keywords: Renewable Energy, Fossil Energy, CO_2 Emission, Economic Growth, Panel Data Regression Analysis

Abstrakt

Tato studie analyzuje vztah mezi užíváním obnovitelné energie a ekonomickým růstem na případě zemí Evropské unie. Na základě regresní analýzy panelových dat má za cíl prokázat pozitivní dopad spotřeby obnovitelné energie na HDP per capita. Energie obecně patří mezi nejvýznamnější ekonomické faktory. Hraje zásadní úlohu v hospodářském rozvoji zemí. Energie též představuje jednu z hlavních složek produkce a přímo souvisí s ekonomickým růstem. Státy potřebují vyvíjet strategie týkající se jejich vlastních energetických zdrojů. K obnovitelným zdrojům energie se uchylují ve snaze snížit svou energetickou závislost. Růst energetické spotřeby a poptávky nutí země hledat alternativní zdroje energie. Kvůli klimatické změně a emisím skleníkových plynů jsou obnovitelné zdroje energie považovány za alternativy k fosilním palivům. V posledních letech ekonomové často diskutovali o substituci neobnovitelných energetických zdrojů za obnovitelné. Důvodem je všeobecná obava z budoucího nedostatku zdrojů. Kromě toho jsou studovány dopady těchto dvou typů zdrojů energie na ekonomiku a životní prostředí.

Tato práce nejprve nastíní typy zdrojů energie a případy jejich užití ve světě. Specifičtěji se zaměří na obnovitelné zdroje energie, které definuje a indikuje jejich podíl a význam ve vztahu k energetickým zdrojům jako celku. Představuje moderní technologie, které jsou dnes aktivně využívány. Navíc práce shrnuje historii a vysvětluje teorie modelů ekonomického růstu. Následně práce diskutuje problematiku energetické ekonomie a politik v Evropě a ve světě. Konkrétně analyzuje energetické zásoby Evropské unie a význam obnovitelných energií ve vztahu k nim, přičemž zvažuje strategie týkající se obnovitelné energie, její podporu a cílů a dále budoucnost obnovitelné energie a její úlohu v ekonomice.

Regresní analýza panelových dat je založena na datech poskytnutých databází indikátorů světového rozvoje Světové banky. Údaje zemí EU o spotřebě obnovitelné energie, emisích CO2 per capita a HDP per capita mezi lety 1996 až 2015 byly vybrány z této databáze s cílem vytvořit panelová data pro tento výzkum. Regresní analýza panelových dat byla provedena za použití estimátoru zobecněné metody momentů (GMM). Práce dospěla k závěru, že všechny tři nezávislé proměnné měly pozitivní vliv na HDP. Dopad spotřeby fosilních paliv na HDP byl větší než dopad spotřeby obnovitelných zdrojů energie. Příčinou je, že podíl spotřeby fosilních paliv na celkové energetické spotřebě je stále vyšší než podíl spotřeby obnovitelné energie. Přesto zejména z důvodu probíhající klimatické změny je podpora obnovitelné energie v EU nutná pro ekonomicky a environmentálně udržitelnou budoucnost.

Klíčová slova: obnovitelná energie, emise CO2, ekonomický růst, regresní analýza panelových dat

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List of Abbreviations

EU	European Union
PE	Primary Energy
KTOE	Kilotonnes of Oil Equivalent
CO_2	Carbon Dioxide
EJ	Exajoule
PV	Photovoltaic
BNEF	Bloomberg New Energy Finance
LCOE	Levelized Cost of Electricity
WPP	Wind Power Plants
EWEA	The European Wind Energy Association
IGA	International Geothermal Association
GDP	Gross Domestic Product
ECSC	The European Coal and Steel Community Treaty
NPP	Nuclear Power Plants
LNG	Liquefied Natural Gas
USD	The United States Dollar
MTEP	Million-Ton Equivalent of Petroleum
WEC	World Energy Council
VECM	Vector Error Correction Model
VAR	Vector Autoregression
ARDL	Autoregressive Distributed Lag Bound Test
OLS	Ordinary Least Squares
GMM	Generalized Method of Moments
BRICS	Brazil, Russia, India, China, and South Africa
REC	Renewable Energy Consumption
FEC	Fossil Fuel Energy Consumption
COE	CO_2 Emissions
IID	Independent and Identically Distributed
GLS	Generalized Least Squares
VIFs	Variance Inflation Factors
LLC	Levin, Lin, and Chu
IPS	Im, Pesaran, and Shin
ADF	Augmented Dickey–Fuller
LM	Lagrange Multiplier

1. Introduction

Energy is one of humankind's fundamental needs. Energy is vital for the sustainability of the universe and humanity. The usage area of energy expands in direct proportion to the development of society. Energy was used for basic needs such as housing, heating, nutrition, and defense in primitive times. Thanks to technological and economic developments, energy is used in every field today [1].

Energy, as an important part of life and an indispensable element, is a concept that has been studied for many years. Especially after the Industrial Revolution, energy has become the most critical input of the global economic system. For this reason, energy, which has become an economic and politically discussed concept, has also been the determinant of many political and economic developments.

Having energy resources is one of the solid reasons to be one of the critical countries in the world. In addition to owning energy resources, managing and using these resources is necessary for the country's economy. There are energy wars in the world to have and benefit from energy. Especially due to the oil crisis in the 1970s, it has led the developed countries to seek alternative energy [2]. Renewable and nuclear energy production has started to be increased and integrated into the economy. In addition, the concept of energy efficiency, which means maintaining existing economic activities with less energy consumption or realizing more economic activities with the same energy consumption, has come to the fore.

Developed countries have turned to clean energy resources in order to reduce emissions due to fossil fuels they use widely. In addition, energy sustainability and security are important issues. In order to eliminate all these problems, they introduced policies and gave incentives for the use of clean energy resources.

The concept of energy is a system that consists of a combination of many parts. Technological, economic, and political parts make up a whole. The relationship between energy and economics consists of energy resources, energy policies, energy economy, energy market, and ecology. The relationship between renewable energy consumption and economic growth in the European Union (EU) countries will be analyzed in this thesis.

This thesis consists of four chapters. In the first chapter, energy and economic growth will be defined conceptually. Accordingly, the thesis's ground will be formed by clarifying the definitions and terms that combine energy and economics. Fossil fuel resources and their consumption, which are used extensively worldwide, will be given. Gas emissions and environmental effects of fossil fuel consumption on nature will be discussed. Renewable energy sources and usage proportions will be shared. Nuclear and hydrogen energies with different properties from fossil and renewable energy sources will be introduced.

In addition, the concept of economic growth and how to measure economic growth will be explained. Economic growth theories and the historical development of these theories will also be shared in this section. The inputs used in calculating economic growth will be defined and their effects will be discussed.

The second part of this thesis, it is aimed to evaluate the energy sectors economically and politically. The political decisions of countries will be discussed by examining energy markets and economies. Development levels according to the economies of the countries will be introduced and the energy economies of these countries will be explained. Studies on the role of energy use in economic developments will be explained in this section.

In the third part of this thesis, literature research of previous similar studies will be done. As a result of this literature research, the theoretical basis of the subject will be formed. The data obtained will be introduced and variables will be determined. As a result of the analysis to be made, it is expected that renewable energy consumption as an independent variable will affect economic growth. After the analysis, an econometric model will be created.

In the last part of this thesis, the results of the analysis will be evaluated. The relationship between renewable energy consumption and economic growth in EU member states will be described.

1.1. General Energy Concept

Humankind needs energy in every field to sustain their lives. In the primitive ages, the energy was used only for survival, but with the advancement of humanity, the uses of energy have expanded. At the moment, energy is intertwined with our lives in many vital activities. We need energy for our many activities such as housing, transportation, defense, services, industry, nutrition [3]. This situation is shown in Figure 1 the energy needed only for food and had spread over many areas with human development.

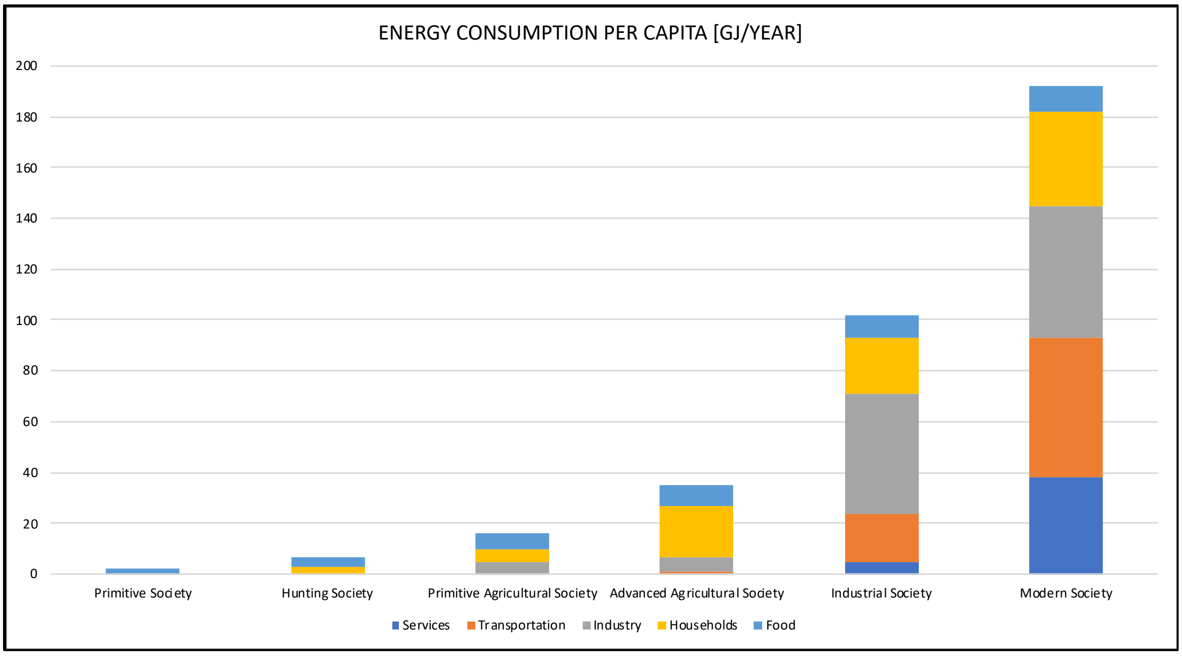

Figure 1. Energy use per capita from primitive to modern ages, based on data from [4].

Energy sources are generally categorized as conventional (non-renewable) and renewable. Conventional energy sources have a significant usage proportion around the world. These include oil, coal, and gas. Renewable energy sources are wind, biofuels, solar, geothermal, and hydro energy.

Primary energy (PE) sources are readily available in nature and have not been subjected to any human-designed transformation process. These energy sources are not subjected to any process other than separation from contiguous material, cleaning, and grading [5]. Primary energy sources are renewable and non-renewable energy sources. Resources such as coal, oil, gas, nuclear, hydro, geothermal, solar, wind, and bio are primary energy sources.

Considering the sources of energy produced and consumed in the world, the importance of primary energy sources becomes apparent. The situation of energy resources in the global energy market can be better understood with the graphics below.

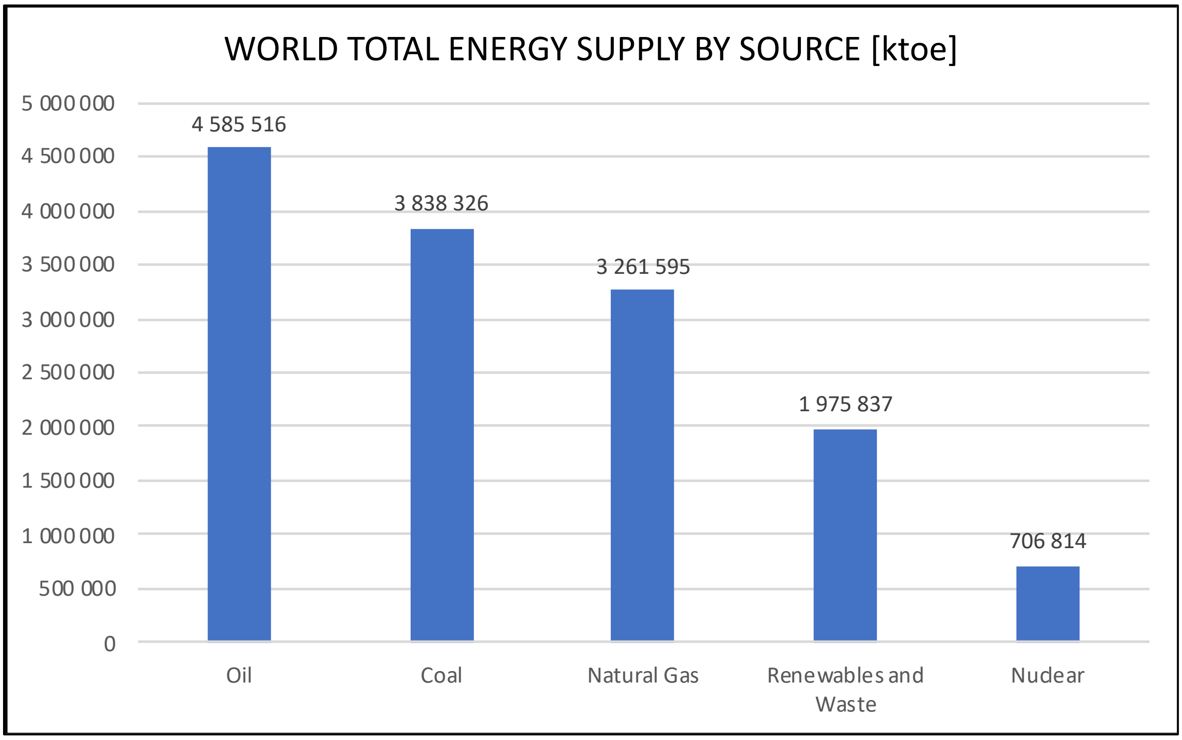

Figure 2. World total energy supply by source in 2018 [ktoe], based on data from [6].

According to 2018 data, 14 281 889 kilotonnes of oil equivalent (ktoe) energy were supplied [6]. Figure 2 shows the amount of this energy according to the sources. Oil is by far ahead of other sources, with a supply of 4.5 million ktoe. Nuclear is the lowest energy source with 706 thousand ktoe. As can be understood from this table, the primary energy sources of today are mainly fossil energy sources.

Even though the share of renewable energy sources increases over the years, there is still a significant difference with fossil fuels. Thanks to the investments and policies that countries have shared in renewable energy resources, this gap seems to close in the coming years.

Nuclear energy is also in an increasing trend compared to previous years, but in recent years, some developed countries find nuclear energy dangerous and want to terminate these energy sources may reduce the amount of supply. These countries are afraid of experiencing similar accidents in Chernobyl and Fukushima. They want to terminate nuclear energy sources because they think the consequences of a possible accident will be severe. They want to replace these nuclear resources with renewable and safer energy sources. On the other hand, some developed and developing countries continue to invest in nuclear energy resources.

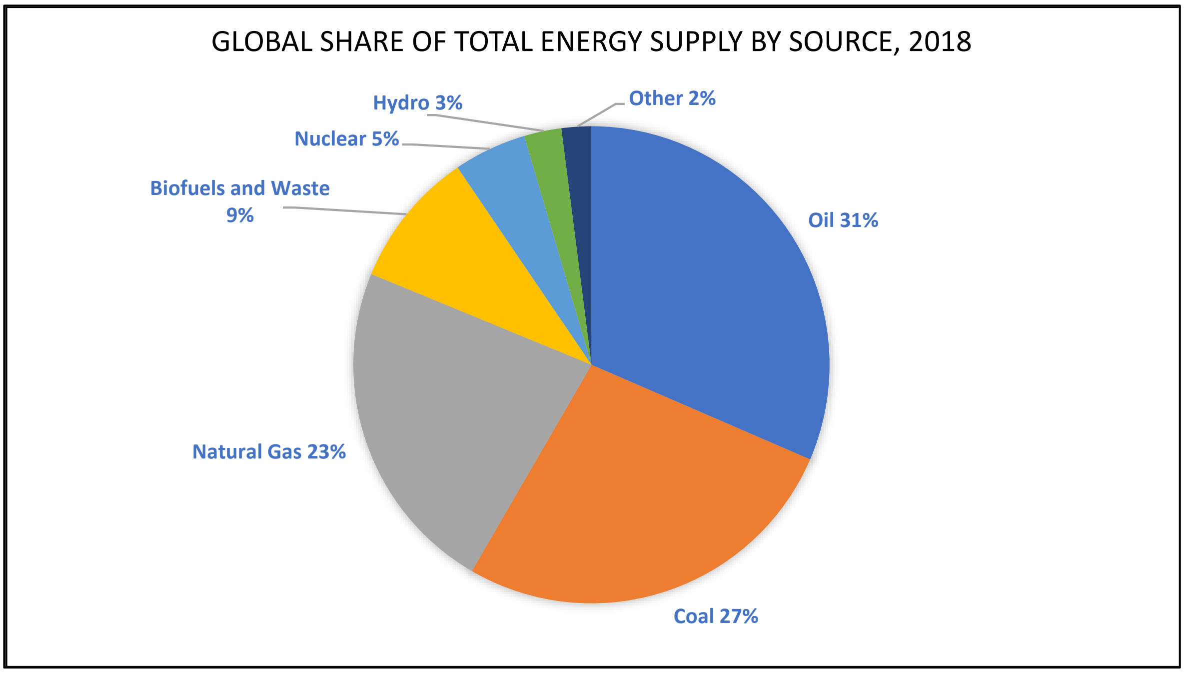

Figure 3. Global share of total energy supply by source in 2018, based on data from [6].

Figure 3 shows the shares of energy resources in the total primary energy supply for 2018. In line with these data, the dominance of traditional energy resources in the global energy market is clearly seen. Petrol ranks first in primary energy supply with a share of 31%. Yet another fossil fuel, coal has a 27% share. Natural gas, which is one of the traditional energy resources, ranks third on a global scale with a share of 23%. Fossil fuels have a share of approximately 81% in primary energy supply.

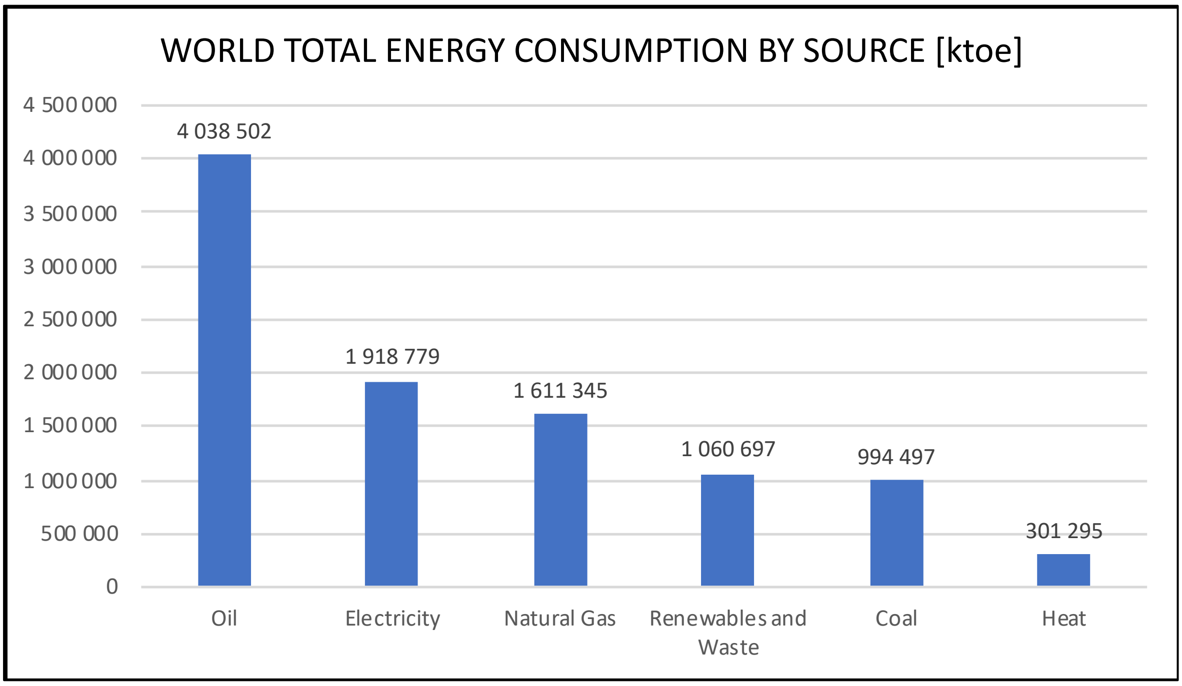

Figure 4. World total energy consumption by source in 2018, based on data from [6].

The sources of the total energy consumed in the world in 2018 are given in Figure 4. As can be seen, the use of petroleum products comes first. Processed petroleum products have used 4 million ktoe and there is a big difference with other energy sources. The amount of energy used by converting into electrical energy is approximately 2 million ktoe. Heat energy is also one of the energies used by converting, and 300 thousand ktoe was used in 2018.

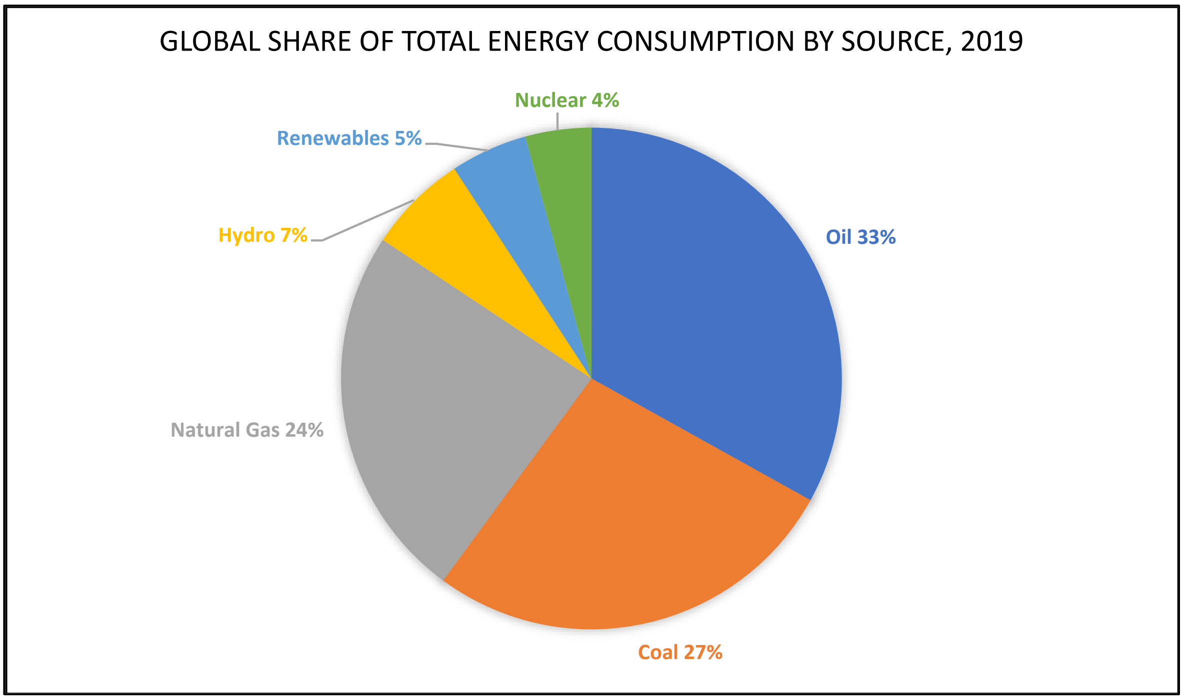

Figure 5. Global share of total energy consumption by source in 2019, based on data from [7].

In Figure 5, the ratios of the energy used in 2019 are given according to the sources. Oil, coal, and natural gas have the largest shares as ever. All together constitute 84% of the total energy consumed. When hydro and renewable energy resources are considered in total, it is seen that they get a 12% share. This situation clearly shows us the difference between renewable energy sources and traditional energy sources.

Energy, which is the main input of economic activities, can be expressed as the most important element of the global economic system. The concept of energy has increasing importance in the globalizing world and has a position that affects the development of national economies [3].

1.2. Renewable Energy Sources

The intensive use of non-renewable energy resources in the world and the fact that they will be depleted in the future due to limited resources has led countries to alternative energy resources. In addition, the environmental problems of fossil fuel-based energy sources have shown the importance of renewable energy.

Renewable energy sources are defined as natural and continuously renewable energy sources. Primary renewable energy sources are solar, wind, hydro, tidal, geothermal, and biomass [8].

The development of renewable energy is an effective option for many countries that want to reduce dependence on energy imports and reduce greenhouse gas emissions. Renewable energy systems have shown an important potential in reducing carbon dioxide (CO_2) emissions, increasing energy supply security, and enabling strong structural changes in the economy in line with the fight against climate change, and have been included in the main incentive areas of industrialized countries. Renewable energy is one of the most important tools to reduce countries' dependence on energy imports [8].

1.2.1. Solar Energy

The world's most important energy source is the sun. The radiative energy of the sun is the main energy source that affects the physical formations in the earth and atmosphere system. Solar energy, which is the origin of many natural energy resources, is directly utilized for purposes such as heating and generating electricity. Almost 4 million exajoule (EJ) of solar energy reaches the earth annually and it is suggested that approximately 50 thousand EJ can be easily harvested. Despite this enormous potential and increase in utilization, the contribution of solar energy to the global energy supply is still underestimated [9].

Among the energy generation sources, solar energy is the cheapest and suitable for use in many applications. Maintenance cost of solar energy systems is also very low compared to others. Energy storage systems are among the items that increase the cost due to weather conditions.

With the world's countries turning towards alternative energy sources, the growth of solar energy has increased exponentially between 1992 and 2020. Especially after small-scale applications, it has become one of the mainstream electricity sources. Since the development of solar cells in the 1950s, many countries have started using solar power generation [10].

The surface of our planet reaches 1366 W/m^2 direct solar radiation [11]. This makes the sun more reliable and sustainable than traditional energy sources. In addition, solar energy has an important environmental advantage compared to other sources.

Solar PV systems are not very complex systems. Generally, the system starts with the series of PV panels where the solar rays are collected. These PV panels generate DC outputs and the charge controller regulates and stores them into batteries. In case of need, the energy stored in the battery is inverted to AC with the help of a DC/AC inverter. A power meter is used to record and measure the electricity flow feeding the load. The general outline of a solar PV system is drawn in Figure 6 [12].

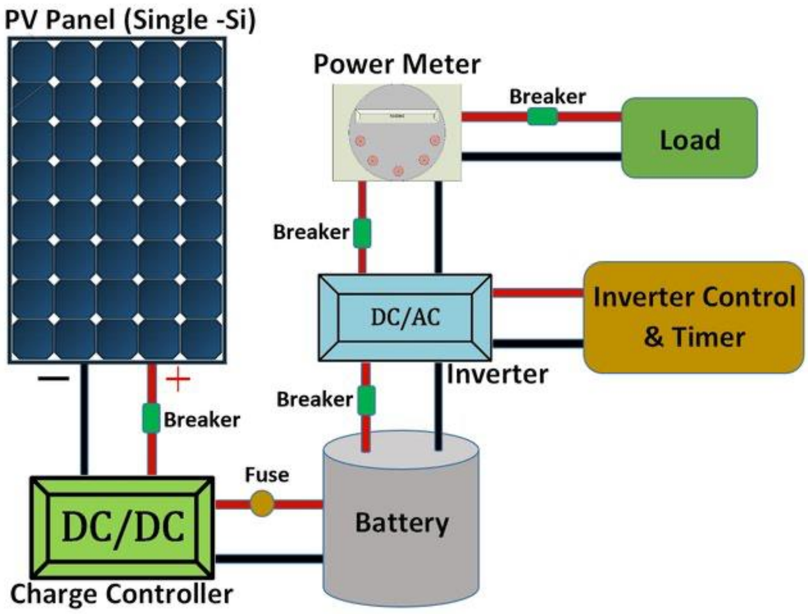

Figure 6. General outline of a solar PV system [12].

PV systems can be applied more easily and faster than other energy sources. In addition, the initial investment in PV cost is not very high. As a result of the development of technology, these costs are decreasing day by day. According to the annual report of Bloomberg New Energy Finance (BNEF), the global levelized cost of electricity (LCOE) for PV systems has decreased by over 77% in 10 years [13]. Batteries, one of the most important costs of the system, decreased by approximately 85% [14]. Increases in the number of PV projects in recent years are due to these price decreases and government incentives. Cumulative installed PV power in the last 10 years is shown in Figure 7.

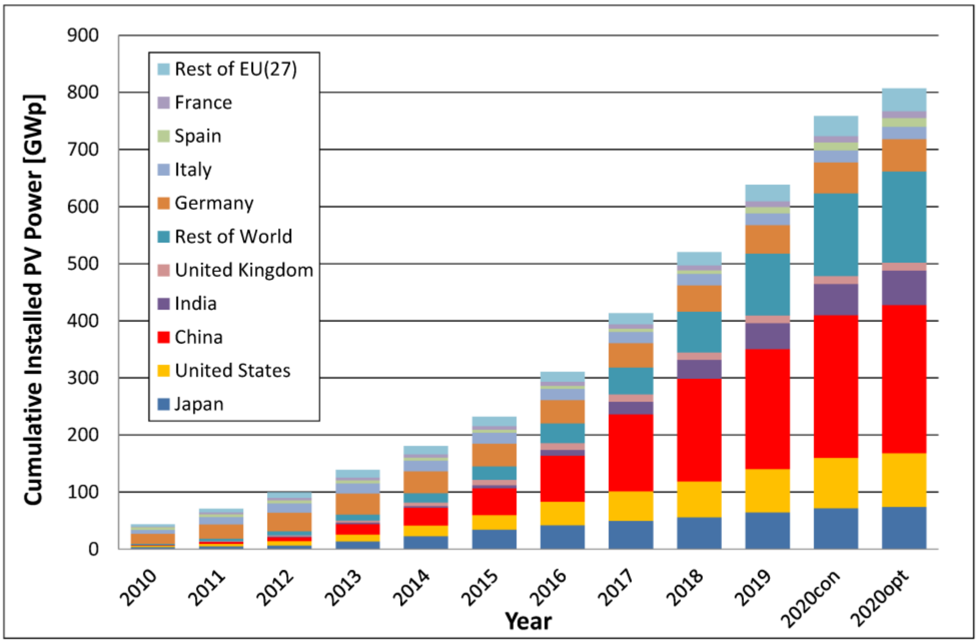

Figure 7. Cumulative installed PV power [GWp] between 2010 – 2020 [14].

1.2.2. Wind Energy

As a result of the different heating of the earth surfaces by the sun, the movement of air masses in the atmosphere creates winds. Different warming of the seas and the air causes the formation of a pressure difference, and this pressure difference causes the movement of the air. This movement of air from high pressure to low pressure is known as wind [15]. Therefore, wind energy is an indirect form of solar energy like hydro. Wind energy is used to generate mechanical energy or electrical energy. The obtained mechanical energy is generally used for irrigation in homes and farms. Wind power plants (WPP) use wind energy to generate electrical energy.

Almost all developed and developing countries continue to invest and provide incentives in wind energy. Investments in countries with a coastline to the sea and the ocean are above the world average. The global cumulative installed wind power capacity for the last 20 years is shown in Figure 8.

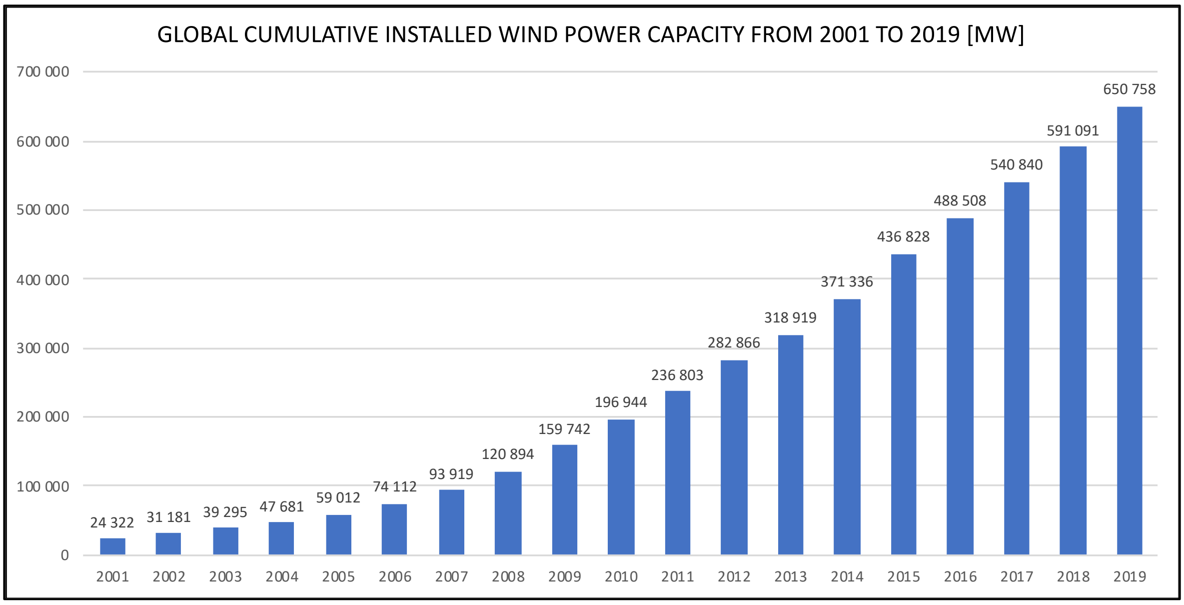

Figure 8. Cumulative installed wind power capacity from 2001 to 2019, based on data from [16].

One of the most important parameters of wind energy is wind speed that changes constantly at any particular location. These speed changes are categorized by duration, there are annual, seasonal, passing weather systems (synoptic), daily, and second to second (turbulence) changes [15]. This makes it difficult to calculate the energy to be obtained from a WPP.

According to the European Academy of Wind Energy, the annual average wind speed of 14 - 25 meters/second are ideal for electricity generation [17]. Figure 9 illustrates a typical wind turbine power curve. In order to determine the potential of a region in terms of wind energy, it is necessary to monitor the data on wind speed and intensity for a long time with devices that comply with the standards.

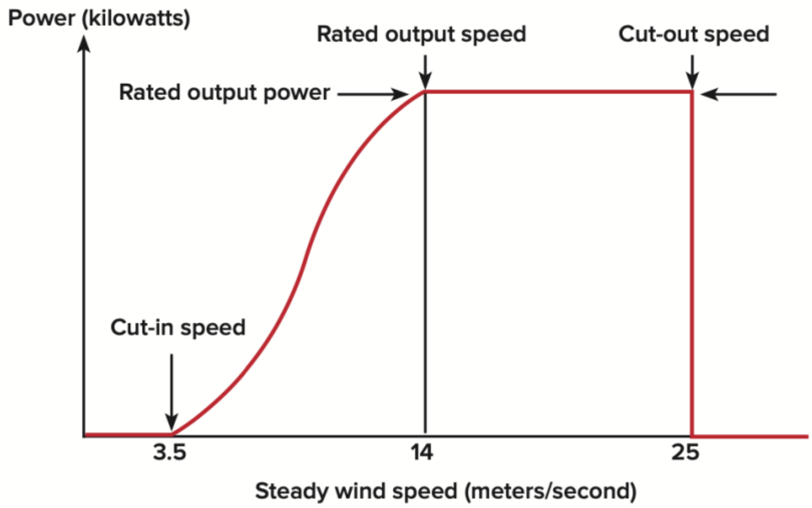

Figure 9. Typical wind turbine power outlet with steady wind speed [17].

It was mentioned in previous chapters that the renewable energy market share is increasing progressively. Adaptation of renewable energy is vital for a greener environment. Therefore, there is an intense global interest in the development of renewable energy technologies. In recent years, significant developments have been observed in wind energy investments and future projections [18]. The improvement in wind turbine rotor size has led to a significant increase in the amount of energy obtained. Figure 10 shows the energy outputs for the growth of wind turbine rotor sizes since 2000 [19].

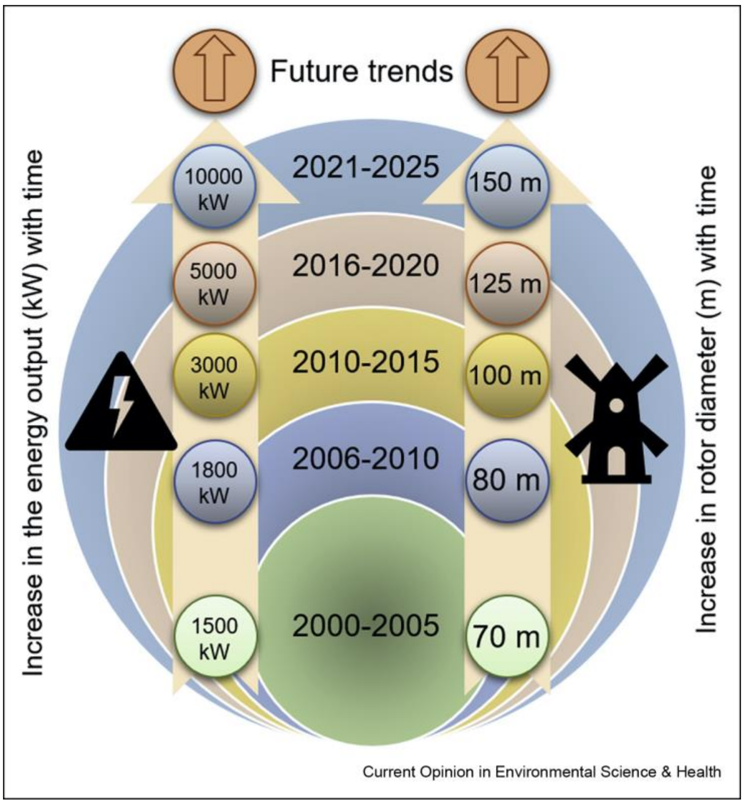

Figure 10. Wind turbine rotor size and their rated energy output since 2000 [19].

1.2.3. Hydro Energy

The most commonly used renewable energy source around the world is hydroelectricity. The direct source of hydropower is water, but it is an indirect form of solar energy. Solar radiation evaporates the waters of the oceans, seas, and land. The heated steam rises and starts to cool. It forms clouds by condensing at a certain height and temperature. It eventually falls in high places as rain. Water gaining potential energy thanks to the sun, begins its journey to reach the sea again [15].

Hydroelectric energy is the type of energy that converts the power of flowing water into electrical energy through hydroelectric power plants (HPP) built on moving water bodies. The HPPs can be divided into two as dam (large-head) and river (low-head) type power plants [15].

Dam-type HPPs create large reservoirs from rivers to store and raise water. The stored water is allowed to flow out of the reservoir in a controlled manner, during which the turbines rotate and electricity is generated. The biggest advantage of dam type power plants is that they generate electricity according to demand and reduce costs [15]. Figure 11 demonstrates the structure and units of the dam type hydroelectricity power plant.

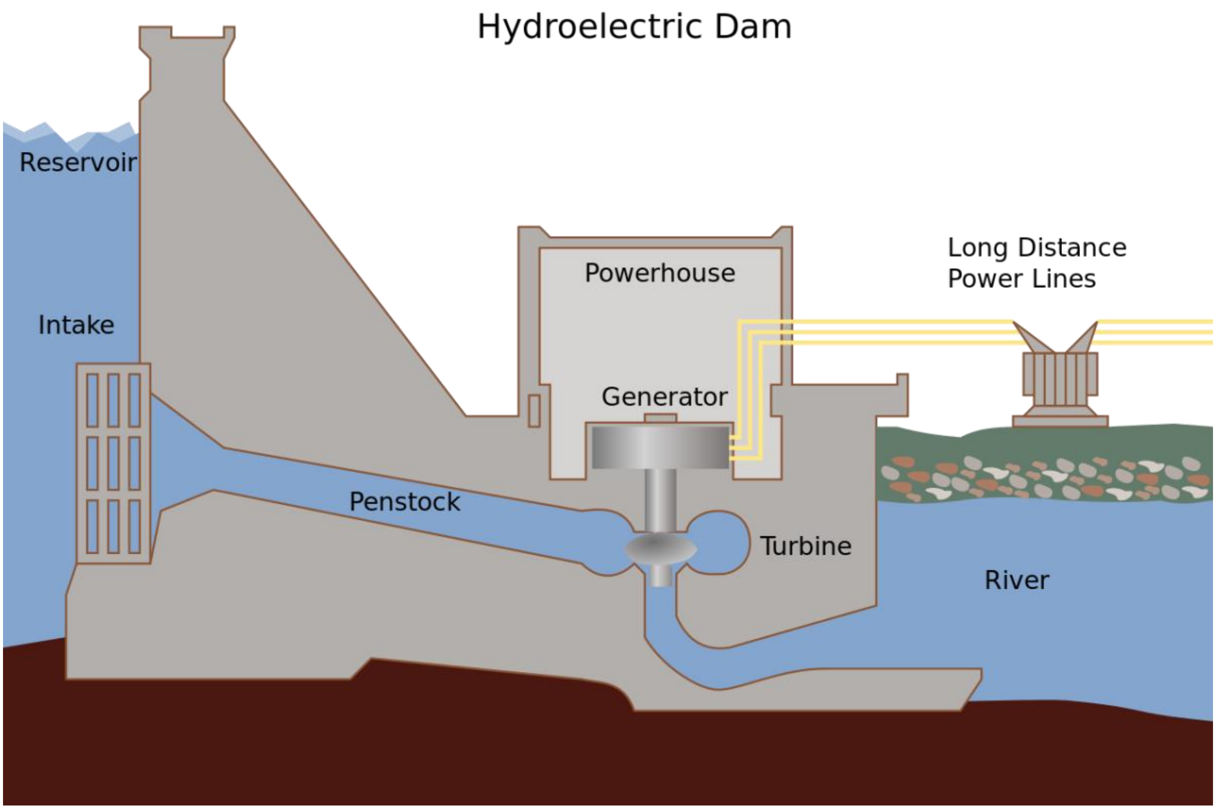

Figure 11. Schematic diagram of hydroelectric power plant [21].

River (low-head) type HPPs generate electricity with the power of flowing water. It does not need any dam or reservoir for this production. Therefore, there is no need to hold and store water. There is an estimated production amount for HPPs, but it varies according to rainfall. The low amount of snow and rainfall in winter and spring affects the production capacity negatively.

1.2.4. Tidal and Wave Energy

Tide occurs as a result of the interaction of gravity between the earth, moon, and sun. Although the surface-level changes due to the tides in the middle of the oceans are limited, the changes in the surface level towards the coasts are increasing and the magnitude of the change occurs at different levels depending on the shape of the coastline. Tidal energy is not a type of energy that can be applied wherever tidal events occur. In order for tidal movements to be used for energy production, the difference between rising and falling tides must be at least five meters. In addition, gulfs are the most suitable places to produce energy through the tides [22]. Tidal energy is produced by tidal streams, barrages, and tidal lagoons nowadays.

- **Tidal Streams**

Tidal streams are used to obtain tidal energy. The tidal stream consists of a large body of fast-flowing water. Turbines are placed in these streams and the turbines generate energy from these streams. Similar turbines are used in wind energy, but since water is much denser than air, tidal energy is stronger than wind energy. Since it is possible to calculate and predict tides, stable and reliable energy can be obtained from these sources [23].

- **Barrages**

Barrages are used for generation in this type of tidal energy. Water flows from the high side of the barrage to the low side over or through the turbines. Barrages gates open as the tide rises. At high tide, the barrage gates close and forming a pool or tidal lagoon. The water is released from the turbines of the barrage and energy is obtained in this way. Tidal barrages are built along rivers, bays and estuaries. This type is more expensive than other tidal energies. In addition to the lack of fuel costs, there are construction and machinery costs [23].

- **Tidal Lagoon**

It is necessary to build a lagoon to generate energy. A lagoon is a partially natural and man-made body of ocean water. It can also be in estuaries and harbor fresh water. While tidal lagoons generate energy, the logic of operation can be compared to dams. But unlike dams, lagoons are built along the coastline. Energy is generated as the lagoons fill and empty [23].

The wave energy is generated by wind movements based on solar energy. The total energy of a wave consists of the sum of the potential energy of the moving water body starting from the still water surface and the kinetic energy of the water particles in motion. Unlike other forms of solar energy, wave energy is the most suitable for use in the winter months. Unlike tidal energy, it is possible to obtain wave energy, although the power potential changes on almost all coasts. There are some technical problems that limit the use of wave energy. The necessity of a turbine design suitable for every wavelength, the routes used by marine vehicles, fishing grounds, and underwater cables are important issues to be taken into account when making projects for this energy source.

1.2.5. Geothermal Energy

Geothermal energy is considered the natural heat of the earth. It is the energy of hot fluids (water, water vapor, gas) or hot and dry rocks under high pressure in the depths of the ground. Geothermal energy is obtained by the emergence of water vapor or high-temperature water that comes to the surface as a result of the magma, which is miles below the earth's crust, heating the groundwater. This energy is used for electricity generation or heating.

Countries which have a geothermal energy source, meet most of their energy needs from this source. Countries such as Iceland, El Salvador, New Zealand, Kenya, and Philippines supply a significant part of their electricity consumption from this source. Iceland supplies more than 90% of its heating demand with geothermal resources [24]. The importance and capacity of geothermal energy have increased in recent years. According to the International Geothermal Association's (IGA) report, the increment of the capacity of installed geothermal energy resources in the world between 2010 and 2025 is shared in Figure 12. As can be seen below, it is expected to double.

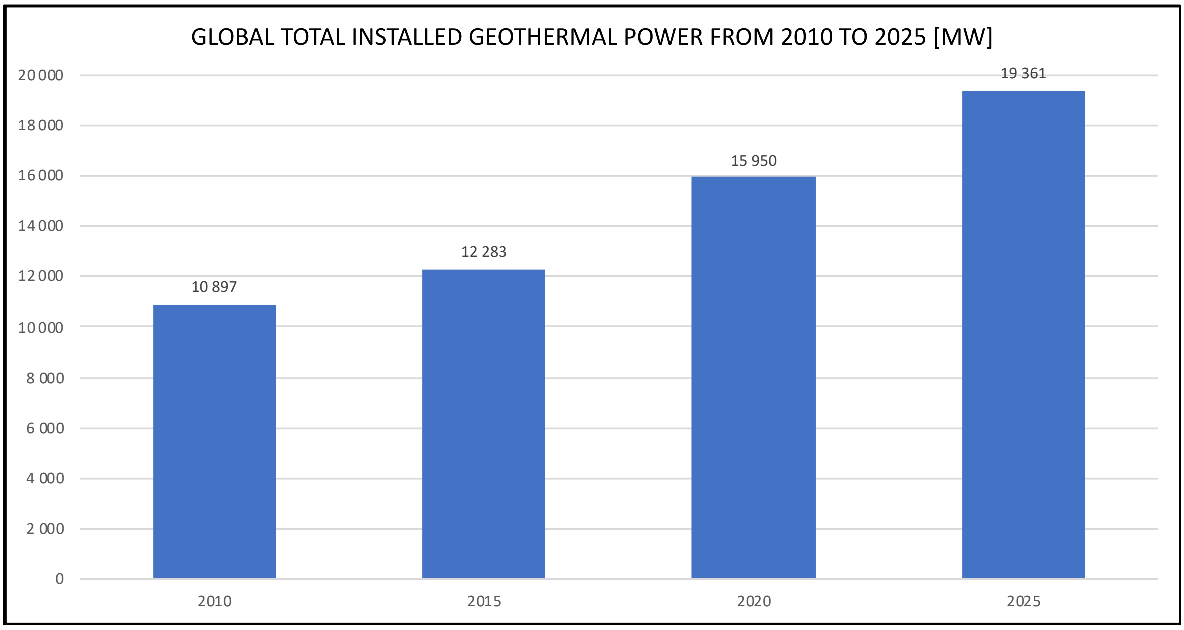

Figure 12. World total installed geothermal power from 2010 to 2025, based on data from [25].

1.2.6. Biomass Energy

Biomass is a source of organic matter that occurs as a result of green plants transforming solar energy into chemical energy through photosynthesis. Basically, all natural substances of vegetable or animal origin, consisting of carbohydrate compounds, are biomass energy sources. The energy obtained from these sources is defined as biomass energy. In other words, it can be defined as all organic substances that can be renewed in less than a century, grown land and water plants, animal waste, food industry, forest products, and urban waste [26]. Biomass materials can be processed into solid, liquid, and gaseous fuels. As a result, they form main products such as biodiesel, bioethanol, pyrolytic gas, and by-products such as fertilizers and hydrogen. Biomass energy is used in three main areas; electricity, heat, and biofuel production, which is mainly used for transportation purposes.

Biomass is considered an inexhaustible source of energy, as it can be grown everywhere, and helps socio-economic developments in rural areas. The use of biomass is becoming important to solve the energy problem since the other energy resources such as petroleum, coal, and natural gas are limited and fossil fuels cause environmental pollution. Due to their nature, biomass energy sources are very diverse and some examples are given below;

- Wood (energy forests, wood residues)
- Oilseed crops (sunflower, rape, soybean, safflower, cotton, etc.)
- Carbohydrate crops (potato, wheat, corn, beet, etc.)
- Fiber plants (flax, hemp, hemp, sorghum, etc.)
- Vegetable residues (branches, stalks, straw, roots, bark, etc.)
- Animal waste
- Urban and industrial waste

1.3. Economic Growth and Theories

Economic growth represents the increase in the amount of final goods and services produced in a country in a given period. The concept of economic growth, which is also an expression of increases in real income per capita, basically defines long-term increases in production capacity that concern the supply side of the economy. These increases in production capacity are closely related to the development process in advanced technological and institutional structuring. Economic growth interacts with many factors. Economic growth is affected directly and indirectly by the following factors.; per capita income, physical and human capital, technological development, demographic factors, geographical factors and climate, cultural or institutional factors, level of democracy, income distribution, government policies, and macroeconomic stability [27].

Real gross domestic product (GDP) is the value of final goods and services that are produced in a given year within a country's borders at market prices for an essential year. It is possible to evaluate the living standard in a country in two different ways based on the real income per capita criterion. The first is to look at the change in real income per capita in the country over time. The second is to compare the per capita income of the country with those of other countries. In order to make such a comparison, it is necessary to express the per capita output values of countries calculated in national currency in terms of a country's currency (for example, US dollars). Growth means increasing the income obtained in a certain period. The change in GDP expressed in real terms after clearing the price changes generally gives the result of the measurement of growth [27].

Growth models can generally be divided into two separate classes as exogenous growth models and endogenous growth models. The neoclassical model considers technology as the inexplicable share of production. In other words, the level of technological development is accepted as an exogenous variable. Studies conducted in recent years highlight the relationship between economic indicators and technology. This situation shows technology as an internal variable. There is a close relationship between technology level and production knowledge in endogenous growth models. It is seen that some factors play an essential role in the production of technological knowledge [27].

1.3.1. Classical Growth Theory

The classical growth model is essential because it is the first systematic growth theory. According to the classical growth theory, economic growth has two stages. The first stage is the growth stage, the second stage is the stagnation stage. According to classical theory, the level of national income and employment is determined by the amount and productivity of land, population growth, and capital accumulation. Population growth brings new needs with it, and people are looking for new lands to meet these needs. This search generally results in the cultivation of less fertile soils. Increasing capital accumulation causes a decrease in the return on capital by reducing productivity. The decreasing level of income affects the entrepreneurs about new investments and causes capital accumulation to stop. In addition, the increasing population reduces the wage rate. The low levels of wages also cause the population growth rate to decrease. In a period when capital accumulation, investments, and the land area used are in a state of stagnation, national income and employment cannot exceed this by remaining at a certain level. In this recession period, all factors of production and employment level reach full use level and determine the level of full employment [28].

The classical growth model is important not because it can accurately model real-world development, but because it is the first systematic growth theory. Thinkers like A. Smith and D. Ricardo, T. R. Malthus, J. S. Mill, J. Mill, J. R. McCulloch, and N. W. Senior shaped the classical growth model. The model introduced by A. Smith, the founder of classical economics, was later developed by other classical economists.

Smith examined the change in the shares of production inputs in the growth process and attributes the reason for reaching the natural upper limit of growth to this change. Departing from a newly settled country with rich natural resources; deals with the relationship between the rate of profit and the rate of wages as the economy develops. Drawing attention to the law of increasing efficiency for both labor and capital, he argues that there are three main pathways for growth: capital accumulation, division of labor and specialization, mechanization. According to Smith, if the accumulation of capital remains the same in an economy, the economy will fall into recession. That is, production and consumption are equalized and growth stops. He related the effect of the division of labor and specialization on growth with foreign trade and tried to explain this with absolute superiority theory. The international division of labor is considered an essential factor in accelerating growth. According to Smith, economic growth means adapting the machines and the business division to the industry. If mechanization is applied to every segment (agriculture, industry, services) and provides real income per capita in every segment, growth will occur [29].

In the classical growth theory, the model developed by Ricardo is in a leading position. The Ricardo model is referred to as the classical growth theory. Investments in the model are the most important source of growth. Investments develop thanks to the increasing profits of entrepreneurs. According to D. Ricardo, it is impossible to have a continuous increase in productivity in the industry sector. One day, due to the increasing costs in the agricultural industry, the level of wages will increase, profit rates will decrease and eventually economic growth will stop. Because the factor that causes investments is the profit motive; if the profit rate falls, growth will stop [29]. The basic criteria of Ricardo's economic growth theory are:

- Perfect competition,
- Full employment,
- The state does not interfere with economic life,

- The law on decreasing yields in agriculture is valid,
- While wages depend on the supply and demand of labor in the short term, they depend on the minimum subsistence level in the long term (here shows Malthus' population theory),
- In the industry, the law on increasing yields is valid.

1.3.2. Keynesian Growth Theory

The Keynesian economy, which emerged with the great economic depression in the world in the 1930s, dominated the economic structure of many states until the 1960s. In the "General Theory of Employment, Interest, and Money (1980)" written by John M. Keynes, the intervention of the state in the economy is inevitable. While there are many factors in this, the main reason is the total lack of demand. Keynes's thoughts have been the basis of the economic philosophy of many states, especially with the participation of economic growth models and other analysis tools [29]. Keynes main views of the economy;

- The full-employment equilibrium in the economy is an accidental equilibrium and there is no guarantee that it can be maintained. Without the intervention of the state, instability in the economy can be a permanent situation. Keynes included the macro analysis method in economics. In particular, he studied and researched issues such as national income, consumption expenditures, capital accumulation, taxes, and foreign trade.

- Prices and wages may not be particularly downward flexible, as classical economists thought, due to institutional arrangements and non-economic reasons.

- Every demand creates its own supply. Therefore, it is the demand front that matters. Revitalization and supervision of the economy can only be done by demand policies.

- Its difference from the classics is that he acknowledges the role and intervention of the state in the economy. It is not possible to reach full employment without state intervention. He stated that the optimal balance between consumption and investment expenditures can only be achieved with the government's interventionist policies in the economy.

Keynes founded his theory on demand, not on supply. In Keynes' economic growth model, neither technological investments and innovations nor qualified human capital were included. The emphasis has been placed on the issue of how an economy can escape from the recession and how the resources that trigger growth will accelerate. The fact that it has not entered into the problems faced by a growing economy and the factors affecting the growth process has left the model incomplete and made the model static. It is an important deficiency that it uses developed countries in the Keynes model and does not consider the growth process of less developed countries [30].

- **Harrod-Domar Growth Model**

Based on the underemployment balance, Harrod investigated the conditions of growth that would achieve full employment balance. Based on the full employment balance, Domar researched the conditions that would ensure the sustainability of growth. Growth models prepared independently from each other; They are parallel due to the assumptions they reached in terms of cause and effect, and are mentioned together for this. Although Harrod and Domar models are essentially the same, there is a difference between them. While Harrod chooses the starting point of underemployment and emphasizes the conditions that will enable it to reach full employment, Domar sets out the conditions necessary to maintain it as a current process, based on the full employment situation [30]. The Harrod Domar model suggests that the path to growth in the economy stems from the increase in capital accumulation. The source of the capital increase is the increase in investments. Increasing investments increase production and GDP

1.3.3. Neo-Classical Growth Theories

Neo-classical growth theory emerged as a result of empirical studies in two separate articles of Solow (1956) and Swan (1956). It is possible to present the Solow economic growth model in four variables: income (Y), physical - tangible capital (K), labor (L), and knowledge or labor efficiency (A). Production function at time t:

$$Y(t) = F(K(t), A(t), L(t)) \qquad (1.1)$$

The main purpose of neo-classics is trying to prove that it is a tool that regulates the behavior of the market and individuals by using the price mechanism by taking the income level as data. A normative growth model has been introduced within the assumptions made within the framework of perfect competition. The reason why this growth model is normative is that the balances are optimal and effective. The neo-classical growth model is to create the dynamic conditions necessary for the economy to reach full employment. The basis of this model is the capital stock and productivity function. It considers the relationship between input and output per unit of labor. The rate of increase between the amount of capital per capita and real GDP and income per capita is directly proportional. Basic factors determining growth; technology change and population growth rate. However, these two elements are determined outside of the model.

According to equation (1.1), the amount of output per worker is determined by the capital per worker. In other words, as the capital per worker increases, the amount of output per worker also increases. However, since the law of diminishing yields applies in the model, the increase in capital causes less increase in output after a while. The model has a consistent approach in terms of its assumptions and tools used. In addition, the law of diminishing yields is not continuous as indicated in the model.

1.3.4. Endogenous Growth Theories

The externality of the population and technology revealed by the Neo-Classical model has been criticized on various issues over time. This situation deeply affected theoretical and practical economists based on endogenous growth models. According to endogenous growth theories, growth is a process that is provided from within, nourished and formed by its own internal dynamics. The main issue in endogenous growth is that economic growth is a result of factors stemming from within the economic structure itself [30].

Its main determinants can be summarized as follows, in addition to education, health, and technology policy, the cultural, social, and other characteristics of that country are among the basic principles of internal growth. The unique characteristics of the country lead to research and development activities. This situation causes the emergence of new products. In addition, it reveals different design and production processes with more effective production methods. The endogenous growth theory developed by Robert Lucas and Paul Romer, contrary to neoclassical thought, evaluated the growth rate as an internal variable rather than an external variable [29].

Differences between endogenous and neo-classical growth:

- Endogenous growth theories suggest that economic growth occurs due to internal factors.
- Technological development is considered as an endogenous variable in endogenous growth theories.
- Endogenous growth theory takes into account increased yield. According to Romer, the information that comes out as a by-product in the production and investment process provides productivity increase not only for that company but also for the economy in general.
- Endogenous growth theory rejects full convergence.
- Many economic and socio-cultural factors such as education level, public policies, foreign trade, tax, income distribution, regional factors, cultural structure, religious factors, fertility rates, management style, health, inflation, and investment rates are effective on long-term economic growth.
- State intervention is needed to achieve the optimal growth rate in endogenous growth theories.

Robert Barro's economic growth model brings R&D activities to the fore. Barro argued that public revenues affect R&D activities. In other words, tax policies affect economic growth through R&D activities. If R&D activities include tax exemptions within the scope of incentive policies, then R&D activities pave the way for technological development, which is one of the main determinants of economic growth [31].

2. Energy Economics

Due to its energy structure, it is in contact with many branches of science. In addition to the fact that energy is a multidirectional concept, production, consumption, and trade processes of energy are carried out at certain costs, which has led to the interest of energy in economics. General economic theory provides several insights into analyzing energy markets. In particular, although energy resources are physically intense, they are considered in the limited resources category. For this reason, energy resources should be studied in economics [32].

As in other markets, the energy economy consists of supply and demand sides. Considering the situation from the supply side, if the number of independent suppliers is high, the energy market converges to the perfect competition market. In other words, suppliers choose the amount they are willing to put on the market at a certain price. Maximizing profits is also one of the most important goals of producers in terms of the economy. Looking at the issue from the demand side, the demand for any good increases when its marginal benefit is higher than its marginal cost. This situation is different for an energy product as a good. Because the benefit does not arise directly from energy use and is affected by factors such as use-related heating, transportation, industry, and technology. Thus, the contribution of energy to these services is taken into account when determining the marginal benefit of energy [33].

The diversification of energy resources and the widespread use of these diverse energy resources in all segments of the industry and society have led to the emergence of energy as an important economic field and brought the energy economy to the agenda. Energy economy refers to the processes of meeting energy needs with limited energy resources. The energy economy examines energy resources and their relationship with economic activities. In addition, energy is a technological as well as an economic issue. As technology improves, energy-related problems are expected to be resolved more easily. In this context, it is possible to say that the energy economy is in a close relationship with energy technology [34].

2.1. Global Energy Market

Since the industrial revolution, a race has been started to have energy resources globally, and unfortunately, this race has caused many wars. There is a direct relationship between economic development and energy resources. Some of the major crises in the last century are First World War, Second World War, Korean Crisis, Cuban Crisis, Vietnam War, Arab-Israeli Wars, Suez Crisis, First Gulf Operation, and Second Gulf Operation. Energy geopolitics and energy security have been involved in some of these crises [35].

Over the past century, the pain of the transition from the coal age to the oil age has been experienced in our world. This period was marked by the effort to seize and control oil reserves. The political and economic power in the world has been shaped around the petroleum raw material. Twentieth-century can be considered as a period dominated by petroleum technologies. However, around 95% of the oil resources in the world have been discovered. The annual oil production of many oil-producing countries has reached the peak, and when the annual consumption amounts are taken into account, the oil century is partially at the end [35].

Most countries today use fossil-based fuels such as coal, oil, and natural gas. Although the production of these fuels is important in meeting the energy needs, they also have various damages. In the global energy market, problems brought by fossil-based fuels accelerate the transition to renewable energy systems [35].

Basic problems of the global energy market;

- Foreign dependency on energy and energy supply security,
- Energy price shocks that adversely affect the national economy,
- Non-renewable energy sources have a significant share of the market,
- Global warming and climate change.

The most important and most remarkable indicator of the global energy market is the increasing energy demand. Accordingly, global energy use is expected to increase by 50% between 2018 – 2050 [36]. There are two important reasons for the depletion of fossil energy sources compared to renewable energy sources and the rapid increase in energy demand. These reasons are the rapidly increasing world population and industrial development. The life expectancy of limited energy resources is estimated to be 30 - 150 years. In addition, the production of these energy resources will decrease between 40% and 60% until 2030 [37].

2.2. European Union Energy Economics and Policies

Meeting the energy needs of the EU is one of the primary conditions of sustainable economic growth. Despite increasing energy efficiency and decreasing energy intensity in consumption, EU energy requirements are still increasing. The EU is the third-largest consumer of energy after China and the United States of America (USA). The EU consumed 68.81 EJ of primary energy in 2019, and this amount is 17% of the energy consumed by the world [7]. Figure 13 demonstrates total final energy consumption of EU by source in 2018.

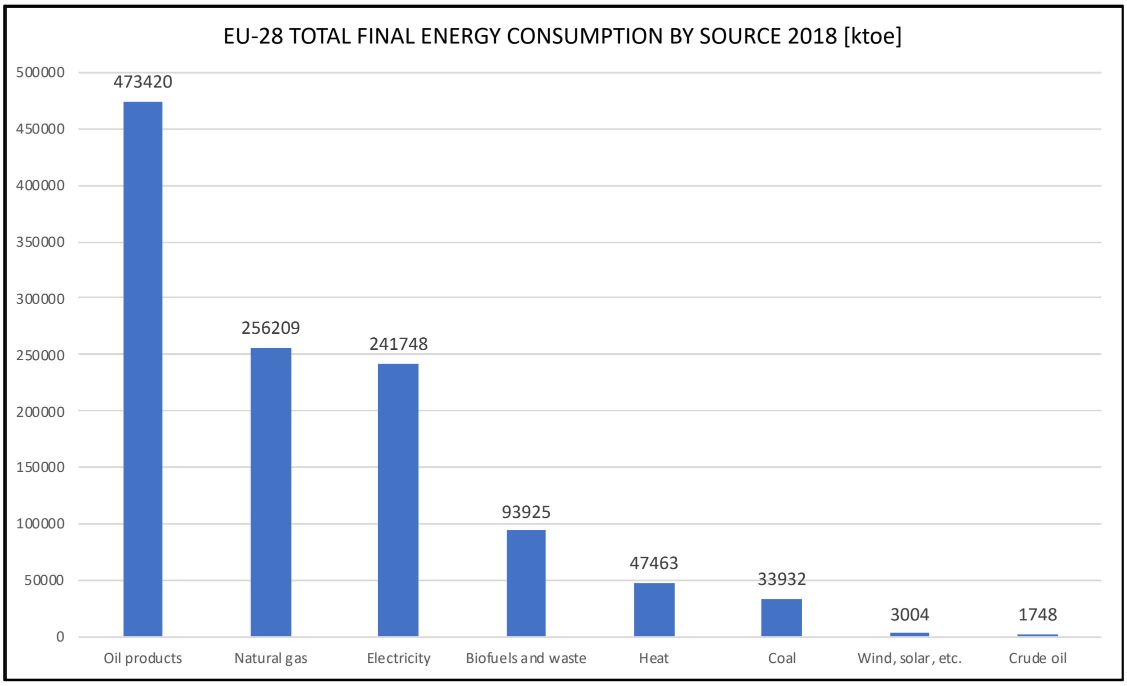

Figure 13. Total final energy consumption of EU by source, based on data from [38].

The EU's energy resources are limited, so its energy requirement is based mainly on imported oil and natural gas. According to Eurostat's 2018 data, 58% of the total energy consumption of the EU is imported energy. The EU is increasingly dependent on imported energy. While the EU's dependence on imported energy was 45% in 1997, between 1997 and 2006 the total energy production of the EU decreased by 9%, and consumption increased by 7%. In 2030, the share of imported energy in total energy consumption is expected to reach 65%. Malta, Cyprus, and Luxembourg are the most dependent member states on imported energy. Estonia, Denmark, and Romania are the least dependent member states on imported energy [39].

The energy mix in the EU in 2018 was mainly made up of five varied sources: Petroleum products (36%), natural gas (21%), solid fossil fuels (15%), renewable energy (15%), and nuclear energy (13%). Oil has been replaced by other sources in a number of sectors in the EU in response to the crises of the 1970s. But despite significant investments and technological advances, oil is still the primary fuel, especially in the transport sector. The EU meets most of its oil needs from Russia (29.8%), Iraq (8.7%), and Saudi Arabia (7.4%). After the collapse of the Soviet Union, EU member states increased their oil imports from Russia. This severe dependence of the EU on imported oil costs member states dearly [39].

The EU's dependence on natural gas imports is different from dependence on oil imports. The EU is the world's largest natural gas importing market, and this situation is predicted to continue until 2030 [40]. Natural gas is the least harmful to the environment among fossil fuels. Therefore, natural gas is of vital importance for the EU to fulfill its goals of combating climate change and sustainable economic growth. Natural gas from Russia constitutes 40.1% of EU imports. Following Russia, Norway comes with a share of 18.5% and Algeria with a share of 11.3% [39].

The EU has large reserves of coal and coal is of historical importance. The European Coal and Steel Community Treaty (ECSC), one of the underlying treaties of the EU, was signed by the states of France, Germany, Italy, and Benelux, who united in their desire to control coal. In the EU, the main coal producers are Germany, England, Spain, Hungary, Poland, Slovakia, Czech Republic, and Slovenia. Although coal is abundant in the EU and cheaper than oil and natural gas, it is not preferred due to its environmental effects. Coal consumption is gradually decreasing in the EU as it is replaced by other energy sources. Research in Europe has intensified for technological innovations that can provide clean energy from coal to reduce import energy dependency. The future demand for coal in the EU depends on whether new technologies are developed that will ensure the attitude of carbon dioxide emissions [39].

Nuclear energy is used in the EU, although it poses a serious threat to the environment and human health and the majority of public opinion in the member states is against it. Although nuclear energy has historical importance for the EU like coal, its use is debatable for the EU. When the negotiations for the Rome treaty began, there were high expectations about the role of atomic energy. Since uranium is rare in Europe, it caused the European Atomic Energy Treaty to be signed [41]. Nuclear power plants (NPP) produced about 28% of the electricity generated in the EU-27 in 2018. NPP owner countries are Belgium, Bulgaria, Czechia, Germany, Spain, France, Hungary, the Netherlands, Romania, Slovenia, Slovakia, Finland, and Sweden. Electricity production from NPP in the EU-27 decreased by 16.7 % between 2006 and 2018 [42].

EU public opinion approaches nuclear energy negatively. The EU Commission leaves the decisions on the use of nuclear energy to the members. As a result of the Chernobyl accident, the increased awareness of the risks of nuclear energy led to the premature shutdown of nuclear power plants in countries such as Spain, the Netherlands, Germany, Sweden, and Belgium in the 1990s. Due to the increase in energy prices in the EU and the improvement in the security measures of nuclear power plants, some member states are reassessing their situation regarding the use of nuclear power [41].

The use of renewable energy sources is very important for the European Union. The EU is turning to renewable energy sources with the aim of reducing dependence on imports, obtaining energy by using its own resources, reducing carbon dioxide gas emissions, and producing environmentally friendly energy. The amount of obtained energy from renewable energy sources is closely related to energy technologies and their development. However, the amount of energy obtained from renewable sources is far below the desired level.

The European Commission aimed at meeting in 2019 to meet approximately 20% of the EU's total energy consumption from renewable energy sources by 2020. Figure 14 shows the ratio of renewable energy to the total energy in the EU-27. This ratio was 18.89% in 2018 and is approaching the 2020 target. At the meeting held in 2018, a new target was set for 2030 and 32% was targeted [43].

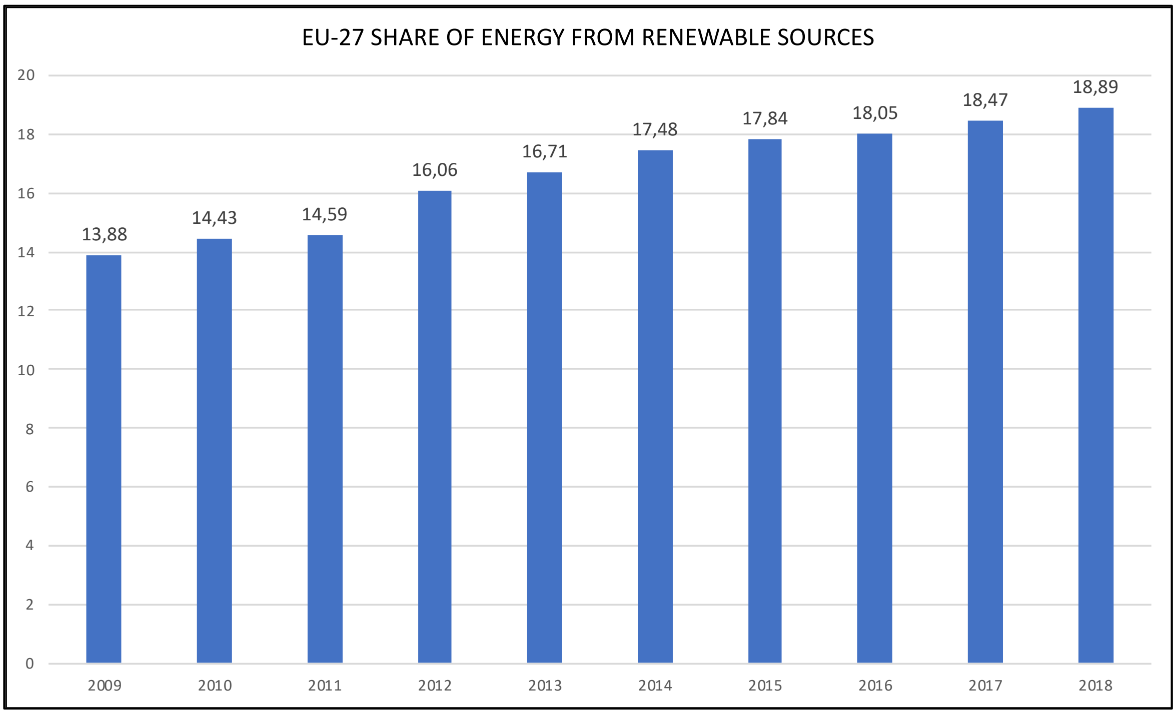

Figure 14. Share of energy from renewable sources of EU-27, based on data from [44].

2.2.1. European Union Energy Supply Security

The EU, which currently meets half of its total energy demand from outside, will be dependent on imported energy around 70% in 2030. Energy consumption is increasing over time and internal generation cannot meet this consumption, undoubtedly this is threatening the EU's energy supply security. The EU faced the problems caused by import energy dependency during the energy crisis of the 1970s. The increase in oil prices caused inflation in member countries and affected their economies negatively for many years. After the oil embargoes of the 1970s, a large part of Europe did not face a serious threat to energy supply security until the 2000s. Except for the First Gulf War, energy supply problems occurred for a short time due to labor problems in the energy sector [45].

The structural change in the global energy market after the 2000s has increased concerns about energy supply security in the EU. These problems regarding world energy supply security threaten the EU. The main concerns regarding the EU's energy supply security are the sustainability of natural gas supply from Russia. The natural gas crisis between Russia and Ukraine has been the milestone for EU energy supply security. The natural gas dispute between Russia and Ukraine in January 2006 caused a short-term deterioration in the energy supply in Europe. This energy crisis has deeply affected the EU and it has been a warning to the EU officials. It has become clear that the fragility of energy supply in the EU and the main exporting states can easily use this as a tool of political pressure [45].

The dispute between Russia and Ukraine was due to the natural gas price and taxes. Russia wanted to increase the price of one thousand cubic meters of natural gas sold to Ukraine from 65 dollars to 95 dollars. This initiative was interpreted by the EU as Russia's use of energy as a tool of political pressure against the pro-Western Ukrainian government [46]. The reliability of Russia as an energy supplier has started to be questioned in the EU. Despite the opposition of the USA after the oil crises of the 70s, the member states made the Soviet natural gas come to Western Europe with the cooperation of the Soviet Union. Since the first natural gas shipment from the Soviet Union, Europe and especially Germany has perceived Russia as a reliable energy supplier. Russia's efforts to become a semi-monopoly as the main energy supplier for the EU did not cause deep concern in the EU. It was an extraordinary situation until the Russia-Ukraine natural-gas conflict [47].

A second crisis affecting the EU is the Estonian-Russian oil crisis. It has made Russia's attitude towards energy very clear. Estonia removed the Red Army Monument in Tallinn in May 2007. During the discussions between Russia and Estonia, Russia stopped oil shipment to Tallinn by the excuse of repair of railways to Tallinn Port which is the largest port of the Baltic Sea and where Russian oil is transported to ships. In addition, Russia decided to shift the oil exports provided to Europe through Estonia to Russian ports. The capacity of Russia to divide the EU politically by using energy and aimed at damaging political solidarity among EU member states has become one of the main problems of the EU energy supply security. Access to energy at a reasonable price is as important as physical availability for the EU [46].

Natural gas demand in the EU is expected to grow in the next two decades. Due to the structural changes in the natural gas market, natural gas supply has shifted from the European regional market to the world market. This forced Europe to compete with markets in other regions. Especially, the increasing natural gas demand of Asia threatens the European natural gas market, there is a competition of the EU with China for the natural gas reserves in the Caspian Region. Another issue that forces the EU to compete with other regions for natural gas is the rapid increase in the share of liquefied natural gas (LNG) in the world natural gas market. With the popularity of LNG in the market, the circulation and availability of natural gas in the world market have increased. Natural gas suppliers such as Russia and Norway were willing to export their natural gas in LNG form to the North American market. The orientation of natural gas supply to the world market in LNG form has made Europe more dependent on natural gas prices in North America. This addiction is expected to increase more in the future [48].

2.2.2. European Union Renewable Energy Policies

Due to the problems related to energy supply security in recent years, it has become obligatory for EU member states to cooperate on energy. In this context, discussions have come up again to form a comprehensive energy policy. Since the European continent does not have sufficient reserves in terms of fossil energy resources, most of its energy needs are imported energy. Some negativities arise that EU countries become dependent on foreign energy. As an example of these negativities, the fact that energy imports cause economic difficulties for each individual who is a citizen of the EU, the energy supply security problem, and the environmental problems caused by fossil-based energy consumption. In order to eliminate all these problems, the EU makes policies to increase the share of renewable energy sources. The EU makes these policies to increase energy diversity, increase energy efficiency, save energy, reduce import energy dependency, and use less harmful energies to the environment. As explained in the previous section, the economic, political, and internal conflicts within the energy exporting countries affect the energy sustainability of the EU. This situation may cause adverse effects on investments. In addition, the fact that energy producing countries become a monopoly can cause it to be used as a political weapon [47].

Some of the EU member states have carried out very fast and above-target activities in the field of renewable energy. However, this situation is the opposite in some countries. The fact that each member country has different natural resources and geological location and this causes differences in their energy production mix. The EU started to work on the impact of energy on the environment in the early 80s. The damage caused by the use of fossil energy resources to the environment has started to attract the attention of society. This situation has brought the production and use of renewable energy resources into the agenda. Government policies related to the industry, agriculture, transportation, and energy have a direct impact on the environment. The problem of protecting the environment and natural resources has led to the development of environmental policies in the EU [49].

For a European Union Energy Policy - Green Paper was first published in 1995. This publication has been an essential resource for the EU due to the emphasis on renewable energy and energy supply security. It was pointed out in the green paper that taking necessary measures on renewable energy is vital for a sustainable economy. As energy use would increase over the years, it was predicted that energy dependency would increase and it was emphasized in this publication that the necessary precaution programs should be determined. After the green paper, many action plans came from the members' institutions. The white paper was written according to these coming plans [50].

White Paper: An Energy Policy for the European Union is repeated the topics previously mentioned in the green paper. In the white paper, it was mentioned that EU members should both comply with the determined energy policy and ensure cooperation and coordination in the implementation process. While the total energy consumption in renewable energy sources was 5.3% as of 1995, it was aimed to increase to 12% in 2010 and this target was achieved [51].

The increases in oil prices caused an increase in the energy dependence of the European Union and the prices of other energy types. Green Paper: Towards a European strategy for the security of energy supply is published in 2000. A long term European Union energy strategy is planned in this publication. Environmental concerns, the welfare of EU citizens, the smooth running of the economy, a continuous energy supply, and affordable energy supply were planned. The importance of acting together in order for member countries to take measures against climate change was emphasized. Developing new energy systems and increasing their production to combat global warming is an important advance [52].

Green Paper: A European Strategy for Sustainable, Competitive, and Secure Energy is published in 2006. Following problems were identified in the green book,

- One trillion euros must be invested in this area urgently in order to meet the energy demand,
- Foreign dependency on energy is increasing,
- Almost all of the imports are from Russia, Norway, and Algeria
- Energy prices are rising as the result of energy demand increases,
- Global warming is increasing,
- A fully competitive internal energy market within the union is needed [53].

A strategy for competitive, sustainable and secure energy, Energy 2020 is published in 2010. The energy policy of the European Union has been reviewed. Five basic energy strategies have been given priority,

- Policies such as increasing the storage and accumulation potential of energy, establishing industrial competition, and creating national energy efficiency plans have been put forward.
- Establishing a common European energy market has been determined.
- Providing reliable and affordable energy is another goal for citizens and business communities.
- The leadership of the EU in technology and innovation in the energy field was targeted.
- The energy market of the European Union needs to be strengthened in terms of foreign relations. In this context, policies have been made to ensure the integration of the European Union's energy markets with its neighbors, to create privileged cooperation with key partners, to harmonize nuclear safety, energy security and standards [54].

The Lisbon Treaty is concerned with developing and promoting the production and use of renewable energy sources [55]. Another agreement on renewable energy is the Energy Community Treaty. Since this treaty considers the rule of law, both the EU and the signatory countries would have the opportunity to regularly invest in the energy field. Thus, targets such as energy supply security will be ensured, an integrated energy market will be formed and developing an environmentally compatible energy supply have been determined [56].

2.2.3. European Union Renewable Energy Subsidies

Due to the different definitions of renewable energy sources in the European Union, there are differences in practice. Wind and solar energy systems built in the sea and on land are considered as renewable energy sources. However, there are some implementation differences among the member countries regarding hydropower. For example, large hydropower plants are excluded from subsidy schemes in a few member states. Hydroelectric power plants with an installed capacity of more than 10 MW are not suitable for subsidies in England. This limit is valid for over 5 MW installed capacity in Germany. Another fundamental difference in the definition is whether the waste is considered as a renewable energy source. Germany and Greece exclude waste from the definition of renewable energy source. Wastes have been among the important renewable energy sources for years in Belgium and Netherlands [57]. However, since the EU Directive on Increasing Renewable Energy Production, which was published in September 2001 and the member states had to implement until October 2003, the biodegradable parts of domestic and industrial wastes have been accepted as renewable energy sources [58]. Renewable energy policies of EU member states differ from country to country. There are various incentives for increasing renewable energy production and investments in this field. Incentives for renewable energy technologies are applied during the production, consumption and investment stages. There is a two-dimensional support system in achieving the goals. The first is the basic support tools and second is the complement support tools [59].

- Basic support tools
  - Feed-in tariffs
  - Feed-in premiums
  - Tender and quota system
  - Green energy certificates

- Complement support tools
  - Investment grant
  - Financial measures
  - Financing support

Feed-in tariffs is purchase support with a fixed price for producers who will produce electricity from renewable energy sources. While the fixed price guarantee is given for a specific time period and is applied differently in each country, it is generally applied for the first 10 to 20 years starting with the commissioning of the power plant. It is a method used when the cost needed for electricity generation is higher than the prices in the current electricity market. This system creates tariffs at different levels in each method of electricity generation. Tariff determination is based on the development of energy generation technology, volume, and production amount. This allows regulators to keep the gross cost of this support method at the lowest possible level [60].

Feed-in tariffs support is applied in five different ways within the European Union:

- **Fixed Feed-in Tariff:** It is the application of a single tariff support model for each generation technologies. Fixed feed-in tariff support is applied in Germany, Portugal, and Lithuania.

- **Time-dependent Feed-in Tariff:** It is the tariff support applied according to various predetermined time variable (day/night or intensive use / infrequent use) in each generation technology type. The tariff support is implemented by Spain for hydroelectricity and biomass.

- **Indexed Feed-in Tariff:** In this type of support, certain market indicators such as natural gas or exchange rate are taken as indicators to determine tariffs. Latvia applies these tariffs.

- **Adjusting Feed-in Tariff:** It refers to the situations in which tariffs are not fixed according to the time the generation technologies are established. It is possible to make arrangements for existing installed systems and it is used by Bulgaria and the Czech Republic,

- **Target-price Feed-in Tariff:** Even if the market prices fall below the guaranteed price, the pre-determined tariff price is paid fully in this tariff type. When the market price exceeds the guaranteed price, the difference is added to the guaranteed price [60].

Feed-in premiums are incentive mechanisms that regulate purchases at a fixed price for producers. In this method, companies that produce renewable energy are provided with an additional premium apart from the prices determined by the electricity market. The premium payment provided to the producer can be collected from the public budget, depending on the economic and financial structure of the country in practice, as well as from the final consumers. There are two types of premiums in this support. Fixed premiums and premiums that vary according to market conditions [60].

The tender system is generally applied for larger programs rather than short and medium-sized projects. Thus, the institutions that manage the electricity markets of the countries agree to buy the electricity they produce in the long term from the company that successfully passes the purchase criteria. Since the lowest offer is taken as a basis in the purchase criteria, the cost of the investment to the society is kept at the lowest level [59]. Quota restrictions or quota requirements, which are also defined as renewable portfolio standards, are the most used support method together with fixed price guarantees to promote renewable energy. It obliges consumers to include a certain amount of electricity from green energies in their electricity use [60].

As producers and consumers increase the amount of renewable energy use, they obtain a commercially available certificate for each unit they produce. This is called Tradable Green Certificates. With this method, it aims to increase investment in new renewable power plants and to encourage obtaining green certificates from other producers and suppliers.

2.3. The Role of Energy in Economic Growth

Energy is one of the essential inputs for humanity and industry. Accessible, adequate, and safe energy supply is of vital importance for the improvement of the country's economies and the sustainability of modern society requirements. Energy is an essential component of sustainable and increasing economic growth. Oil, natural gas, and electrical energies are among the most important inputs of economic growth. However, the importance of crude oil and natural gas in modern economic activities poses a threat to the global energy market due to the fact that these resources may be depleted in the future [61]. Shortness of energy resources is a problem that becomes more important day by day due to the population growth rate in the world. The world population is expected to exceed 10 billion in the 2050s but traditional energy resources would not meet that demand for sustaining life. Harm on the water and food resources due to global warming highlights the possible scarcity problem. Increasing earth temperature damages crops. The problem of decreasing water resources is moving the world away from a sustainable structure in the future [62].

In order for countries to grow economically, they need to consume a significant amount of energy. In the studies conducted, it is observed that countries with high GDP also have high energy consumption. The United States of America (USA) and China are the two countries with the highest GDP [63], consume around 40% of the total consumed energy in the world [64]. The relationship between energy and economic growth is important for policymakers to sustain the development of the country. Numerous studies have been conducted for showing how growth has been affected by various energy crises throughout history. The effects of the financial crisis experienced in 2008 were also seen in the energy sector. In countries with high energy intensity, the rate of increase in energy consumption slowed down and even negative growth figures were achieved in some countries. After the crisis, global welfare and industrialization led to an increase in electricity consumption.

Most part of the energy consumed in the world is consumed by countries that have high GDP. China, USA, India and Russia consume half of the total energy consumed in the world. Table 1 shows this situation for the top 10 countries. Although the USA has higher GDP than China, China consumes 23.5% of the total consumed energy in the world [63]. This situation shows that the Chinese economy is based on industries where energy use is intensive. A possible energy crisis will affect the Chinese economy very negatively. The energy consumption of developing countries is much lower than developed countries. Although the GDP of the USA corresponds to the quarter of the world, the GDP of the developing countries is low compared to the developed countries, just like their energy consumption. The development experience of developed countries shows a gradual transition to more intensive energy types in energy consumption. The main reason for this development is that economic growth depends on the increase in the use of production factors (when energy is considered a production input) and the effective use of these factors.

Table 1. World total energy consumption ranking and GDP in 2019, based on data from [63,64].

Total Energy Consumption and GDP in 2019					
Rank	Countries	Total Energy Consumption		GDP	
		[Mtep]	Share in total	[Trillion USD]	Share in total
1	China	3 284	23,5%	14,3	16,3%
2	United States	2 213	15,8%	21,4	24,4%
3	India	913	6,5%	2,9	3,3%
4	Russia	779	5,6%	1,7	1,9%
5	Japan	421	3,0%	5,1	5,8%
6	South Korea	298	2,1%	1,6	1,9%
7	Germany	296	2,1%	3,9	4,4%
8	Canada	295	2,1%	1,7	2,0%
9	Brazil	288	2,1%	1,8	2,1%
10	Indonesia	269	1,9%	1,1	1,3%
	World Total	13 975	100,0%	87,7	100,0%

The purpose of environmental economics is explaining how much natural capital is needed and what extent the produced capital can be substituted by resources to maintain the existing standard of living. For this purpose, the relationship of energy with other factors has been examined over the years. Researches mostly focused on the energy-capital relationship. The substitution or complement of energy and capital is explanatory in that energy can be a constraint in the production function [65].

Berndt and Wood's study is important in explaining the relationship between energy and capital. In this study, a production function with four inputs (capital (K), labor (L), energy (E), and material (M)) is considered. The function is as follows [66]:

$$Y = F(K, L, E, M) \qquad (2.1)$$

When the prices of the inputs are shown as P_K, P_L, P_E, and P_M the cost function becomes as follows:

$$C = G^*(\mathrm{Y}, \mathrm{P}_K, \mathrm{P}_L, \mathrm{P}_E, \mathrm{P}_M) \qquad (2.2)$$

The production function is positive, concave, and twice differentiable. It is assumed that the production function has separability [67]. This separability can be defined:

- **Primal separability:** It is stated that the density of the production function factor k is not affected by the possibility of substitution between i and j. In other words, the marginal rate of technical substitution between the two factors is not affected by other factors [67].

$$\frac{\partial}{\partial X_k}\left(\frac{\partial X_j}{\partial X_i}\right) = 0 \qquad (2.3)$$

- **Dual separability:** It is stated that the density of the cost function factor k is not affected by the possibility of substitution between i and j. The marginal rate of technical substitution between factors i and j is not affected by the prices of other factors [67].

$$\frac{\partial}{\partial p_k}\left(\frac{X_j}{X_i}\right) = 0 \qquad (2.4)$$

Using the separability assumption, KLEM model can be divided into two sub-functions. The first is the function consisting of K and E that enables the production of utilized capital (K*) [66]. Equation (2.5) demonstrates this situation:

$$\mathrm{K}^* = f[\mathrm{K}, \mathrm{E}] \qquad (2.5)$$

The utilized capital cost subfunction can also be separated with the same inputs partition,

$$C_{K^*} = G[K^*, \mathrm{P}_K, \mathrm{P}_E] \qquad (2.6)$$

The second part of the function consists of L and M that enables the production of labor-materials (L*) [66]

$$\mathrm{L}^* = g[\mathrm{L}, \mathrm{M}] \qquad (2.7)$$

The labor-materials cost subfunction can also be separated with the same inputs partition,

$$C_{L^*} = h^*[L^*, P_L, P_M] \qquad (2.8)$$

After the equations stated above, the master production and cost function can be written as follows,

$$Y = F[K^*, L^*] \qquad (2.9)$$

$$C = G^*[Y, P_{K^*}, P_{L^*}] \qquad (2.10)$$

Based on the equations above, the main production function with four inputs can be drawn as in Figure 15. In the case where the firm produces output of Y = Y_1*, the equity curve shows the prices of K* and L* inputs (P_K* and P_L*, respectively). The firm minimizes its cost at the O_1 point. At this point, it uses K_1* amount of utilized capital and L_1* a mixture of labor and non-energy intermediate goods [66].

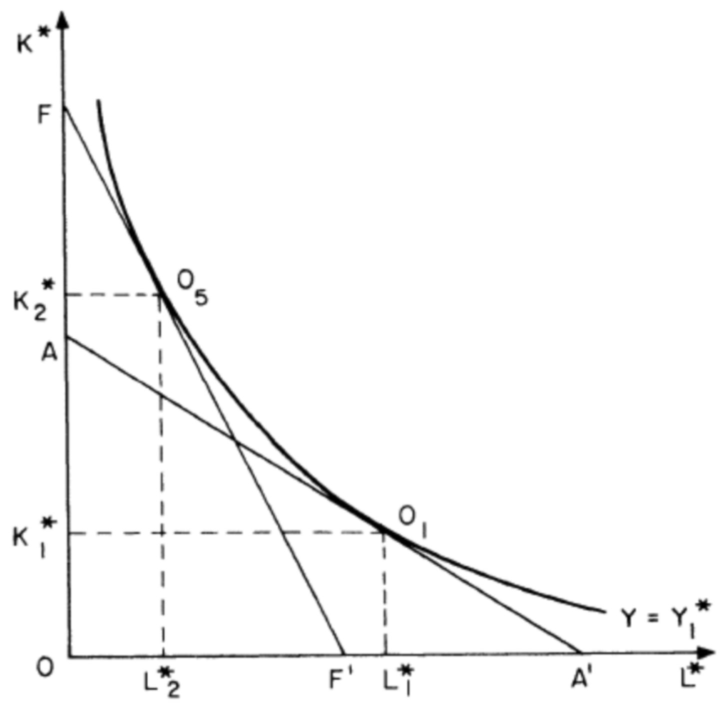

Figure 15. Main production function [66].

The utilized capital production function and the production function of the labor and non-energy intermediate goods mix must also be obtained. In Figure 16, when the equivalent cost curve obtained with capital and energy prices (P_K and P_E) is valid, the firm is at point O_2, which minimizes its cost by using energy as much as E_1 and capital as K_1 [66].

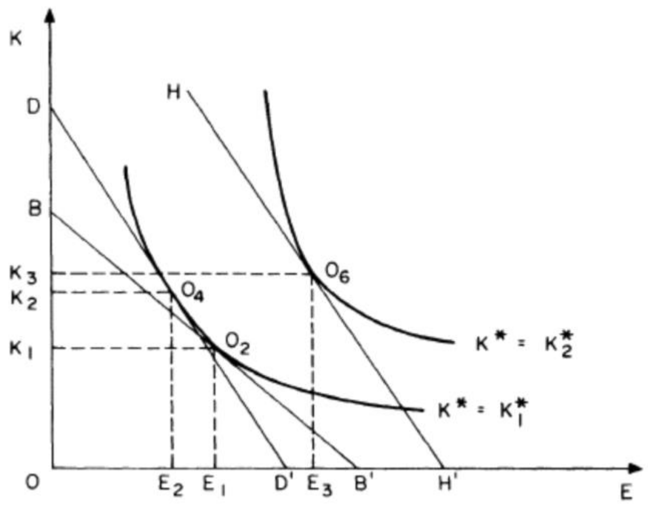

Figure 16. Utilized capital production function [66].

In Figure 17, the firm minimizes its cost by using labor as much as L_1 and non-energy intermediate goods as much as M_1 at point O_3 on the equal cost line with data labor and non-energy intermediate goods prices (P_L and P_M) [66].

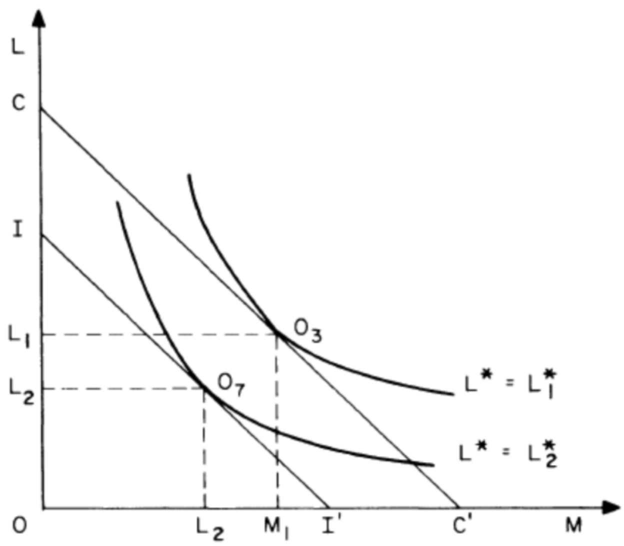

Figure 17. Labor and non-energy intermediate goods mix production function [66].

2.4. The Future of Renewable Energy

Renewable energy is an effective solution in providing energy security and reducing carbon emissions in the face of high energy demand. This situation has placed renewable energy at the center of the agenda of countries. It has been the main vision in the whole world, including Europe, to avoid a loss in economic output and to prevent a decrease in the level of welfare in climate change. The primary energy sources of oil, natural gas, and coal, most of which are found in the Middle East where political instabilities are experienced, are rapidly being spending. Harmful emissions that occur during energy production and consumption cause climate changes. This disrupts the ecological balance and affects public health negatively in the long term. The high dependence on limited resources indicates an energy supply security problem in the near future. Orientation to alternative energy sources, increasing efficiency, and savings in energy use are the most effective and environmentally friendly policies to be implemented against energy supply problems.

Population, income, and energy demand growth projections show that the pressure on energy and natural resources will increase within half a century, especially in emerging economies. Switching to renewable energies to avoid negative scenarios will provide both economic and environmental benefits [68]. Although technological developments reduce the costs of renewable energy, uncertainties regarding supply-demand developments cause volatility in prices of fossil fuels. However, the deficits in the financial balances of the producer countries can bring challenges in the forecast of production. Especially in oil supply, geopolitical developments from countries such as Iran and Venezuela. In addition, hot conflict areas around the world affect energy security.

Trends in the world economy require some changes in the energy world as well. Increases in incomes and an additional 1.7 billion population are expected to increase global energy demand by more than 25 percent by 2040. In contrast, it is worried that this increase may be approximately twice as much in the absence of continuous improvements in energy efficiency. It is estimated that the increase in demand will be largely due to developing economies in Asia [69].

Denmark is known for its confidence in sustainability. The country wants to be independent of fossil fuels by 2050. Denmark's success story didn't come out of anywhere. Its origins date back to the 1970s when the oil crisis led the country to wind energy. Thus, the protests against nuclear energy encouraged the development of renewable energy with positive initiatives. The government organized everything to build wind parks. Tax exemptions were offered to families to produce their own energy. This was used mainly by citizens who took a share from renewable energy cooperatives. The energy cooperative model has matured in Denmark and has set an example for other countries. The Danish wind power industry is the world's largest, with more than a third of the market share, providing more than 40% of all electricity and offering more than 20,000 jobs. By combining wind energy and other renewable energy sources, they want to meet at least half of their energy needs from renewable sources by 2030. While the share of wind energy in the Danish electricity supply increases, the number of turbines is declining because the turbines are getting bigger and more efficient [70].

The future of the environment depends on the future of renewable energy systems. Utilization of energy with the least harm to the environment is possible with the development of renewable energy systems. The type of energy used has an important role in the welfare and quality of social life. In this direction, policymakers will determine the future of the integration of renewable energy with society. Besides, another aspect that affects society is the health-related situation. Environmental pollution and greenhouse gas emissions play a leading role in the incidence of many diseases and decrease the quality of life. The future promised by renewable energy is not only achieved through economic growth, social development, and environmental impacts. Energy is an input that leads to the increase of human capital. Renewable energy is in a leading position in solving basic vital problems through public health and education.

The future of energy is tried to be predicted with prepared future scenarios. The World Energy Scenarios report prepared by the World Energy Council (WEC) predicts the world's future in the long years full of innovation, the digital age, and developing technology. The Council claims that the energy world will be reshaped with some basic guides called Great Transformation. According to the WEC report, the basic assumptions that will cause the "Great Transformation" in the world will lead to 7 possible consequences in the field of energy [71]:

1. The rate of increase in energy demand will slow down. However, when the calendars point to 2030, energy demand will reach its peak in the world. In this process, there will be a great increase in efficiency with the use of unprecedented technologies and the governments following tighter energy policies.

2. The electrical energy demand will double in 2060 compared to today. With the increasing rate of urban living and the level of development, significant investments and policy changes will be required to generate electricity from clean sources as much as possible. The electricity generation investment to be made until 2060 is estimated at 35 - 43 trillion dollars according to the report.

3. Development in solar and wind energy investments and technologies will continue uninterrupted and increasingly. Until 2060, development in renewable energy sources will direct the generation of electricity, and solar and wind will lead it. The costs of energy generation will decrease by 70% compared to today's values. The share of solar and wind energy production, which was 4% of the total electrical energy in the world in 2014, will reach 39% in 2060 according to the optimistic scenario and 20% according to the pessimistic scenario. The development of other energy sources that are not considered as fossil fuels will continue. While hydroelectric resources will become important, especially for Africa, nuclear investments will be concentrated in East Asia, especially in China. As shown in Figure 15, solar power will cover 70% of world energy consumption by 2100. The share of the traditional energy sources such as coal, gas, oil, and nuclear will reduce dramatically [72].

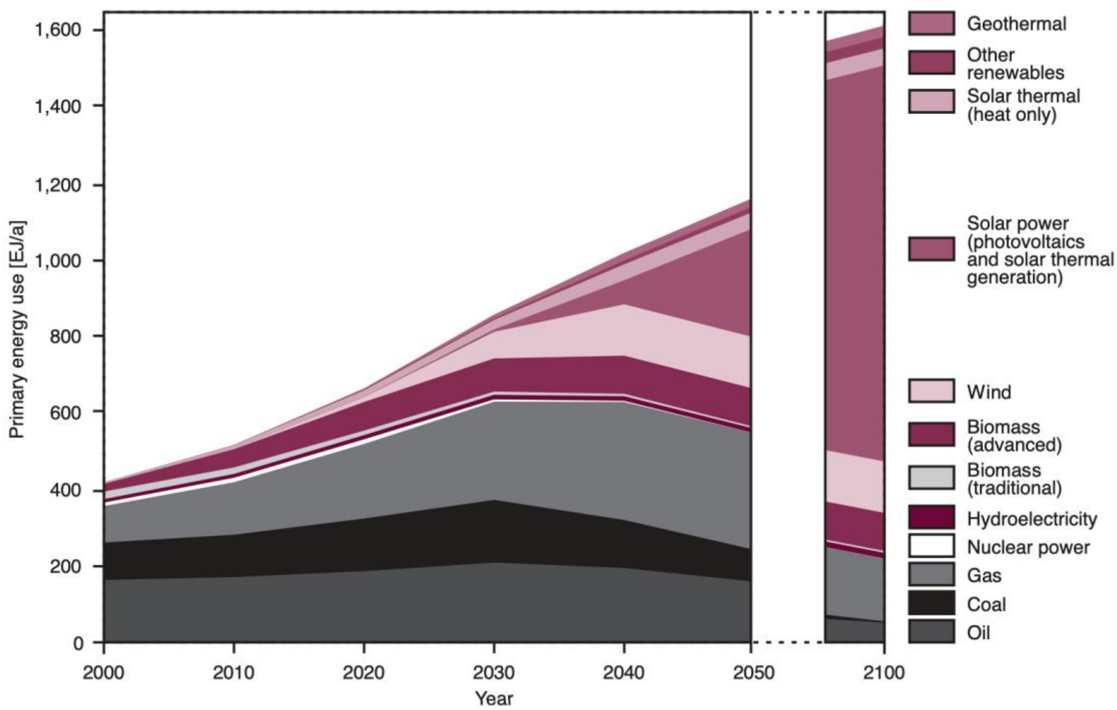

Figure 18. The expectation of change in primary energy shares in electrical energy production for the period 2000 – 2100 [72].

4. The shares of coal and oil in primary energy consumption changed only 5% from 1970 to 2014, declining from 86% to 81%. In particular, it is calculated that the coal demand will reach its peak in 2020 and will tend to decrease. It is stated that coal and natural gas dependency, which is approximately 80% today, will decrease to 70% (hard rock), 63% (modern jazz), or 50% (unfinished symphony) values in 2060.

5. Diversification of primary energy use in the transportation sector is the most important topic. While dependence on oil was 92% in this area in 2014, it is expected to decrease to 78% (hard rock), 67% (modern jazz), or 60% (unfinished symphony) in 2060. It is also among the expectations that the number of light electric vehicles used by the middle class will increase by 2.5 or 2.7 times against today, and that the electric vehicles will reach 26% - 32% in the market. In addition, hybrid vehicles will constitute 24% - 31% of the total vehicle fleet.
6. Reducing carbon emissions and limiting global warming is seen as the most complex issue. It is not considered very optimistic for the next 30 to 40 years for the carbon market to solve the problem. Differences between scenarios also support this prediction. According to the optimistic scenario, the reduction in carbon emissions from 2014 to 2060 is predicted as 61%, while the reasonable scenario states this value as 28%. The pessimistic scenario calculates an increase of 5%, with all three scenarios indicating that emission values will reach their maximum levels between 2020 and 2040.

7. Global cooperation and technological consultancy policies are needed to balance the concepts of "energy security", "equal distribution of energy" and "environmental sustainability", which are referred to as the energy trio. The particularly pessimistic scenario shows that as economic growth comes under pressure and social tensions increase, global effects are considered and the world tends to focus on local energy security.

Scenarios for the future are gathered in three music terms [71].

- **The Unfinished Symphony (Optimistic):** In this scenario states direct energy policies. The main concern is to have a sustainable energy sector that prevents global climate change. International cooperation is important for the sustainability of energy policies. Long-term international policies are developed in energy, and these are implemented in a coordinated manner. There is a strong, coordinated, and policy-oriented world that has long-term plans and acts together against the difficulties faced. However, this coordination has difficulties in reaching the desired level. The difficulties are inequality in access to energy and the inability to prevent carbon emission [71].

- **Modern Jazz (Reasonable):** In this scenario, free-market mechanisms direct energy policies. The main concern is to increase access to energy while reducing costs. Technological innovations are prioritized for this. There is a market-oriented, digitally damaged, and dependent world in a faster and more unequal growth trend. Recent indicators show that this entrepreneurial future will have easier access to clean energy and can accelerate this process both locally and globally. This scenario offers a positive future environment for renewable energy [71].

- **Hard Rock (Pessimistic):** In this scenario, energy policies are partly driven by states and partly by market mechanisms. There is no long-term planning. Short-term policies that best suit local energy needs are implemented. International cooperation is not pursued. It is a scenario in which internal policies are adopted, low growth rates are observed, and global unity will be experienced at a lower level. Countries will be able to put climate problems in the background due to their own internal problems. Besides, this scenario is stated as the undesirable and worst-quality scenario for the future [71].

3. Analysis of the Relationship Between Renewable Energy and Economic Growth

3.1. Purpose and Scope of the Subject

Energy is one of the most important needs of countries and is the most basic and driving factor of economic and social development. Due to the developing technology, population growth, urbanization, and industrialization, the world energy need is increasing day by day. Since this increase could not find a full response in the production-consumption balance, energy has become one of the most important problems in the world. Energy sources are generally classified as fossil-based and renewable energy sources. Fossil-based energy sources are called non-regenerative due to their regeneration rate that is very low compared to their usage rates. Energy resources such as coal, oil, and natural gas, whose renewal processes require long periods, have a large share in the energy market around the world. This situation provides important advantages to some producer countries compared to poor countries in terms of energy resources. The tendency of these countries to renewable energy is increasing due to factors such as ensuring diversity of energy resources, ensuring energy supply security, eliminating the greenhouse gas emission problem, and preventing external deficits caused by energy imports.

Using energy efficiently will make a great contribution to the economy and development of the country. In this situation, every country should establish an effective energy policy. Countries should act with uninterrupted, reliable, clean, and cheap energy strategies while creating their energy policies. The main reason why energy has an important role in the development of societies is that energy is a necessary input in industrial production. Energy is an indispensable component in transportation, communication, manufacturing industry, health, and household, etc. generally in all areas necessary for the continuation of life. The fact that energy is an important factor in the economic development processes of countries is due to the structural link between it and other sectors. Energy is one of the most important factors defining countries' power; energy is also accepted as an indicator of the development levels of countries. Most of the indicators of countries are directly related to their energy reserves, such as national security, social welfare level, and economic strength. Energy consumption of countries provides foresight about the countries' economic, consumption habits, and socio-cultural structure.

Renewable energy sources are found in nature in an unlimited and natural way throughout life. It has a higher renewal rate than its usage. Renewable energy sources are solar, wind, geothermal, biomass, hydraulic, and hydrogen. The main characteristics of renewable energy sources; protecting the environment by reducing greenhouse gas emissions, providing employment opportunities, each country can produce its own energy, reducing energy imports, and reducing energy dependency.

European Union countries' economies have basic macroeconomic targets throughout their economic life. Energy policies have an important place among the policies developed to achieve these targets. This study aims to analyze the relationship between renewable energy usage and countries' economies. In this direction, it is desired to be determined that the use of renewable energy resources of EU countries has a positive effect on economic growth. It is aimed to make investments in renewable energy technologies more attractive for EU countries. Renewable energy facilities are generally included in the medium and long-term plans of the countries due to their high installation costs. The existence of the climate change problem makes it necessary to accelerate the switching to these systems.

This study examines the economic growth and renewable energy use of 27 EU countries. Another aspect of the study is the effects of fossil-based energy and renewable energy resource usage on economic growth. The preference for renewable and traditional energy is examined according to the development levels of the EU countries. CO2 emission is another important indicator of preference, and it is added to the model. Although it is not a direct growth indicator, CO2 emission level is an indicator of the energy resources that emit and impact economic growth.

3.2. Theoretical Basics of the Subject

The relationship between energy use and economic growth is examined in different countries, different periods, and using different methods. The results of these studies are different from each other, and to explain these differences, four hypothesizes are defined [73];

- **The Growth Hypothesis:** The first hypothesis tries to explain the relationship between energy use and economic growth. This hypothesis argues that energy use has an important role in economic growth. The hypothesis states that the relationship between energy use and economic growth has a uni-directional causality. The direction of causality is from energy use to economic growth. Accordingly, it is stated that energy policies that will cause a reduction in energy use will have negative effects on economic growth. Energy is vital for the economy and directly or indirectly affects economic growth as a complement to labor and capital factors [73].

- **The Conservation Hypothesis:** The existence of another uni-directional causality between energy use and economic growth is called the conservation hypothesis. However, the difference of this hypothesis from the growth hypothesis is that there is a uni-directional causality relationship from economic growth to energy use. Accordingly, it is argued that energy policies that cause energy savings will not impact economic growth. An increase in economic growth increases energy use, and a decline in economic growth decreases energy use [73].

- **The Feedback Hypothesis:** The difference of the feedback hypothesis from previous hypothesizes is there exists bi-directional causality between energy use and economic growth. In addition to the existence of causality from energy use to economic growth, there is causality from economic growth to energy use. In this respect, when energy policies to reduce energy use are implemented, there will be negative effects on economic growth and economic recession will affect energy use [73].

- **The Neutrality Hypothesis:** It explains the situation where there is no causality between energy use and economic growth. In this case, policies that save energy or increase energy use do not affect economic growth. In addition, the neutrality hypothesis states that economic growth does not have an increasing or decreasing effect on energy use [73].

Researchers stated that energy use directly affects GDP in some of the studies. Increasing energy prices due to the energy crisis in the 1970s had an effect on these views. The relationship between energy use and economic growth has been studied frequently since the end of the 1970s. There are also studies that interpret the relationship between energy consumption and economic growth through positive or negative coefficients rather than the causality relationship.

3.3. Studies on Relationship Between Energy Consumption and Economic Growth in Literature

Kraft and Kraft (1978) determined a uni-directional causality from GDP to energy consumption for the American economy with the Sims causality test using annual data during the 1947-1974 period [74].

Adjaye (2000) studied using annual data for the economies of India and Indonesia for the period 1973-1995, for the Philippines and Thailand economies for the period 1971-1995. According to the result of the Johansen cointegration test and vector error correction model (VECM), a uni-directional relationship was found from consumer prices and energy consumption to GDP for India and Indonesia in the long run. A bi-directional causality relationship was found between consumer prices and energy consumption, and GDP for the Philippines and Thailand [75].

Aqeel and Butt (2001) did not find any cointegration between energy consumption, consumer price, and GDP with Engle-Granger cointegration test for Pakistani economy by using annual data during 1955-1996 period. They determined a bi-directional causality relationship between gross domestic product and electricity consumption, and a uni-directional causality relationship from GDP to oil consumption and from energy consumption to employment by using the Hsiao causality test [76].

Chang, Fang, and Wen (2001) determined three cointegrated vectors due to the Johanes cointegration test for the Taiwan economy using monthly data during the 1982-1997 time period. As a result of the Hsiao causality test and vector autoregression (VAR) analysis, they determined a bi-directional causality relationship between employment - national income and energy consumption. Besides, there is a uni-directional causality from energy consumption to GDP [77].

Ghali and Sakka (2004) found bi-directional causality between gross domestic product and energy consumption due to the JJ cointegration test and VECM for the Canadian economy by using annual data in the period 1961-1997 [78].

Oh and Lee (2004) found a uni-directional causality from GDP to energy consumption as a result of the boundary test and VECM for the South Korean economy by using quarterly data for the period of 1981-2008 [79].

Zou and Chau (2006) found a uni-directional causality from oil consumption to GDP due to the Johanes cointegration, VECM, and VAR analysis for the Chinese economy by using annual data for the period 1953-2002 [80].

Mucuk and Uysal (2009) found a uni-directional causality from energy consumption to GDP due to the Granger causality and the Johanes cointegration test for the Turkish economy by using annual data for the period 1960-2006 [81].

Fuinhas and Marques (2011) found a bi-directional causality between energy consumption and GDP in the short run, a uni-directional causality from energy consumption to GDP in the long run due to the boundary test and VECM for the Portuguese economy by using annual data for the period 1965-2008 [82].

Tuğcu, Öztürk, and Aslan (2012) studied the relationship between renewable energy resource usage and economic growth due to autoregressive distributed lag bound test (ARDL) and Hatemi-J test for the G7 countries by using annual data for the period 1980-2009. They found no relationship for France, USA, Canada, and Italy. There was a uni-directional causality from renewable energy use to economic growth for the UK and Japan. There was a uni-directional causality from economic growth to renewable energy usage for Germany [83].

Apergis and Danuletiu (2014) analyzed the relationship between renewable energy use and economic growth due to the Canning and Pedroni long-term causality test for 80 countries by using data for the period 1990-2012. As a result, a long-term causality relationship from renewable energy use to real GDP has been determined [84].

Leitao (2014) analyzed the correlation between economic growth, carbon dioxide emission, globalization, and renewable energy due to ordinary least squares (OLS), generalized method of moments (GMM), Granger Causality, and VECM for the Portuguese economy by using data for the period 1970-2010. As a result, carbon dioxide emission and renewable energy have a positive effect on economic growth. In addition, the globalization index has a positive effect on economic growth [85].

Lin and Moubarak (2014) analyzed the relationship between renewable energy use and economic growth due to ARDL and Granger Causality Test for China by using data for the period 1977-2011. They found bi-directional causality between renewable energy and economic growth [86].

Sebri and Ben-Salha (2014) analyzed the relationship between renewable energy use and economic growth due to ARDL and VECM for Brazil, Russia, India, China, and South Africa (BRICS) by using data for the period 1971-2010. They found bi-directional causality between renewable energy and economic growth [87].

Lyke (2015) found bi-directional causality between inflation and GDP, uni-directional causality from electricity consumption to GDP, and from inflation to electricity consumption due to JJ cointegration and VECM for the Nigerian economy by using data for the period 1971-2011 [88].

Magazzino (2015) studied the relationship between energy consumption per capita and GDP per capita due to JJ and Engle-Granger cointegration tests for the Italian economy by using data for the period 1970-2009. Bi-directional causality was found in the long run, and uni-directional causality was found from energy consumption per capita to GDP per capita in the short run [89].

Destek (2016) studied the relationship between renewable energy use and economic growth due to asymmetric causality tests for industrializing countries by using data for the period 1971-2011. When renewable energy use increases, GDP decreases for South Africa and Mexico [90].

Ito (2017) analyzed the relationship between renewable energy use, non-renewable energy use, economic growth, and CO2 emissions due to the GMM for 42 developing countries by using data for the period 2002-2011. As a result, non-renewable energy sources have a negative effect on economic growth, whereas renewable energy sources have a positive effect [91].

Amri (2017) studied the relationship between renewable energy use, trade growth, and economic growth due to GMM for 72 countries by using data for the period 1990-2012. A mutual relationship between renewable energy use and income level, trade and renewable energy use, trade and income level [92].

Ouyang and Li (2018) analyzed financial development, economic growth, and energy use due to GMM for the six different regions of China by using the data for the period 1996-2015. As a result, energy use affects economic growth positively [93].

3.4. Data Set and Variables

The main goal of this thesis is to determine whether renewable energy use has a positive effect on economic growth for EU-27 countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden). The empirical analysis is used in the study to support this hypothesis, and the annual data of EU-27 countries for the time period 1996-2015 were used [63]. United Kingdom (UK) left the European Union by 2020. Since the data period of this thesis is 1996-2015, the UK is in many datasets. The analysis will be performed for the EU-27, which consists of the current members of the European Union. The data of each country have been separately created and brought together for the dataset. There is no information about the UK in the dataset which is used in this thesis.

The variables used in the study were taken from the World Development Indicators database of the World Bank. GDP per capita, renewable energy consumption (% of total final energy consumption), fossil fuel energy consumption (% of total final energy consumption), and CO_2 emissions (metric tons per capita) for the time period 1996-2015 are used [63]. I investigated to use more updated data in my thesis, but the most recent data is provided by the World Bank. I found additional data for some years after 2015 from other sources and organizations. I tried to combine the data to create an up-to-date data set, but I could not create a data set that would be able to analyze. However, the data I have found seem to belong to the same subject since they were indifferent to each other. Because of this reason, the data set from the World Bank until 2015 was used in this thesis. For ease of calculations, the abbreviations of variables are used as GDP per capita (GDP), renewable energy consumption (REC), fossil fuel energy consumption (FEC), and CO_2 emissions (COE). The attributes of the variables used in the model of this thesis are shared in Table 2.

Table 2. Variables attributes table.

Variables Table								
Countries	Variable	Variable Type	Indicator	Definition	Unit	Source	Period	Expected Impact
EU-27	GDP	Dependent	Enocomic Growth	GDP per capita	US Dollar	World Bank Data Indicator	1996 - 2015	
EU-27	REC	Independent	Renewable Energy Consumption	Renewable energy consumption (% of total final energy consumption)	Ratio	World Bank Data Indicator	1996 - 2015	Positive
EU-27	FEC	Independent	Fossil Fuel Energy Consumption	Fossil fuel energy consumption (% of total)	Ratio	World Bank Data Indicator	1996 - 2015	Positive
EU-27	COE	Independent	CO_2 Emissions	CO_2 emissions (metric tons per capita)	Metric Ton	World Bank Data Indicator	1996 - 2015	Positive

GDP is the dependent variable and the effects of the independent variables REC, FEC, and COE are tested in the study. As a result of previous studies, it is thought that REC and FEC variables positively affect economic growth. In addition, CO_2 emission is added to the model based on the Environmental Kuznets Curve. This curve shows economic growth and environmental pollution is in the shape of an inverted U. This curve states that as the economic growth of a country increases, environmental pollution will increase, but this situation will reverse after a certain level of income [94]. Annual data of GDP, REC, FEC, and COE are included in the analysis at logarithmic levels to examine the relationship. RStudio, STATA, and SPSS econometrics package programs are used in this study.

Three types of data are used in econometric analysis. These are time series, cross-section, and panel data. Cross-section data is a type of data gathered from multiple subjects at a certain time period. For instance, the economic growth rates of G20 countries for 2020 examines 20 countries for a single year. The time dimension increases in time series data. The annual inflation rates of the Czech Republic between the years 1990-2020 are an example of time-series data. Panel data is the combination of these two types of data and panel data contains N units and T observations. For example, annual economic growth rates of G20 countries between 1990 and 2020 is a panel data. In this thesis, panel data that contains GDP per capita, renewable energy consumption, fossil fuel energy consumption, and CO2 emissions of EU-27 countries between 1996-2015 were used.

The descriptive statistics of variables are presented in Table 3. The variables are plotted over the time period and presented in the following four figures respectively GDP, REC, FEC, and COE. The development of GDP, which is the most important economic indicator, between 1996 and 2015 demonstrates an increasing trend. The negative effects of the 2008 financial crisis experienced worldwide can be seen in Figure 19. As a result of this crisis, which affected almost all sectors and business areas, the decline in GDP continued for a few years.

The increase in renewable energy consumption for all countries is a promising indicator for our planet's future. Due to some countries' geographical location and natural wealth, the rate of renewable energy usage is higher than in other countries. Especially northern countries are rich in some renewable energy sources. However, thanks to developing technologies, renewable energy costs have decreased and their efficiency has increased.

The fact that fossil fuel energy consumption rate is in a stable or decreasing trend and this is another promising indicator. Especially in northern countries, severe policies have been implemented to reduce the usage rate. As a result of these policies and can be seen below the graph, Estonia, Sweden, and Finland have further reduced their low usage rates. In parallel with the fossil energy consumption rates, a decrease in CO_2 emission is observed. This is due to both the increase in the rate of renewable energy use and the change in energy usage habits. Energy is used more efficiently and carefully by people.

Table 3. Summary of descriptive statistics table.

Statistics Table				
	GDP	REC	FEC	COE
Mean	25448,76	14,79	74,97	7,94
Median	21914,96	11,02	78,23	7,38
Minimum	1361,39	0,09	13,06	2,68
Maximum	118823,65	53,25	100,00	24,82
Standard deviation	19672,18	11,30	18,35	3,54
C.V.	0,77	0,76	0,24	0,45

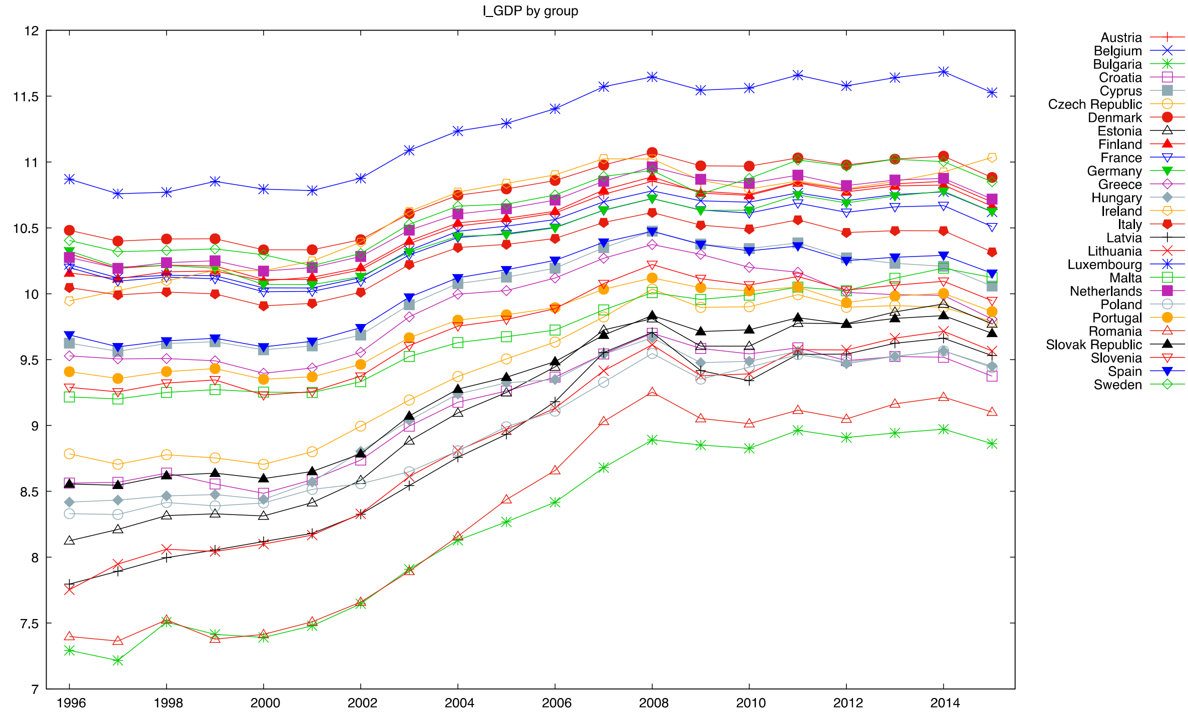

Figure 19. GDP per capita of EU-27 countries from 1996 to 2015, based on data from [63].

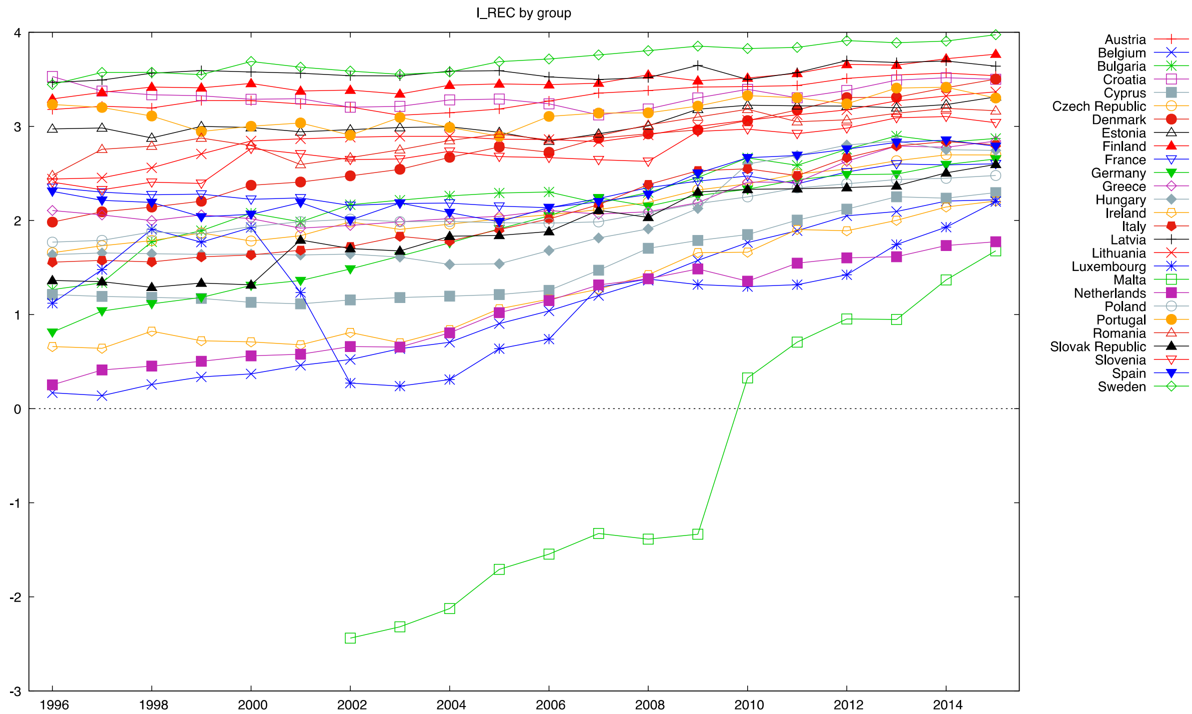

Figure 20. Renewable energy consumption of EU-27 countries from 1996 to 2015, based on data from [63].

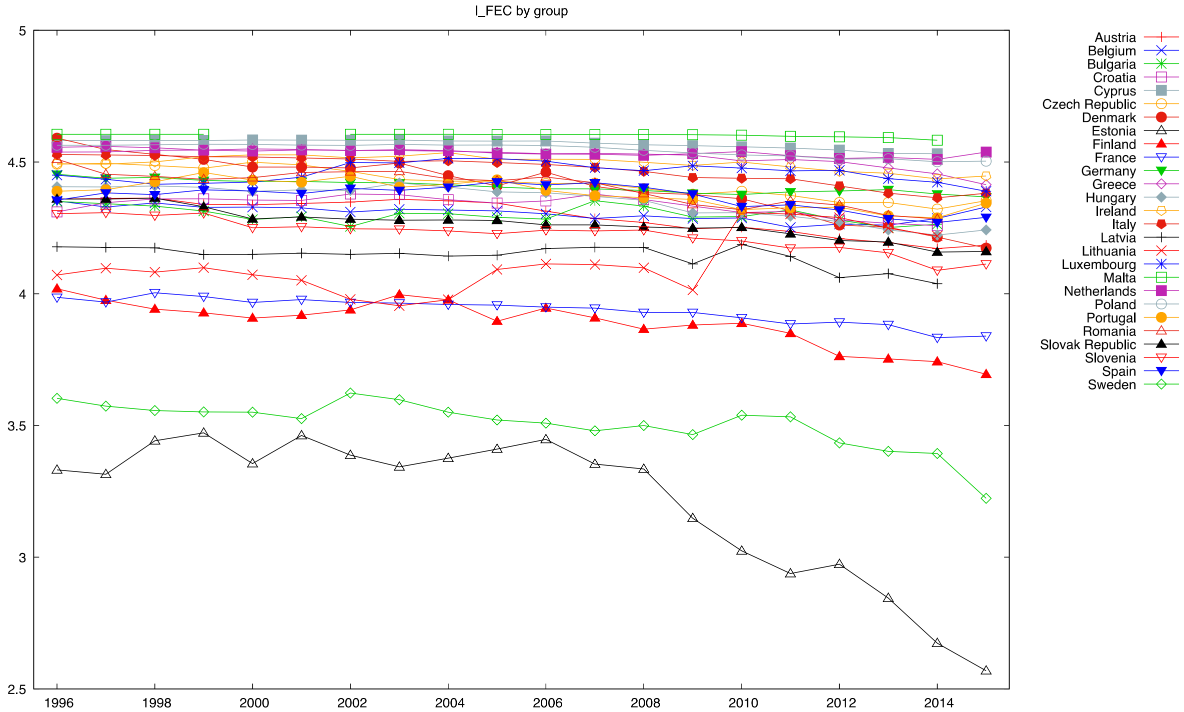

Figure 21. Fossil fuel energy consumption of EU-27 countries from 1996 to 2015, based on data from [63].

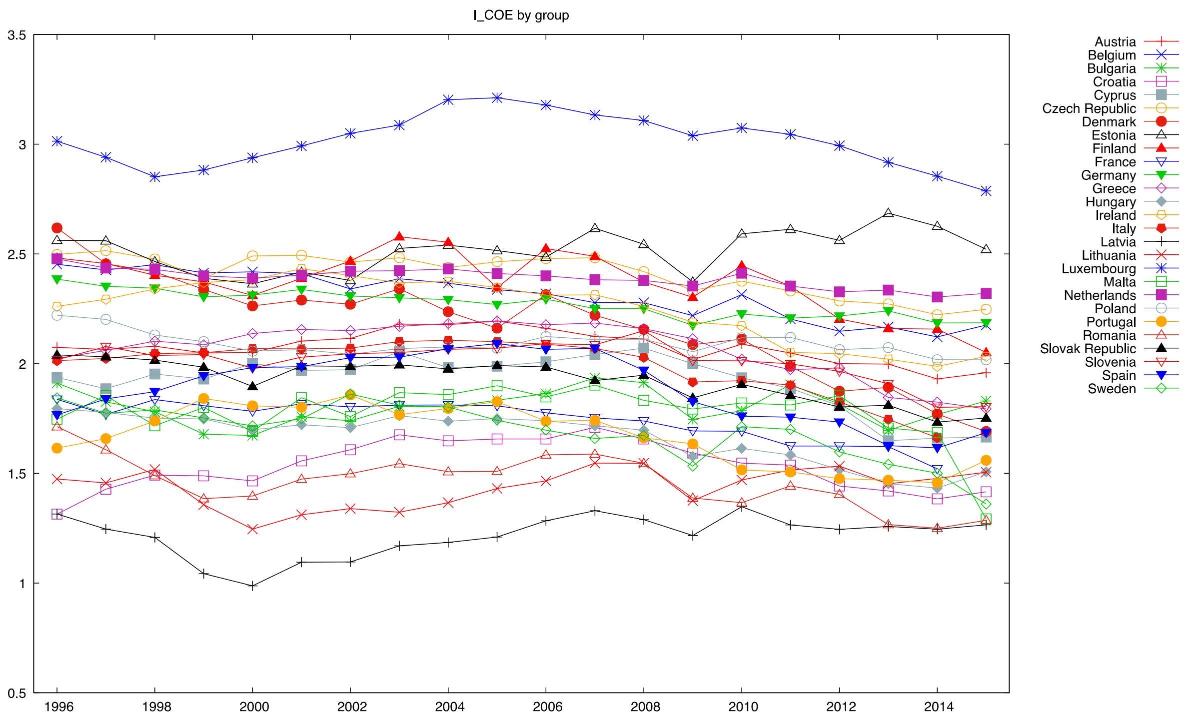

Figure 22. CO_2 emissions of EU-27 countries from 1996 to 2015, based on data from [63].

The mean of the dependent and independent variables used in the model was plotted with a scatter plot diagram. Firstly, the mean of dependent variable GDP and the independent variable REC were plotted and demonstrated in Figure 23. This drawing will help us look at the big picture in terms of seeing and interpreting the general situation. Luxemburg is by far ahead of the European Union countries in terms of GDP per capita. However, the renewable energy consumption rate does not differ much from other countries. Considering the population, surface area, and location of Luxemburg, renewable energy consumption is similar to other countries. We can see that countries' renewable energy consumption rate is concentrated between 5 - 15%. Renewable energy consumption rates of northern countries such as Sweden, Estonia, Finland, and Latvia are higher than other countries. It is known that this rate will increase even more with the energy policies of the northern countries and their investments. I hope a similar situation will practice in other countries, but this may not be possible because each country's energy resource richness is different.

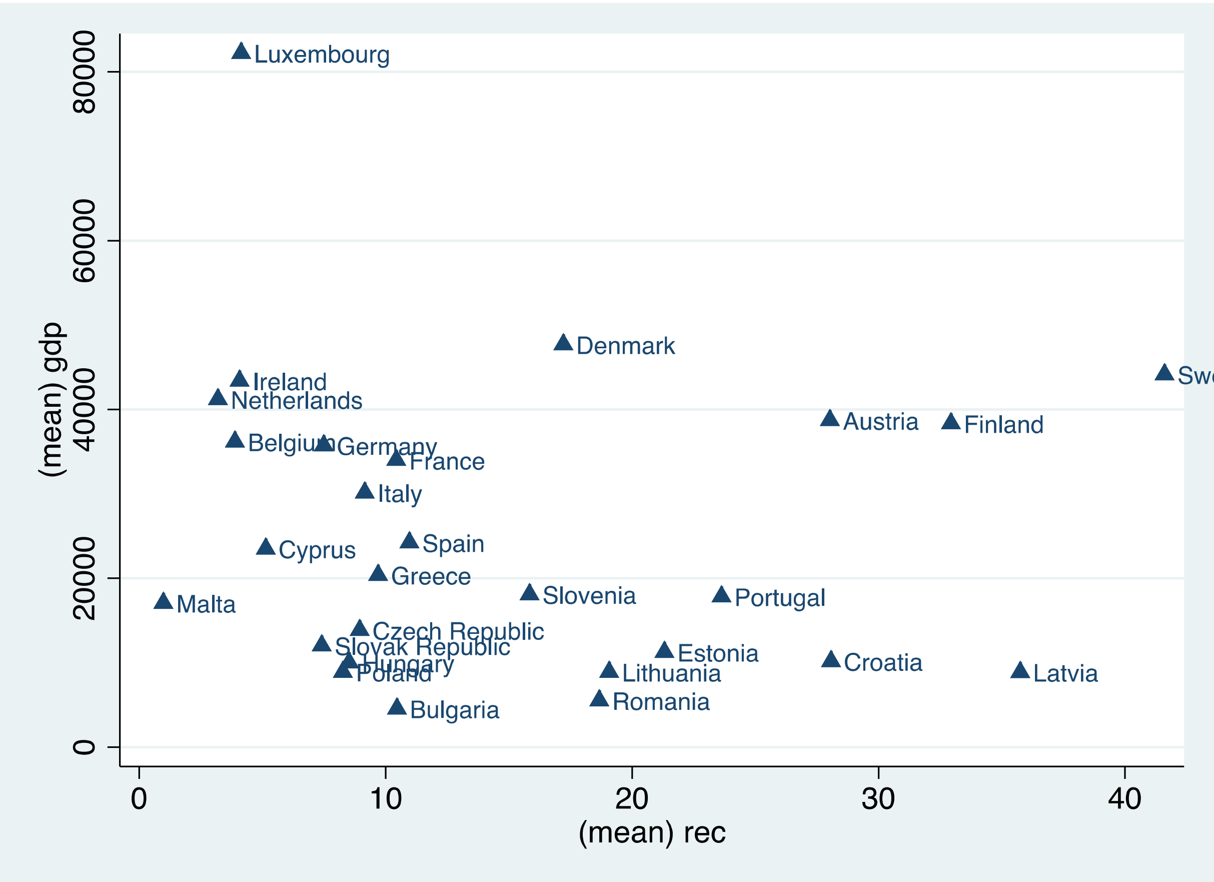

Figure 23. Scatter diagram of GDP and REC means, based on data from [63].

The mean of the dependent variable GDP and the independent variable FEC were plotted and demonstrated in Figure 24. As can be seen from the drawing, the fossil energy consumption rate of northern countries and France is very low compared to other countries. The reason for this low rate in northern countries is mostly due to the high rate of renewable energy consumption in their energy mixes. On the other hand, nuclear energy sources meet half of the demand in the energy mix in France. In countries with limited resources such as Malta and Cyprus, the rate of fossil energy consumption is almost 100%. The solar energy source has great potential for these countries, but they have a field problem because they are an island country.

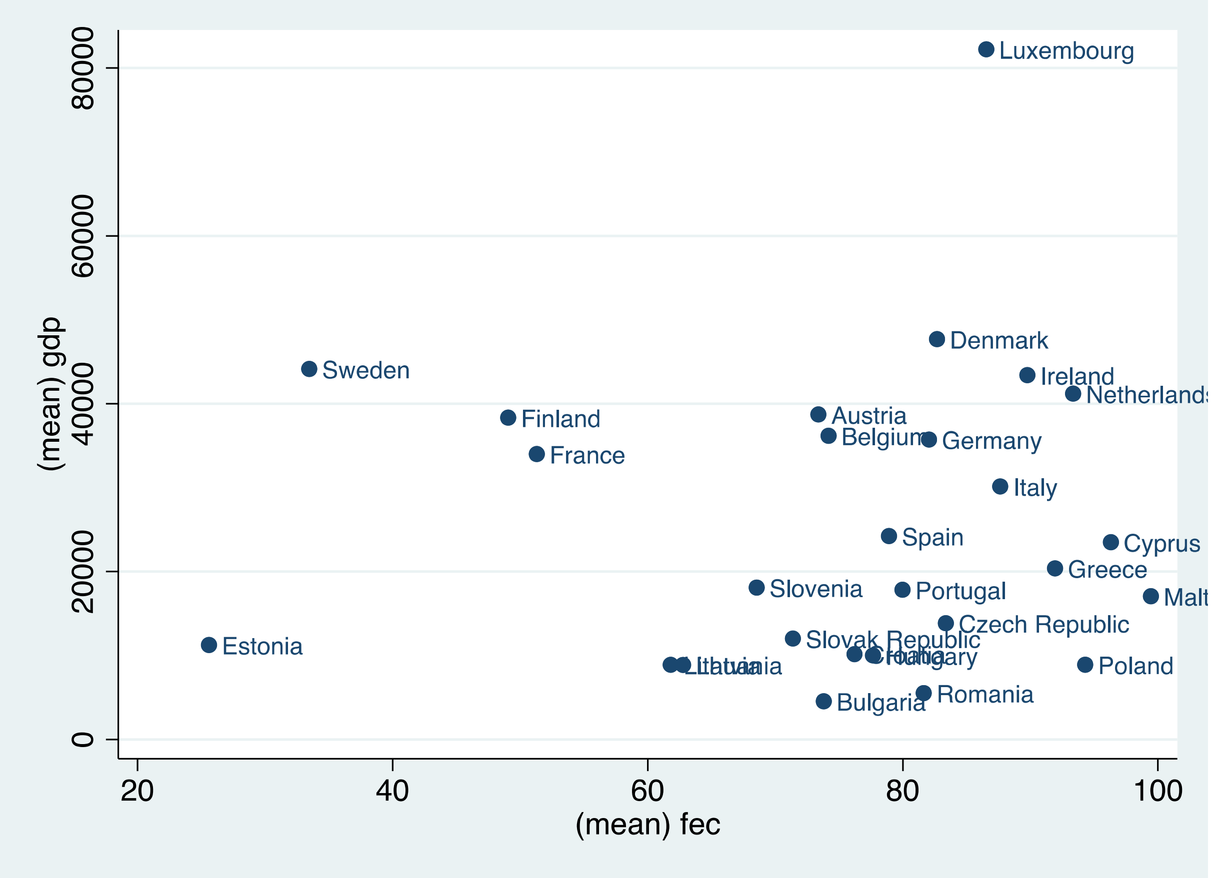

Figure 24. Scatter diagram of GDP and FEC means, based on data from [63].

The mean of the dependent variable GDP and the independent variable COE were plotted and demonstrated in Figure 25. Reducing fossil energy consumption is not the only reason for the reduction in CO2 emission. As mentioned in the previous chapters, the European Union wants to reduce its carbon emissions in the coming years significantly. Each member country has its own specific targets in line with the signed agreements and the set targets. In addition to increasing the use of renewable energy resources, energy efficiency is increased. Energy efficiency and saving are important components for the environment. Regardless of the source of energy, we must review our use and achieve maximum savings. As in other graphs, Luxembourg differs from other countries in terms of both GDP and CO2 emissions. The low population of the country and being economically rich cause this segregation.

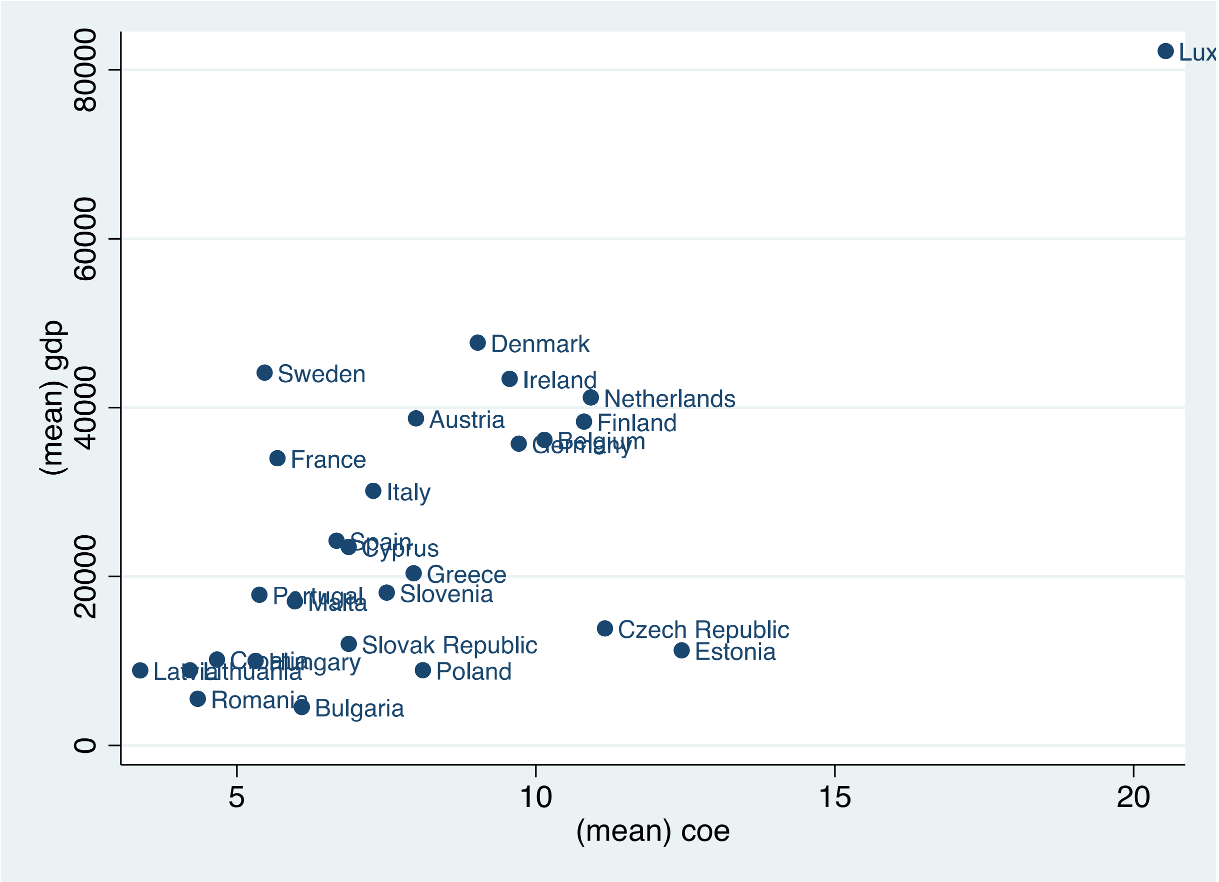

Figure 25. Scatter diagram of GDP and COE means, based on data from [63].

3.5. Panel Data Analysis and GMM Estimator

Static and dynamic panel data are used in the literature. The static panel data does not use the lagged values of the dependent or independent variables while explaining the dependent variable. Static or dynamic processes might determine many economic relations subjects to research. The panel data analysis can be applied to static processes as well as dynamic processes. Economic and financial relations are mostly dynamic. In other words, relations and events in the current period are seen as a result of past activities [95]. In this study, the dynamic link between energy consumption and economic growth is analyzed. When examining this link, variables are under the influence of past behaviors and experiences, so their lagged values are considered explanatory factors.

Many economic relations are dynamic due to their nature. An important advantage of dynamic panel data analysis is that it helps researchers to understand the dynamics of corrections. There are dynamic panel data models developed for this purpose. A dynamic panel data model to contain the lagged value of the dependent variable can be written as [96]:

$$y_{it} = \delta y_{i,t-1} + x'_{it}\beta + u_{it} \qquad i = 1, \dots. N;\ t = 1, \dots T \qquad (3.1)$$

δ is a scalar, x'_{it} is 1 x K, and β is K x 1 matrices in this model. In addition, it is assumed that u_{it} follow a one-way error component model [96]:

$$u_{it} = \mu_i + v_{it} \qquad (3.2)$$

Here μ_i and v_{it} are independent and identically distributed (IID) of σ_μ^2 and σ_v^2 respectively. $\mu_i \sim IDD(0, \sigma_\mu^2)$ and $v_{it} \sim IDD(0, \sigma_v^2)$ are independent of each other and among themselves. However, this equation has a significant problem. The lagged value of the dependent variable that is included in the model as an independent variable is associated with the error term u_{it}. The inclusion of the lagged dependent variable among regressions causes autocorrelation, while individual effects characterize the heterogeneity. The main reason of this problem is that μ_i, which expresses the heterogeneity specific to the sections, is the same for each observation of each group. Whereby y_{it} variable is a function of μ_i, the lagged $y_{i,t-1}$ is also a function of μ_i. Hence, $y_{i,t-1}$ is correlated with the error term. As a result, although v_{it} is not serially correlated, it makes the OLS estimator partial and inconsistent [96].

The method that is currently used and popular in the literature is the Generalized Moments Method (GMM) [Arellano and Bond (1991) and Arellano and Bover (1995)] estimators [97]. Arellano-Bond and Arellano-Bover estimators can be used in the following situations [97];

- Panel data with short time periods and large number of sections.
- Existence of linear functional relationship.
- In dynamic panel data processes.
- Situations where independent variables are not strictly exogenous.
- Fixed individual effects
- Presence of heteroskedasticity and autocorrelation within cross-sections, but not across them

The advantage of GMM is that it can formulate models and estimators without the need for strong distribution assumptions. GMM is an effective estimator for large samples. Another strength of GMM is that it allows over-definition in the number of instrument variables while estimating model parameters. Since negative autocorrelation is generally observed in the error terms of the first difference models, Arellano and Bond's GMM gives more reliable results. In this method, the model created by using the instrument variable is estimated by the Generalized Least Squares (GLS) method [97].

The relationship between errors and variables that is the endogeneity problem causes the least-squares estimator to be inconsistent and deviating. The main problem in estimating equation (3.1) with least squares is that $y_{i,t-1}$ has a heterogeneity problem with u_{it}. Therefore, the first thing that needs to be done is to eliminate the heterogeneity problem. The heterogeneity is usually eliminated by taking the first difference of the model [98].

$$y_{it} - y_{i,t-1} = \delta\left(y_{i,t-1} - y_{i,t-2}\right) + \left(x_{it} - x_{i,t-1}\right)'\beta + (u_{it} - u_{i,t-1}) \qquad (3.3)$$

The model can be represented by difference operator:

$$\Delta y_{it} = \delta(\Delta y_{i,t-1}) + (\Delta x_{it})'\beta + (\Delta u_{it}) \qquad (3.4)$$

However, the model is still problematic. After taking the first difference, the relationship between the error term MA(1) in the model and the lagged dependent variable continues. Therefore, Arellano and Bond's transformation is proposed to eliminate this problem. Equation (3.3) eliminates the cross-sectional effects by taking the first difference of the model, but the explanatory variables $y_{i,t-1} - y_{i,t-2}$ and the error term $u_{it} - u_{i,t-1}$ are still related. This relationship is due to the correlation between $y_{i,t-1}$ and $u_{i,t-1}$. Arellano and Bond proposed transforming the differential model given in equation (3.1) by the instrument variable matrix, and then estimating this transformed model using a GLS estimator [98].

- **Arellano and Bond GMM Estimator**

While analyzing the model presented in equation (3.3), in the case where all x_{it} and μ_i are related and $E(x_{it}\, v_{is}) = 0$ is valid for all t and s, all x_{it} exogenous variables in the model become valid instrumental variables for all equations [95]. The instrumental variable matrix is demonstrated below;

$$P_i = \begin{bmatrix} [y_{i1},\ x'_{i1}, \dots,\ x'_{iT}] & \cdots & 0 \\ \vdots & [y_{i1},\ y_{i2},\ x'_{i1}, \dots,\ x'_{iT}] & \vdots \\ 0 & \cdots & [y_{i1}, \dots, y_{iT-2},\ x'_{i1}, \dots,\ x'_{iT}] \end{bmatrix} \qquad (3.5)$$

The first difference model transformed with instrumental variables is shared below in matrix form:

$$P'\Delta y = P'(\Delta y_{-1})\delta + P'(\Delta X)\beta + P'(\Delta u) \qquad (3.6)$$

ΔX is a matrix where the observations of Δx_{it} are accumulated as $N(T-2)K$. Then GMM with matrices:

$$\binom{\hat{\delta}}{\hat{\beta}} = \left([\Delta y_{-1}, \Delta X]' P \left(P'\hat{\Omega}P\right)^{-1} P'[\Delta y_{-1}, \Delta X]\right)^{-1} \left([\Delta y_{-1}, \Delta X]' P \left(P'\hat{\Omega}P\right)^{-1} P'\Delta y\right) \qquad (3.7)$$

$\hat{\Omega}$ represents the variance-covariance matrix of error terms. If x are predetermined variables, $E(x_{it}\, v_{is}) = 0$ s < t and the current instrument can be used as a variable in the difference equation. As a result of this, the instrumental variables matrix can be shown as follows [96]:

$$P_i = \begin{bmatrix} [y_{i1},\ x'_{i1},\ x'_2] & \cdots & 0 \\ \vdots & [y_{i1},\ y_{i2},\ x'_{i1},\ x'_{i2},\ x'_{i3}] & \vdots \\ 0 & \cdots & [y_{i1}, \dots, y_{iT-2},\ x'_{i1}, \dots,\ x'_{iT-1}] \end{bmatrix} \quad (3.8)$$

- **Arellano and Bover GMM Estimator**

Due to some disadvantages of the first difference transformation method in dynamic panel data models, Arellano and Bover proposed the orthogonal deviations method in obtaining the effective instrumental variable estimator. The orthogonal deviations method suggests that the average of all accessible future values of the variable instead of extracting previous period observations from the current observations. Derivation can be made for all observations except the last observation of each section. Therefore, since lagged observations are not included in the transformation, they can be used as instrumental variables [99]. If we want to demonstrate the transformation for each variable, assume that r is a variable:

$$r^{\perp}_{i,t+1} \ = \ w_{it} \left[r_{it} - \frac{1}{T_{it}} \textstyle\sum_{s>t} r_{it} \right] \quad (3.9)$$

The transformation occurs according to equation (3.9) and here w_{it} is the scale factor and T_{it} is the number of such observations [98]. If we define a static panel data model from here:

$$y_{it} \ = \ x'_{it}\beta + Z'_i\gamma \ + \ u_{it} \quad (3.10)$$

The Z_i are constant of variables that do not change with time, and x_{it} consists of variables that change according to time and cross-sections [98]. If this expression is shown in vector form and with the changes after a unidirectional error component model, which is more useful:

$$y_i \ = \ J_i h + \ u_i \quad (3.11)$$

$$u_i = \mu_i \iota_T + \ v_i \quad (3.12)$$

Here ι_T is a vector of ones of dimension T and;

$$y_i \ = (y_{i1}, \dots, y_{iT})' \quad (3.13)$$

$$u_i \ = (u_{i1}, \dots, u_{iT})' \quad (3.14)$$

$$h' \ = \ (\beta', \gamma') \quad (3.15)$$

$$J_i \ = \ [X_i,\ \iota_T Z'_i] \quad (3.16)$$

$$X_i = (x_{i1}, \ldots, x_{iT})' \qquad (3.17)$$

In addition, the model is assumed to have unidirectional error components and E is not restricted by $J_i = (x_i', Z_i')'$ when $x_i = (x_{i1}', \ldots, x_{iT}')'$. Arellano and Bover transformed equations (3.10) by means of H matrix that a non-singular TxT dimensional. H matrix was defined as follows;

$$H = \begin{bmatrix} G \\ \iota_T'/_T \end{bmatrix} \qquad (3.18)$$

G is a $(T-1) \times T$ dimensional matrix with rank $(T-1)$ satisfying $G\iota_T = 0$. G can be the first line of $(T-1)$ the first difference operator or the within group operator. The transformed errors:

$$u_i^+ = Hu_i = \begin{bmatrix} Gu_i \\ \bar{u}_i \end{bmatrix} \qquad (3.19)$$

The first (T-1) is independent of transformed errors μ_i, i.e. it does not contain μ_i. Therefore, all of the exogenous variables are valid instrument variables for the first (T-1) equation [96]. If a valid instrument variable matrix is defined for a fully transformed system would be like below:

$$M_i = \begin{bmatrix} j_i' & & & 0 \\ & \cdots & & \\ & & j_i' & \\ 0 & & & m_i' \end{bmatrix} \qquad (3.20)$$

The moment conditions can be presented as $E(M_i', Hu_i) = 0$. Defining following $\overline{H} = I_N \otimes H$ and $\widehat{\Omega} = I_N \otimes \Omega$, and premultiplying equation (3.11) by $M'\overline{H}$ the following equation will be obtained [96]:

$$M'\overline{H}y_i = M'\overline{H}J_i h + M'\overline{H}u_i \qquad (3.21)$$

The Arellano and Bover estimators are obtained from the estimation of this final equation using the generalized least squares method. h is estimated below:

$$\hat{h} = [J'\overline{H}'M\left(M'\overline{H}\widehat{\Omega}^+\overline{H}'M\right)^{-1}M'\overline{H}J]^{-1}J\overline{H}'M\left(M'\overline{H}\widehat{\Omega}^+\overline{H}'M\right)^{-1}M'\overline{H}y \qquad (3.22)$$

When the instrumental variable matrix is arranged according to these new definitions, the following matrix appears. The GMM estimator, which uses it as an instrumental variable matrix, does not change with the choice of G if G meets the necessary conditions [96].

$$M_i = \begin{bmatrix} (j_i', y_{i0}) & & & & 0 \\ & (j_i', y_{i0}, y_{i1}) & & & \\ & & \cdots & & \\ & & & (j_i', y_{i0}, \ldots, y_{i,T-2}) & \\ 0 & & & & m_i' \end{bmatrix} \tag{3.23}$$

- **Sargan Test**

The instrument used in the dynamic panel data model estimations by GMM should be tested. The Sargan's test of over-identifying restrictions can be used [96]:

$$ST = \Delta\hat{v}'P\left[\sum_{i=1}^{N} P_i'(\Delta\hat{v}_i)(\Delta\hat{v}_i)'P_i\right]^{-1} P'(\Delta\hat{v}) \sim \chi^2_{b-K-1} \tag{3.24}$$

Subindex b refers the number of columns of the instrumental matrix P, and $\Delta\hat{v}$ refers the residuals obtained from the two-step estimation given in equation (3.7). Instrumental variables have a significant effect on the outcome of GMM analysis. Choosing the instrumental variables and adding them to the calculation make the results significant or insignificant. For the GMM analysis to be accurate and usable, the result of the Sargan test should be statistically insignificant, that the p-value should be greater than 0,05. Sargan tests the model according to the following hypothesis;

H0: overidentifying restrictions are valid

Ha: overidentifying restrictions are not valid

- **Autocorrelation Test**

One of the basic assumptions of the classical linear regression model is that the random error terms are unrelated to each other. The relationship between error terms shows the existence of autocorrelation. In the case of autocorrelation, the least-squares estimators of the parameters are accurate and consistent but ineffective. The estimator of the variance of the error term deviates, so the variances of the parameters also deviate. If there is a positive autocorrelation, the deviation will be negative. Therefore, variances are found smaller than they are. As a result, the t-test statistic value becomes higher. Thus, the probability of an insignificant coefficient being significant increases. Therefore, the value of F is found larger than it is. As a result, t and F tests lose their reliability and give misleading results. One of the assumptions we accept in the least-squares method is that the continuous values of the random variable u are independent from each other. The value taken by u in any period is different from the value taken in any previous period [96].

Autocorrelation is a situation encountered especially in time series data. The autocorrelation problem is not very much related cross-section data, since the sequence of the data does not follow any order. Various methods have been found to determine whether the error term is autocorrelated in a model [96]. The Durbin-Watson test is explained;

$$d_p = \frac{\sum_{i=1}^{N}\sum_{t=2}^{T}(\tilde{v}_{it}-\tilde{v}_{i,t-1})^2}{\sum_{i=1}^{N}\sum_{t=1}^{T}(\tilde{v}_{it})^2} \qquad (3.25)$$

Durbin-Watson tests the model according to the following hypothesis;

H0: There is no autocorrelation in error terms

Ha: There is autocorrelation in error terms

3.6. Econometric Model and Preparation Tests

In the previous sections, energy types, renewable energy sources, economic models, energy-economy relations, previous studies on the subject, and panel data analysis were explained. The econometric model will be analyzed in this part of the thesis. The regression analysis of the panel data that was described in Section 3.4 will be performed. The GMM technique that was mentioned in Section 3.5 will be used for regression analysis. However, before starting the regression analysis, we need to apply some preparation tests to the panel data we will use.

The main question of the study is to determine whether the use of renewable energy has a positive effect on economic growth for the European Union countries. In addition, the impact of fossil energy consumption and CO_2 emission on economic growth is also investigated. The empirical analysis is used in the study to support this hypothesis. In this section, the model setup, preparation tests, applied analysis method, and analysis results are examined. While examining the relationship between renewable energy consumption and economic growth in the literature, non-renewable energy resources are generally added to the model. Besides, CO_2 emission is also included in the model, and it is accepted as an explanatory variable on growth in some studies. Accordingly, the model is demonstrated as follows:

$$GDP_{i,t} = \alpha_0 + \beta_1 GDP_{i,t-1} + \beta_2 REC_{i,t} + \beta_3 FEC_{i,t} + \beta_4 COE_{i,t} + u_{i,t}$$

$$i = 1, \dots, 27; \; t = 1, \dots, 20$$

Here definitions of variables and coefficients:

$GDP_{i,t}$ the per capita income of country i at time t. This expression, which is an indicator of economic growth, is used as the dependent variable in the model.

α_0 constant

β independent variables coefficients

$GDP_{i,t-1}$ the per capita income of country i at time $t-1$

$REC_{i,t}$ share of renewable energy consumption in total energy use of country i at time t

$FEC_{i,t}$ share of fossil fuel energy consumption in final energy use of country i at time t

$COE_{i,t}$ CO_2 emissions (metric tons per capita) per capita of country i at time t

$u_{i,t}$ Error term of country i at time t

In models where GDP is the dependent variable, lagged GDP data is add to the model as an independent variable. The current data of the GDP is affected by the results of previous years' experiences. In this case, dynamic panel data is formed and the analysis will be done according to this dynamic panel data. As can be easily guessed from the model, the lagged GDP will have the greatest impact on economic growth compared to other independent variables. It is expected that renewable energy consumption, fossil energy consumption, and CO2 emission will positively impact GDP.

Correlation analysis is one of the fundamental tests to be done before starting the regression analysis. The significance and strength of the correlation between the variables are important for the reliability of the test. A strong and statistically significant correlation between the dependent and independent variables is expected to obtain a strong and reliable result. The opposite of this situation is desired among the independent variables.

The correlation between the variables of the model described above is shared in Table 4. Correlations between the dependent variable GDP and the independent variables REC, FEC, and COE are 0,081, 0,131, and 0,268, respectively. The correlation between dependent variables and independent variables is statistically significant and positive at 0,05 significance level. This situation meets expectations. The correlation values between independent variables are shared in Table 4. and they are not strong enough to manipulate the analysis result. There is a semi-strong positive correlation between FEC and COE. This is expected.

Table 4. Correlation matrix of variables

Correlation Matrix				
Variable	GDP	REC	FEC	COE
GDP	1,000			
REC	0,081*	1,000		
FEC	0,131*	-0,208*	1,000	
COE	0,268*	-0,267*	0,453*	1,000

Signif. codes: 0‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 ‘.’

In most of the regression analysis, there is a relationship between the independent variables. In some cases, there is a very strong linear relationship between the independent variables. In such cases, interpretations made with the help of the regression model cause misleading and errors. However, the interpretation of the regression equation is based on the assumption that the independent variables are not strongly correlated. Breaking this assumption, the existence of one or more relationships between the independent variables brings up a multicollinearity problem.

Although the estimates are unbiased in the case of multicollinearity, the results regarding the evaluation of the strong relationship of the independent variables and their combined effects cannot be relied on. In other words, even if the best predictive values are obtained with independent variables, beta coefficients and R^2s cannot be interpreted reliably. As a rule of thumb, a correlation between independent variables above 0,80 indicates a multicollinearity problem.

- **Variance Inflation Factors (VIFs)**

VIFs identify multicollinearity in regression analysis. The diagonal elements of the inverse of the independent variables' correlation matrix are called variance inflation factors. VIFs calculate how much the variance of a regression coefficient is inflated because of multicollinearity in the model. The VIF formula is shared below:

$$VIF = \frac{1}{1-R^2} \qquad (3.26)$$

The VIFs value changes from 1 upwards with the change of R2. The VIF represents what percentage of the variance is inflated for each coefficient. For instance, 1,5 shows that the variance of a presented coefficient is 50% greater than expected if there was no multicollinearity. What the VIF value ranges mean for multicollinearity is shared in the following scale [100],

- VIF = 1, not correlated
- 1 < VIF < 5, moderately correlated
- 5 < VIF, highly correlated

The VIFs values of the regression model used in this thesis are demonstrated in table 5. The model is moderately correlated according to the intervals described above.

Table 5. Variance inflation factors of regression

Variance Inflation Factors (VIFs)		
Variable	VIF	1/VIF
REC	1,590	0,629
COE	1,480	0,676
FEC	1,390	0,719
GDP L1	1,290	0,775
Mean VIF	1,44	

- **Unit Root Test**

Granger and Newbold stated that if the regression analysis is performed with non-stationary series, the series that are not actually related to each other can be found statistically significant in their study. They created the concept of Spurious Regression. Until this study, it has been assumed that the series subject to regression analysis are stationary and the error terms are zero mean and finite variance in classical econometric applications. If the means, variances, and covariances of the series do not change on time, these series are stationary series. This situation can also be called covariance stationary, weak stationary, second-order stationary, and broadly stationary [100]. Since the studies by Levin and Lin [102] and Quah [103], unit root studies have played an important role in empirical analysis of panel data. Panel unit root tests have been applied to different areas of the economy: analysis of purchasing power parity, growth and convergence, investment and savings dynamics, international research and development distributions.

When a series is stationary, it fluctuates around the fixed mean and returns to the mean. In the non-stationary series, there is no tendency to return to the mean. In other words, in the case of random shock, the effect of this shock is temporary in stationary series, while it is permanent in non-stationary series. In addition, the stationary series are suitable for the white noise process, while the non-stationary series are suitable for the random walk process [104]. One of the first things to be examined is the data stationarity in panel data analysis as in classical time series analysis. The stationarity of the panel data is directly related to the significance of the estimators. The stationarity of the panel data is examined by determining how the value of the previous period of the series affects the current period. Unit root tests are needed to determine this interaction.

As mentioned before, it is very important to test the stationarity of the series subject to analysis in order to avoid the spurious regression problem. The stationarity test can be done with unit root tests. Four different panel data root tests, which are most commonly used in the literature, were applied to the data of this thesis. These tests are as follows:

- **Levin, Lin and Chu (LLC)**

LLC study is the edited version of the Lin and Levin study mentioned above. LLC evaluated in their study, that unit root hypotheses have a limited effect on the alternative hypothesis that shows a high rate of continuous deviation from the equilibrium level. They observed that this situation was more severe especially in applications with small samples, and they recommended a more effective unit root test for each cross-section evaluated compared to the currently applied unit root tests [105].

The unit root test suggested in the article deals with time trends and individually specific intersections. It also allows free variation of higher series correlation and error variance seen between units. Unlike the nonstandard distributions seen in unit root tests based on a single time series, panel test statistics have a restrictive normal distribution. Apart from these, LLC observed that the asymptotic variance and mean changes under different definitions of the regression equation in unit root test statistics [105].

LLC assumes that all units in the panel have first-order partial autocorrelation. Three different models are predicted for the y_{it} series in the article. These models are created without fixed parameters, with fixed parameters and trends, as given in the equation below.

$$\Delta y_{it} = \rho y_{i,t-1} + u_{it} \tag{3.27}$$

$$\Delta y_{it} = \alpha_{0i} + \rho y_{i,t-1} + u_{it} \tag{3.28}$$

$$\Delta y_{it} = \alpha_{0i} + \alpha_{1it} + \rho y_{i,t-1} + u_{it} \tag{3.29}$$

It is assumed that the u_{it} process is distributed independently among individuals in this test, and it is modeled as shown in the following equation:

$$u_{it} = \sum_{j=1}^{\infty} \theta_{ij} u_{it-j} + \varepsilon_{it} \tag{3.30}$$

LLC hypotheses are as follows;

H0: Panels contain unit roots

Ha: Panels are stationary

- **Im, Pesaran and Shin (IPS)**

IPS considers the heterogeneous coefficient of $y_{i,t-1}$ and proposes an alternative unit root test statistics process based on the average of individual. The IPS allows for the heterogeneity of the ρ_i value under the alternative hypothesis. Although the model allows for individual effects, it does not have a time trend. IPS proposed a more flexible and computationally easier unit root test process for the panel, which considers simultaneous stationarity and non-stationarity using the likelihood draft [106]. IPS' formula is shared below:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{z=1}^{P_i} \beta_{iz} \Delta y_{i,t-z} + \varepsilon_{it} \qquad (3.31)$$

IPS hypotheses are as follows;

H0: All panels contain unit roots

Ha: Some panels are stationary

- **Fisher Type - Augmented Dickey–Fuller (ADF)**

Classical Dickey-Fuller model established as first order autoregressive model AR (1) is expressed in equation 3.32 [107].

$$Y_t = \rho Y_{t-1} + \varepsilon_t \qquad t = 1,2, \dots \qquad (3.32)$$

If the Y_t variable follows an actual p degree autoregressive process AR(p), then a specification error has occurred and the error terms are autocorrelated. The Dickey-Fuller distribution assumes that the error term has a sequence characteristic, and the autocorrelation of the error terms breaks this assumption. Therefore, the DF distribution is not valid in this case [107]. In 1981, Dickey and Fuller suggested adding the lagged values of the difference of the dependent variable to the right of the three models used in the unit root test to solve this autocorrelation problem. These models are expressed below [108]:

$$\Delta Y_t = \theta Y_{t-1} + \sum_{i=2}^{p} \gamma_i \Delta Y_{t-i+1} + \varepsilon_t \qquad Y_0 = 0 \qquad (3.33)$$

$$\Delta Y_t = \mu + \theta Y_{t-1} + \sum_{i=2}^{p} \gamma_i \Delta Y_{t-i+1} + \varepsilon_t \qquad Y_0 = 0 \qquad (3.34)$$

$$\Delta Y_t = \mu + \beta t + \theta Y_{t-1} + \sum_{i=2}^{p} \gamma_i \Delta Y_{t-i+1} + \varepsilon_t \qquad Y_0 = 0 \qquad (3.35)$$

As in the DF unit root test Augmented Dickey and Fuller (ADF, 1981), the hypotheses of the unit root test are set as below:

H0: All panels contain unit roots

Ha: At least one panel is stationary

- **Hadri Lagrange Multiplier (LM)**

Hadri proposes a residue-based Lagrange Multiplier (LM) test for a panel in which the alternative has a unit root versus the null hypothesis that time series for each i are stationary around a deterministic trend. Unlike the first-generation tests, the test proposed by Hadri is based on the stationarity null hypothesis [109]. The hypotheses of the unit root test are set as below:

H0: All panels are stationary

Ha: Some panels contain unit roots

The 4 different unit-root tests that are most commonly used in the literature have been explained above. In line with these tests, the variables used in this thesis are tested. Unit-roots are determined in the tests performed as level. In the tests where the first difference is used, the variables turned out to be stationary. In LLC, IPS, and Fisher ADF tests, the p-value for the level is greater than 0,05. For this reason, the H0 (all panels contain unit roots) hypothesis is not rejected for these tests. For the first difference in LLC, IPS, and Fisher ADF tests, the p-value is less than 0,05 and the H0 (all panels contain unit roots) hypothesis was rejected. As a result, the Ha (panels are stationary) hypothesis is accepted and it is proved that they are stationary. Since the Hadri test works in the opposite direction to the other tests, the p-value is lower than 0,05 in the level tests. For this reason, H0 (all panels are stationary) has been rejected. In the difference tests, the p-value is higher than 0.05 and H0 is accepted.

Table 6. Panel unit-root tests results

Panel Unit-Root Test				
Variable	LLC		IPS	
	Level	First Difference	Level	First Difference
GDP	6,131 (1,000)	-4,299 (0,000)***	2,252 (0,987)	-5,974 (0,000)***
REC	7,491 (1,000)	-5,665 (0,000)***	6,555 (1,000)	-10,105 (0,000)***
FEC	5,428 (1,000)	-3,904 (0,000)***	9,465 (1,000)	-7,802 (0,000)***
COE	3,114 (0,991)	-6,948 (0,000)***	3,864 (0,999)	-10,797 (0,000)***
Variable	Fisher ADF		Hadri	
	Level	First Difference	Level	First Difference
GDP	-1,882 (0,970)	4,375 (0,002)***	53,197 (0,000)***	-0,170 (0,567)
REC	-3,472 (0,997)	15,553 (0,000)***	49,223 (0,000)***	-0,518 (0,696)
FEC	-3,892 (1,000)	13,675 (0,000)***	46,191 (0,000)***	-0,027 (0,510)
COE	-2,379 (0,991)	15,259 (0,000)***	29,482 (0,000)***	-1,937 (0,264)

Signif. codes: 0‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 ‘.’

Many studies in the economics literature contain a dynamic process due to their nature. Usually, the issue of growth is also a dynamic process. Therefore, it is important to work with dynamic models while investigating the effects on economic performance. Lately, GMM estimator has been used frequently in the analysis of dynamic panel data. Its features have proven to be a reliable estimator in dynamic panel data analysis, where economic growth and financial issues are investigated.

The GMM estimator, dynamic regression model, and preparation tests are described in the previous sections. The regression analysis result of the model is shared in Table 7. It would be more critical to evaluate the result of the Wald test (also called the Wald Chi-Squared Test) before evaluating the results of the regression. One of the important tests that can be used to test whether the regression coefficients are significant is the Wald test. Coefficient significance means that variables add some value to the model. The no value-added variables could be removed without significantly affecting the model. The distribution of the test statistics for the Wald test approximates the standard normal distribution. Z test is performed using standard errors for each variable. The Wald test formula shared below:

$$W_T = \frac{[\hat{\theta}-\theta_0]^2}{1/I_n(\hat{\theta})} = I_n(\hat{\theta})[\hat{\theta}-\theta_0]^2 \qquad (3.36)$$

The hypotheses of the Wald test are set as below:

H0: The coefficients are simultaneously equal to zero

Ha: The coefficients are not simultaneously equal to zero

The p-value of the Wald test obtained after the regression analysis is approximately zero. In this case, the H0 hypothesis is rejected. In other words, renewable energy consumption, fossil energy consumption, CO_2 emission, and lagged GDP used as independent variables in the model explain dependent variable GDP significantly.

Table 7. Regression analysis results

Result of Model			
Variables and Tests	Coefficients	Std. Error	p-values
$GDP_{i,t-1}$	0,9016	0,0132	0,000*
$REC_{i,t}$	0,0452	0,0219	0,003*
$FEC_{i,t}$	0,1790	0,0200	0,000*
$COE_{i,t}$	0,0173	0,0295	0,001*
Wald Test (χ^2)	4242,70		0,000*
Sargan Test	26,98		0,374
Arellano-Bond Autocorrelation Test AR(1)	-2,382		0,006*
Arellano-Bond Autocorrelation Test AR(2)	-1,072		0,283

Signif. codes: 0‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 ‘.’

The validity of the instrument variables used in GMM estimation, in other words, whether there are over-identification constraints in the panel estimates, were analyzed using the Sargan test. The validity of the instrument variables was tested with the null hypothesis showing the relationship between the instrument variables and the error terms. The results of the Sargan test, which tests the validity of the instrument variables, show that the instrument variables are valid. The probability value of the Sargan test is 0,374 and the null hypothesis (over-identification constraints are valid) cannot be rejected. It is decided that the instrument variables are valid in the model.

Other test that evaluate the accuracy of the results of the analyzed model are the Arellano-Bond Autocorrelation Test AR (). The AR (1) and AR (2) test whether there is autocorrelation in the model. The result of Arellano-Bond Autocorrelation Test AR (1) in the first step is found -2,382 and the probability value is 0,006. In this case, we can reject the H0 (there is no autocorrelation in error terms) hypothesis and say that there is autocorrelation in the model in 1st step. The result of Arellano-Bond Autocorrelation Test AR (2) in second step is found -1,072 and the probability value is 0,283. In this case, we can say that there is no autocorrelation in the model in step 2 by accepting the H0 (there is no autocorrelation in error terms) hypothesis.

When the regression analysis results of the model established at the beginning of this chapter are evaluated, it is seen that the explanatory variables of the model have positive effects on GDP per capita. This situation is in line with the studies conducted for different developed country groups in the literature. These positive effects also support the main idea of the thesis. The lagged value of GDP effects current GDP more than other independent variables and this is an assumed effect. When the share of renewable energy consumption increases 1%, GDP per capita increases 0,045%. On the other hand, 1% increase in the share of fossil energy consumption increases GDP per capita by 0,17%. When CO_2 per capita, which is most related to the environment, increases by 1%, GDP per capita increases by 0,017%.

According to the regression analysis results made with the GMM estimator, the effect of fossil energy consumption on GDP per capita is more than the effect of renewable energy consumption for European Union member countries. Although the EU has developed policies to increase the use of renewable energy sources and its proportion in the energy mix, it is still low compared to the use of fossil energy sources. Although some countries' renewable energy consumption rate, especially the northern countries, is higher than the fossil energy consumption rate, the total fossil energy consumption rate is still very high within the union. The renewable energy usage rate will increase in line with 2030, 2050, and long-term plans and targets of the European Union. With the increase in the use of renewable energy due to targets and policies, the effect of renewable energy on economic growth will also increase.

It is an expected result that the CO2 emission per capita is directly proportional to economic growth. An important reason for this is that fossil energy use still positively affects GDP. However, when the results are evaluated, it is seen that the CO2 emission per capita does not affect GDP per capita as much as the fossil energy consumption rate. Energy efficiency and energy saving policies are important to reduce CO2 emissions. Although CO2 emission per capita has decreased over the years in most countries, it is not yet at the desired levels.

Conclusion

In order to increase the total output, the factors used in production should also be increased. Energy is a vital factor in increasing production output. The most important and widely used energy resources in the world are fossil resources. Although important steps have been taken regarding renewable energy and nuclear energy, fossil energy sources are still preferred in households, industry, and transportation. Energy is vital for every economy and production is dependent on it. The concept of energy dependence, which expresses a situation where the need for energy is unsatisfied and the need is constantly increasing, is related to the development levels of economies. Energy dependence is about not having enough energy resources. Especially developed economies invest in renewable and nuclear energy sources to reduce their energy dependency.

Energy policies have become important worldwide with the oil crisis in 1973. Before the crisis, energy policies covered investments in traditional energy resources and ensuring the supply security of transmission networks. However, the 1973 Oil Crisis changed energy policies according to supply security of energy resources, energy price shocks, transportation of energy, and energy lead international commercial and political relations. Promotion, development, consumption, and commercialization of renewable energy systems have become inevitable for states.

In this thesis, the relationship between energy consumption and economic growth has been investigated. For this purpose, firstly, types of energy, economic growth models, energy economy, and the role of energy in production were discussed. Studies about the relationship between energy and growth from a theoretical point of view have been examined. The theoretical relationships between energy consumption and economic growth are four types in the literature:

- There may not be any relationship between them, in which case energy incentive or policies will not have any effect.
- There can be a correlation between energy consumption and growth. In this case, energy incentives and policies increase growth, and high growth rates increase energy consumption.
- Energy conserving (restrictive) policies are preferred when there is a causal relationship from growth to energy consumption. Growth does not slow down when energy consumption is reduced.
- When a causal relationship from energy consumption to growth is determined, energy incentive policies should be implemented. Energy production and imports should be increased, and energy consumption should be subsidized.

The European Union is one of the regions with the highest energy consumption in the world. Therefore, European Union countries had some difficulties in energy supply, and their energy dependency increased over the years. The EU needed renewable energy to decrease imported energy dependency since the fossil resources needed to meet the increasing energy need are insufficient. Thus, using renewable energy resources has come to the fore by reducing the use of existing fossil resources used in the European Union. In order to meet the energy needs, the environmental factor has been another issue that needs to be considered. Using energy systems by preventing environmental damage has been the main goal of the European Union states. While formulating environmental policies, the greenhouse gases that have increased in recent years, climate change, and global warming are considered. Therefore, instead of fossil fuel energy that harms the environment, it is aimed to increase clean, environmentally friendly, and cheaper energy sources.

Renewable energy resources have gained importance in terms of energy resource consumption and production in European Union member countries. The existing renewable energy capacities are operating quite well and some member states are using renewable energy almost more than fossil energy. It is observed that the tendency to these resources in some member countries has increased in recent years, but it is not sufficient yet. In this thesis, I tried to answer whether renewable energy consumption affects economic growth by using the data of 27 EU member countries for time period 1996 - 2015. In addition, it is aimed to evaluate the effect of fossil energy use and renewable energy use on economic growth.

As a result of the regression analysis made in the last part of the thesis, the model is as follows:

$$GDP_{i,t} = 0{,}901 * GDP_{i,t-1} + 0{,}045 * REC_{i,t} + 0{,}179 * FEC_{i,t} + 0{,}017 * COE_{i,t}$$

In the last part of the thesis, the effects of renewable energy consumption, fossil energy consumption, and CO2 emissions on economic growth for European Union countries are examined with empirical study. The impact of fossil energy consumption on economic growth is greater than renewable energy. This situation should not be interpreted as increasing the use of fossil energies. As a result, meeting the energy demand of the entire union with renewable energy does not seem to be a realistic target for the time being. However, with the increase in the use of renewable energy, the effect on GDP will increase. The impact of renewable energy on economic growth will be higher and sustainable. Renewable energy sources have become more attractive with rapidly developing renewable energy technologies and decreasing initial investment costs. In addition, the subject has an ecological aspect besides its economic aspect. Uncontrolled consumption of limited natural resources and wealth will leave an uninhabitable environment for future generations. Renewable energies are an indispensable resource to stop this situation and to ensure the protection of nature.

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