Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

Effects of Renewable Energy on European Union's Energy Import

Master's Thesis

Study Program: Electrical Engineering, Power Engineering and Management

Field of Study: Management of Power Engineering and Elektrotechnics

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MASTER'S THESIS ASSIGNMENT

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Prepare general research on renewable energy in Europe
Describe main renewable energy sources and shares in Europe by years
Describe and evaluate the European Union's energy import by years
Evaluation and Analysis of energy import and renewable energy data

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Bigerna, S., Bollino, C. A., Micheli, S. (2015). The Sustainability of Renewable Energy in Europe. Springer Science & Business Media.
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The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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Topic Registration Form

Student: Isa Cakir

Study Program: Electrical Engineering, Power Engineering and Management

Topic: Effects of Renewable Energy on European Union’s Energy Import

Details:

- Prepare general research on renewable energy in Europe
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Literature for registration:

- Bigerna, S., Bollino, C. A., Micheli, S. (2015). The Sustainability of Renewable Energy in Europe. Springer Science & Business Media.
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I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

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Abstract

Energy is used in all fields of the modern world and its usage has vital importance in all of our lives. Even a short interruption in energy supply will cause serious consequences in the supply chain since almost all sectors are energy-dependent. Therefore, all countries have started to take measures to ensure energy security and uninterrupted energy supply. The European Union countries have also taken various measures for this purpose and they continue to do so. One of these measures is that the European Union is trying to reduce energy dependency by reducing energy imports. This is possible by the EU investing in renewable energy and increasing the share of renewable energy in total energy produced. Therefore, In order to decrease the energy imports, the EU countries have started to increase their renewable energy production. The main goal of this study is to see if there is a relationship between renewable energy production of the European Union and the energy import of the European Union and if so, to find the degree of this relationship.

In the first part, I gave information about what renewable energy is and the detailed definitions of main renewable energy resources. In the second part, I tried to show the current situation in the European Union regarding renewable energy. I gave information about the main renewable energy sources and energy shares of the European Union and the most and least common renewable energy resources in the EU. In the third part, I gave information about the energy dependency, energy import, and energy security of the EU. I supported all information with the previous years' statistical data and graphs. Finally, in the last part, I did correlation and regression analysis to find out whether there is a relationship between the energy import of the EU and the renewable energy production of the EU.

Although some previous studies and common belief are claiming that increasing renewable energy production will decrease energy imports, according to the results and conclusions of my study, the increase of renewable energy production of the European Union has a positive effect on the increase of energy imports of the European Union. The detailed results are presented in the conclusion part of my study.

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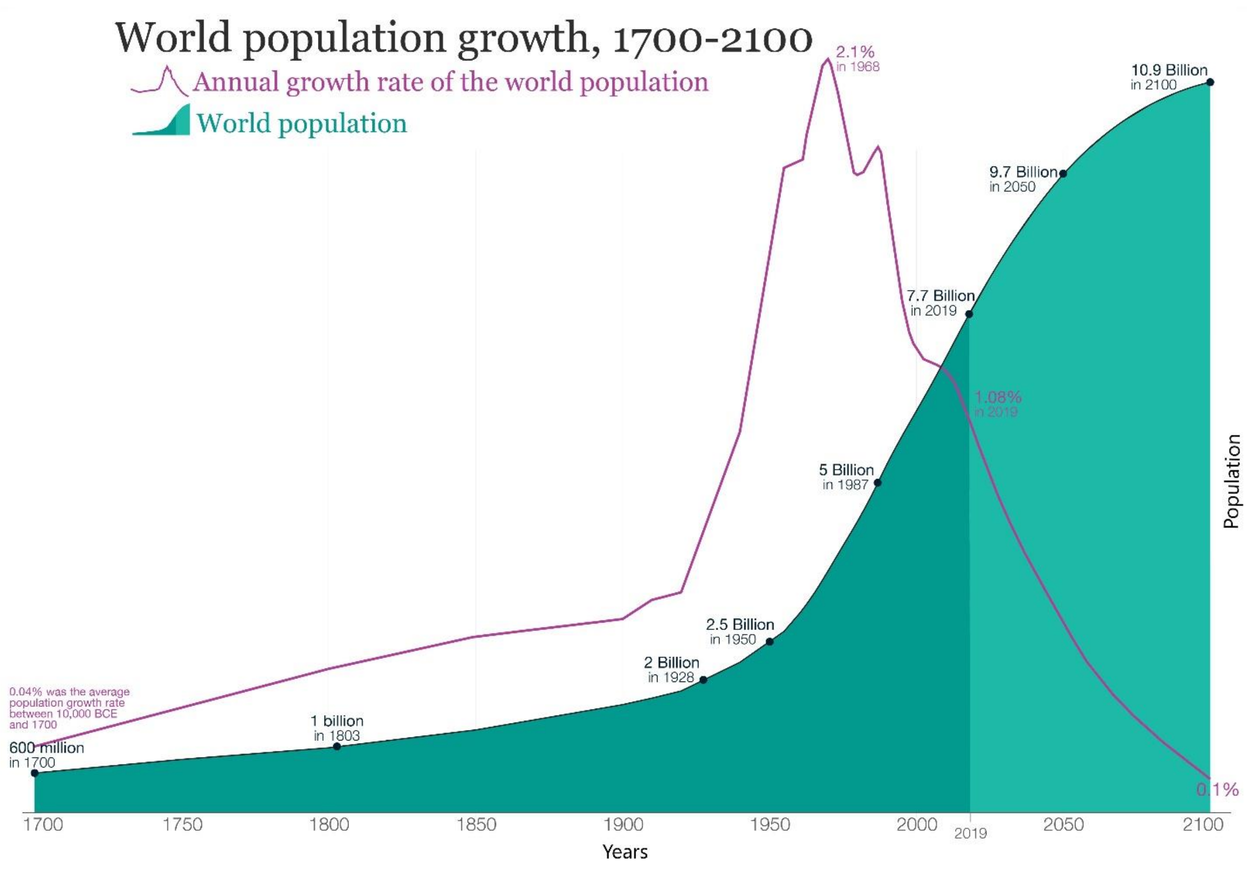
List of Abbreviations

EU-28	The 28 member countries of the EU
IEA	International Energy Agency
PRB	Population Reference Bureau
GHG	Greenhouse Gas
PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
HPWH	Heat Pump Water Heaters
OTEC	Ocean Thermal Energy Conversion
GSHP	Ground Source Heat Pump
RES	Renewable Energy Systems
MTOE	Million Tonnes of Oil Equivalent
EC	European Commission
ENTSOG	European Network for Transmission System Operators for Gas
TOE	Thousand Tonnes of Oil Equivalent

Introduction

The energy demand of human beings is increasing significantly year by year. According to the IEA, in 2018, global energy demand is increased by 2.3 percent, which is the highest increase rate in the past 10 years, due to a strong global economy and increased heating and cooling demand in some countries [1]. These increase rates are higher in developed and developing countries. The reasons can be industrialization, population growth, economic developments. If we think about the European Union, the reasons will be economic developments, industrialization, and increasing quality of life.

The energy needs of the world increased fast and sharply after the industrial revolution in the 1800s. Parallel to this, also the world's population started to increase rapidly. According to the World Bank, the world's population was 3.02 billion in 1960, and now it's 7.6 billion [8]. That means the world's population has increased by 2.5 times in only 60 years. As a result of all these, the world's energy consumption increased. More importantly, according to PRB, the world's population will be 9.9 billion in 2050, more than 2.3 billion from a calculated 7.6 billion people now in 2019 [9]. That means energy consumption will continue to increase more and more.



Graph 1 – World Population between 1700- 2100 [12]

Non-renewable energy resources of the world are not infinite and they are not equally distributed among countries. It's quite obvious that some countries have more resources than they need, while others have less. Therefore some countries have to import energy. If we talk about importation, some political issues also come into play. And as a result of these, unavoidable energy dependency and energy security problems start to occur.

According to the EU, the energy dependency rate shows "the proportion of energy that an economy must import" [4]. Due to inequality about the energy sources of the countries, the energy dependency rate is very high for some countries. The European Union countries are also energy-dependent countries of the world. EU-28 imported 55.1 percent of its gross available energy in 2017 [5].

One of the other important terms about energy is energy security. IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price" [6]. That term is closely linked with the term energy dependency. Because it's hard to say that an energy-dependent country's energy supply is secure enough. Energy supply has many critical risks including disruption from countries from which EU oil is imported, but also industrial, extreme weather, environmental, cyber or terrorist attacks, and hybrid threats [7].

As we can see above, limited non-renewable energy resources of the world will be not enough to meet the energy needs of the world in the future due to the increasing population and industrialization. Even if it's enough to meet the energy needs of the world, there can be other problems due to unequally distributed energy resources. Therefore, to meet the energy needs of the world, to be energy independent, and to provide energy security, countries have to find a solution. As a solution, countries started to invest renewable energy sources. If every country can meet its national energy requirements on its own, then we can say these countries are energy independent and achieved energy security.

1. What is Renewable Energy?

European Union Energy Directive defines renewable energy as "energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas" [2]. In other words, renewable energy refers to the energy that is obtained from a wide range of self-renewing resources such as sunlight, wind, flowing water, the earth's internal heat, and biomass [10]. These resources can be used to generate electricity. If there is renewable energy, there should be non-renewable energy sources as well. These sources are fossil fuels that cannot be produced continuously and it will take many years to be replenished.

1.1. Wind Energy

Wind power's history goes back 3000 years ago which is used for watering purposes [11]. Historical sources provide evidence that windmills are used in Afghanistan for grain milling in the 7th century which was very basic systems and had very low efficiency [11]. From the beginning of the 12th century, wind power started to be important in Europe and by the development of the new systems over the following centuries, in the 17th and 18th centuries the Netherlands, tens of thousands of windmills were used for land drainage which was advanced and could track the wind autonomously [11]. Later, electricity started to be used for such kind of systems, therefore wind power became useless. With the oil crises in the 1970s, wind power gained its importance back and instead of the past centuries' mechanical wind systems, modern wind converters started to generate electricity as a primary product [11].

The wind energy can be accepted as an indirect form of solar energy. Because the wind occurrence process starts with the heating characteristic of the sun. The sun heats the land, the seas and the atmosphere. These different parts of the world absorb different amounts of heat. As a result of this, horizontal air movements, which move from the high-pressure area to the low-pressure area, occur and that is named wind. In recent years, when the importance of renewable energy sources is understood more clearly, wind energy started to be one of the most rapidly developing renewable energy sources. Wind turbines are used to produce wind energy and kinetic energy of wind is converted into a different type of energy like electricity [10].

The Beaufort scale is a scale that is used often in meteorology to give the wind force without complicated calculations [11]. In Table 1, the different Beaufort scale values and their effects are given. The best Beaufort scale for wind turbines to operate is like the following: [13]

Cut-In Wind Speed: Scale – 3

Operate Wind Speed: Scale – 4 to 7

Stall Wind Speed: Scale – 7

Cut-Out Wind Speed: Scale – 8

Table 1 – Wind Speed Classification of the Beaufort Wind Scale [11]

Beaufort Force	Wind Speed (m/s)	Description	Effects
0	0-0.2	Calm	Smoke rises vertically
1	0.3-1.5	Light Air	Smoke moves slightly and shows the direction of wind
2	1.6-3.3	Light Breeze	Wind can be felt. Leaves start to rustle
3	3.4-5.4	Gentle Breeze	Small branches start to sway. Wind extends light flags
4	5.5-7.9	Moderate Breeze	Larger branches sway. Loose dust on ground moves
5	8.0-10.7	Fresh Breeze	Small trees sway
6	10.8-13.8	Strong Breeze	Trees begin to bend, whistling in wires
7	13.9-17.1	Moderate Gale	Large trees sway
8	17.2-20.7	Fresh Gale	Twigs break from trees
9	20.8-24.4	Strong Gale	Branches break from trees, minor damage to buildings
10	24.5-28.4	Full Gale/Storm	Trees are uprooted
11	28.5-32.6	Violent Storm	Widespread damage
12	≥32.7	Hurricane	Structural damage

1.1.1. Advantages of Wind Energy

There are several different advantages of wind energy as shown below.

- **Renewable, sustainable, and environment-friendly:** Wind energy is a renewable, sustainable, and environmentally friendly type of energy. It will not run out as long as the sun shines and the wind blows [16]. The majority of non-renewable energy sources like coal or natural gas need to be burnt and after the burning process, some gases are released into the atmosphere like nitrogen oxides, and sulfur dioxide which can cause health problems [16]. But in wind energy, there are no atmospheric emissions that can cause acid rain, smog, or greenhouse gases [16].

- **It reduces fossil fuel consumption and free:** By using wind energy to generate electricity, fossil fuel usage decreases [15]. We pay for buying fossil fuels and it increases the dependency, but for wind energy, there is no additional fuel cost [18].

- **It provides electricity to remote locations:** Providing electricity to some locations, which is too far away from central locations, can be costly [17]. Therefore wind energy can be a very feasible alternative to provide electricity to rural areas [17].

- **It increases energy security:** Using wind energy to generate electricity, helps to reduce the dependency on fossil fuels and fossil fuel importing countries [18].

1.1.2. Disadvantages of Wind Energy

There are also several different disadvantages of wind energy as shown below:

- **Source availability can change:** If the wind speed decreases, in the same way, the efficiency of the wind turbines will decrease relatively. Just as the decreasing wind speed is a problem, increasing wind speed is also a big and important problem. Because wind turbines will operate if the wind speed is between and including 3 and 8 in the Beaufort scale [11].

- **The initial investment cost is high:** While wind power costs have fallen dramatically over the past 10 years, the technology needs an initial investment which is still considerably higher than fossil-fueled generators [16].

- **A threat to wildlife:** Spinning turbine blades cause the death of the birds [16].

- **Noise and visual pollution:** Although the impacts of the wind turbines on the environment is relatively less compared to conventional power plants, the noise produced by the turbine blades and visual impacts of the wind turbines to the landscape is still a pending problem [16].

1.2. Solar Energy

Solar energy is very powerful energy produced by the fusion reaction that converts hydrogen gas in the nucleus of the sun into helium [20]. To benefit from this kind of energy that comes to our world through solar radiation, technologies such as solar collectors, solar power plants, and solar cells (photovoltaic batteries) have been developed [20].

Annually, the amount of 3.9×10^{24} J = 1.08×10^{18} kWh solar energy reaches the Earth's surface [11]. It's approximately ten thousand times more than the world's total energy needs per year and much more than all other energy reserves on earth [11]. In other terms, only one ten-thousand of the incoming sunlight covers humanity's entire energy demand [11]. Therefore we can say that the biggest energy source is the sun. From Figure 1, it can be seen how big the energy coming from the sun is.

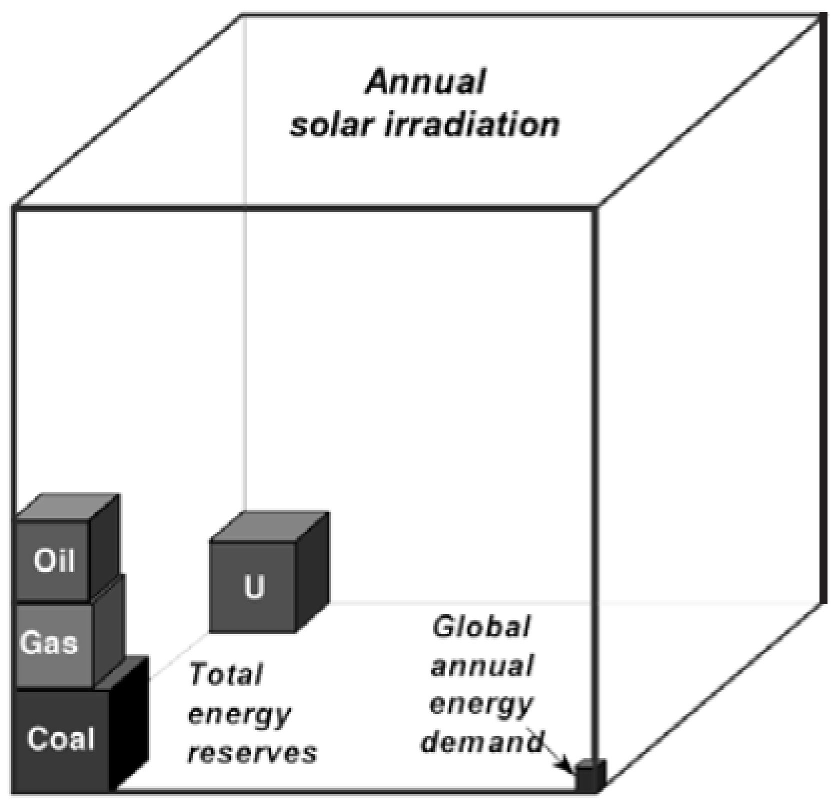


Figure 1 – Illustration of Energy Reserves, Annual Energy Demand, and Solar Radiation [11]

The direct use of solar energy can be analyzed in two parts: solar thermal and solar photovoltaic [11].

1.2.1. Solar Thermal

In general, solar thermal stands for the thermal use of solar energy [11]. The key principle of solar thermal processing is the transformation of short wave solar radiation to heat [19]. With this method, solar energy is focused using various focusing systems and by using conventional methods, energy production is carried out from the superheated steam at high temperature, and heat can be used both directly or can be used to generate electricity [21]. The main usage areas of solar thermal like below [11]:

- Solar swimming pool heating
- Solar domestic water heating
- Solar low-temperature heat for space heating in building
- Solar process heat
- Solar thermal electricity generation

1.2.2. Solar Photovoltaic

The term “photovoltaic” is composed of two words “Photo” and “Volta” which “Photo” means light (Greek phos, photos: light) and “Volta” (Count Volta, 1745–1827, Italian physicist) means the electricity voltage unit [11]. Photovoltaic (PV) means, in other words, the direct transformation of sunlight into electricity [11].

The history of solar photovoltaic goes back to 1839 when the photo effect was invented by Becquerel [11]. However, the technology at that time was not well developed enough to make this invention usable [11]. About 100 years later, the semiconductor era began with a model developed by Shockley for the p-n junction. After all, in 1954, the first solar cell was produced by Bell Laboratories [11]. Over the years, the efficiency of solar panels has continuously increased. It was about 5 percent in 1954 but now it’s around 25 percent for laboratory silicon solar cells [11].

To generate electricity from solar energy, photovoltaic cells are used and these cells work according to the photovoltaic principle [21]. This principle is based on the principle that when the sunlight falls on the photovoltaic cells, it generates an electrical voltage at the poles of the cells [21]. In other words, a photovoltaic cell that acts as a semiconductor diode converts the energy carried by sunlight into electrical energy directly by taking advantage of the photoelectric reaction [21].

The efficiency of solar energy is determined by the structure of the photovoltaic cells [21]. Many photovoltaic cells are mounted on a surface by connecting in parallel or in series, thus achieving power levels from several watts to hundreds of megawatts [21]. As can be seen in Figure 2, DC electrical energy produced by solar cells is stored with the help of the equipment such as charge regulator and battery [21]. With the inverter and other additional equipment, DC is converted to AC and prepared for electrical energy consumption [21].

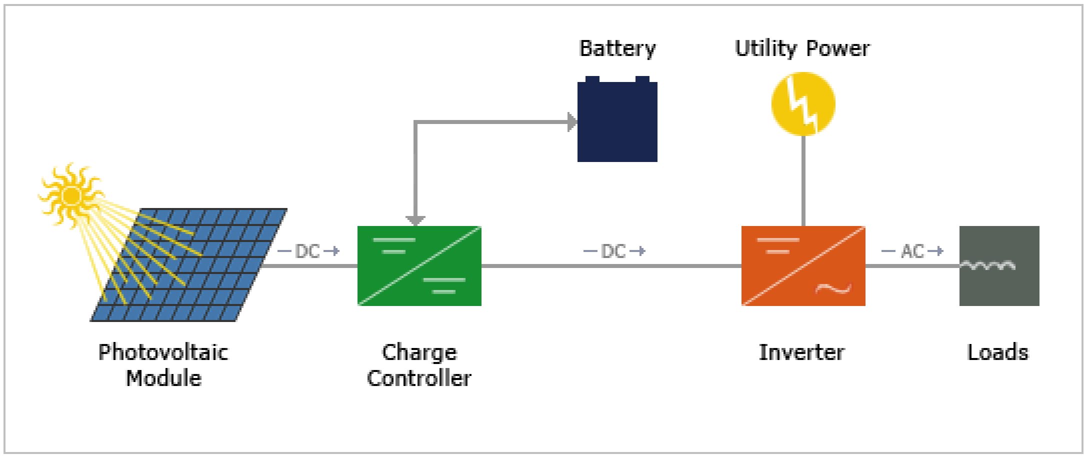


Figure 2 – Illustration of Electricity Generation from Solar Photovoltaic [22]

1.2.3. Advantages and Disadvantages of Solar Energy

There are several different advantages of wind energy as shown below. These advantages are mainly the same as wind energy. Therefore the features will be listed but details will not be mentioned here as it was mentioned above.

- **Renewable, sustainable and environment-friendly**
- **It reduces fossil fuel consumption and free**
- **It provides electricity to remote locations**
- **It increases energy security**
-

However, there are several different disadvantages of wind energy as well. Some of them are the same as wind energy. Therefore for them, the features will be listed but details will not be mentioned here as it was mentioned above. These disadvantages can be listed below:

- **Source availability can change**

- **The initial investment cost is high**

- **Some toxic materials:** Some toxic substances and chemicals are used for the production of photovoltaic (PV) cells [23]. Some solar thermal systems use liquids in heat transfer which can be harmful to the environment [23].

- **Large areas for installation:** Large areas that are cleared to build solar panels are damaging the plant and animal ecosystem living in that area in the long term [23].

1.3. Geothermal Energy

The word geothermal is a combination of the Greek words geo (world) and thermal (heat) [24]. Geothermal energy uses the internal heat of the earth and geothermal power stations use that geothermal heat to convert it into electricity or to supply it with district heating [11]. In other words, It is a hydrothermal mass consisting of water and steam, which are located at various depths of the Earth's crust and whose temperature is generated by the water fed from the basins on the earth, and which contains mostly dissolved mineral salts and gases [11].

In the 99.9 percent of the interior of the Earth, the temperature is greater than 100° C [25]. Therefore geothermal energy has a huge potential as a renewable energy source [25]. In Figure 3, it can be seen how geothermal energy is produced. First of all, by using the injection well, the water is pumped to the reservoir which is between impermeable bedrock and impermeable caprock [26]. Some of this water rises along the fault lines and reaches to the earth and forms hot spring or fumarole wells [26]. The geothermal water in the reservoir, which is surrounded by an impermeable caprock and which can not be reachable from the surface, is brought to the surface by geothermal drilling works [26]. In the generating unit, the geothermal steam which comes from reservoirs rotates a turbine to produce electricity [28].

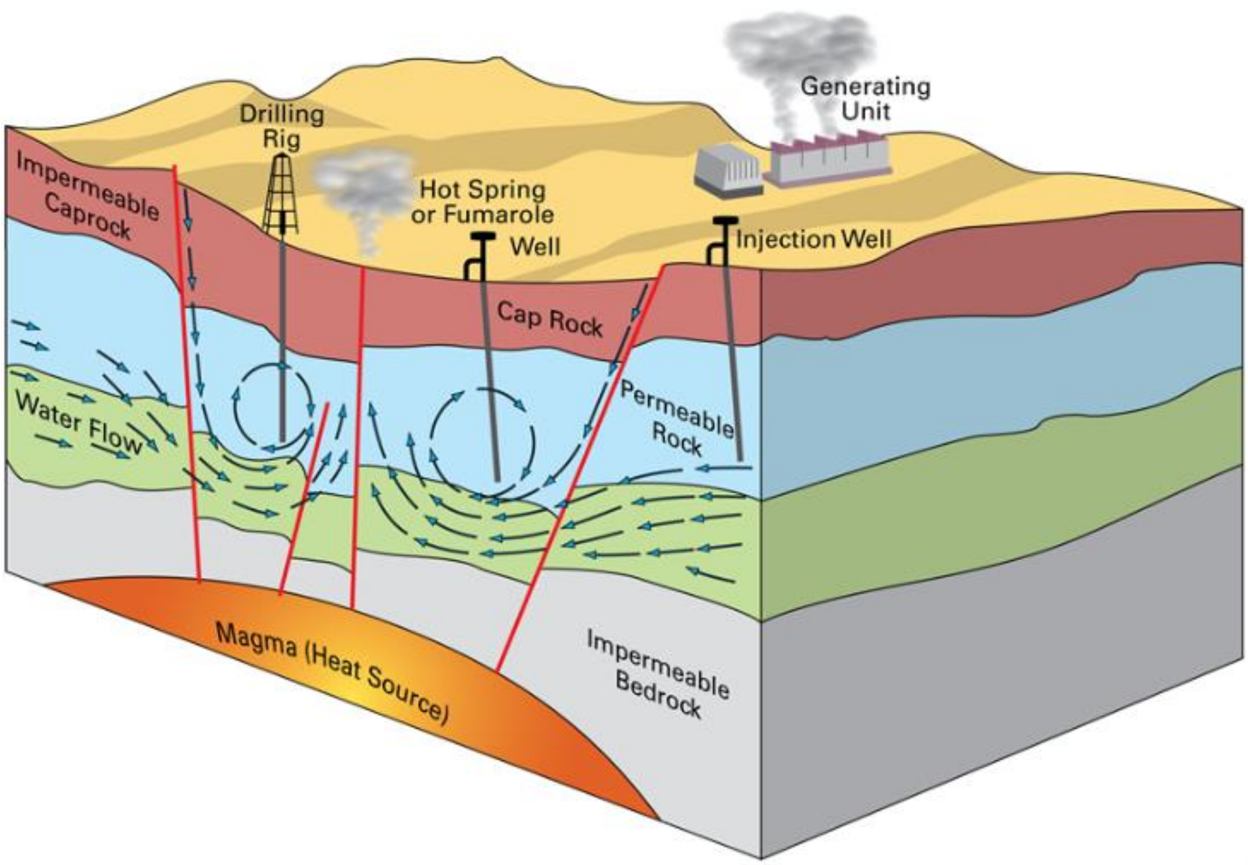


Figure 3 – Illustration of Electricity Generation from Geothermal Energy [25]

The usage areas of geothermal energy are not only limited to generating electricity. Some additional usage areas can be listed below.

- Vegetables, fruit growing, and floriculture is carried out by heating the greenhouses with geothermal energy in various countries of the world [24].
- The geothermal energy is used in central heating systems for space heating [29].
- In many countries of the world, there are thermal cure centers, spa centers, and hot springs that use geothermal resources [29].
- Geothermal energy is used by many countries for agricultural crop drying [29].
- Geothermal energy is also used for snow melting processes very limitedly in Switzerland, Iceland, the United States, Japan, and Argentina [29].

1.4. Ambient Energy

According to Statistics Finland, ambient energy refers to "energy extracted with heat pumps from the environment (ground, air or water) for space heating" [27]. Heat pump systems are heat-generating devices which can provide heated water that can be used in either domestic hot water or space heating applications [30]. There are mostly used two types of heat pumps: Heat pump water heater and ground source heat pump.

Since the 1950s, several kinds of research have been made about heat pump water heater's (HPWH) structure, thermodynamics, operation, controlling, simulation, and economic feasibility [30]. HPWH is one of the promising technologies that operate on the same principle as refrigerators and air conditioners [30]. Just as refrigerators take the heat from the interior of the refrigerator and release it to the kitchen, heat is taken by the HPWH from the environment to heat the water [30].

In figure 4, it can be seen the basic working principle of a heat pump. Firstly, heat is taken from the ambient air by the HPWH and is put in a water storage tank [30]. Now the remaining exhaust air is cooler than the source air [30]. Therefore, the location of HPWH is very important for the building's energy use [30]. For an HPWH, it is easier to heat the water to 60° C, if the ambient air is 20° C than if it is 2° C [30]. If the temperature of the ambient air drops down a limit value (which is typically 0° C but also depends on the specific features of HPWH), the heap pump will not be able to heat the water enough and an additional electrical heating device will be needed [30].

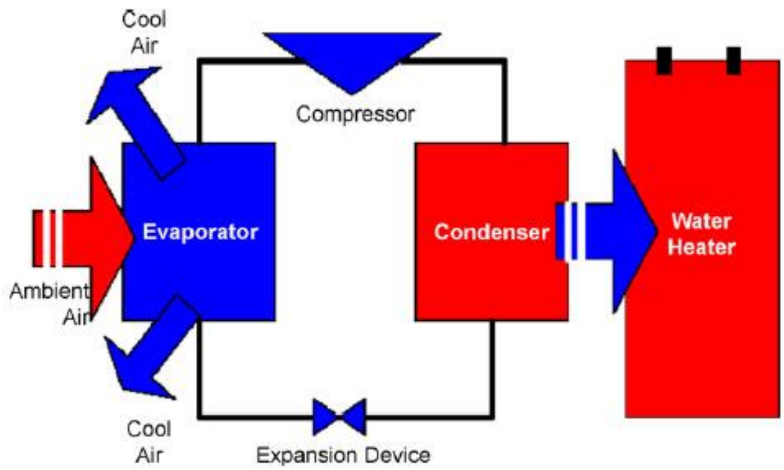


Figure 4 – Working Principle of a simplified HPWH System [30]

As an ambient energy source, HPWH is not the only option to use. The ground source heat pump (GSHP) is also a common usage of heat pumps. The ground source heat pump is basically a group of systems for transferring the heat between the heat pump and ground. As shown in Figure 5, water is sent to the underground by the help of borehole and that water is heated with the underground temperature [31]. In Figure 5, it can be seen as an example of GSHP for a house [31].

There are several different advantages of heat pumps as shown below:

- Heat pumps are much safer than the classical systems which are based on burning [32, 33].
- Operating costs of heat pumps are lower than in some other systems [32, 33].
- Heat pumps are renewable energy systems and reduce carbon emissions [32, 33].

However, there are several different disadvantages of heat pumps and these are the main reasons why heat pump systems are not so common all over the world:

- For a heat pump, initial investment costs are higher than any other system [32]
- Installation of heat pumps requires too much construction work at home and in the garden (for GSHP) [32, 33]
- For circulation, heat pumps need electricity and for a backup system, again they need an additional alternative heating device (photovoltaic, electric boiler) [32, 33]
- In very cold areas, the efficiency of the heat pump will not be high [33]
- Some special permission will be needed for ground digging [33].

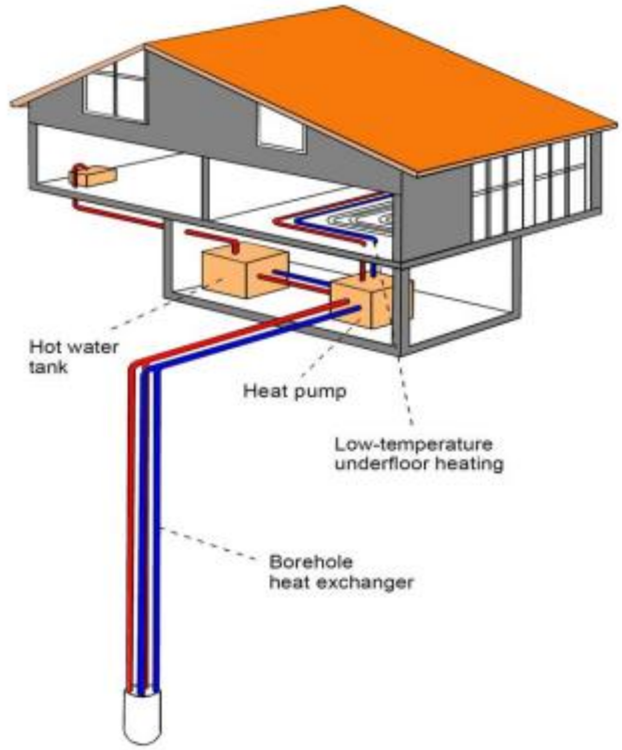


Figure 5 – An example of GSHP for a house [31]

1.5. Tide, Wave and Other Ocean Energy

According to the Australian Renewable Energy Agency, ocean energy refers to "all forms of renewable energy derived from the sea" [34]. According to the International Energy Agency, there are different forms of ocean energy which is still under development phase for commercial use [35].

Ocean energy has a small share in the world for generating electricity from renewable energy and most of the ocean energy technologies are still under development phase for commercial use [34, 35]. These ocean energy technologies can be listed below: [35]

- Tidal power: Tide energy which is a form of potential energy can be utilized by constructing a dam or a dam-like construction [35].
- Tidal (marine) currents: Tidal marine currents that provide kinetic energy can be utilized by constructing modular systems [35].
- Wave power: Wave power which contains both potential and kinetic energy can be utilized by constructing different types of systems [35].
- Temperature gradients: The temperature difference between the surface of the sea and deep of the sea can be used to produce energy by different ocean thermal energy conversion (OTEC) technologies [35].

- Salinity gradients: In the river mouths, where river water and seawater are mixed together, salinity gradients associated energy can be used by pressure based reverse osmosis process [35].

Energy flows in ocean energy projects are changeable due to source availability but it's also highly predictable [35]. Nearly none of the technologies which we listed above are implemented yet and there are significant challenges in terms of engineering in obtaining ocean and wave energy [35]. One of the most important challenges is that the systems produced must be suitable for operation under difficult conditions [35]. One other problem is that these systems should not be a threat to the sea and ocean life, environment, and users (like fishing and shipping industry) [35].

1.6. Hydropower

One of the most widely used renewable energy sources is hydropower [20]. Using hydropower to produce energy goes back centuries [11]. Firstly, people used watermills to convert hydropower into mechanical energy [11]. Then, electricity production from hydropower began in the late 19th century, with the improvements in techniques [11].

The most common use of this energy is to build dams on rivers, to collect water in the reservoir, and to generate electricity in the turbine by utilizing the potential energy of the accumulated water [20]. Hydroelectric power plants are used for this purpose. In a country, the hydroelectric potential determined based on the assumption that all natural flows to the borders of the country or the seas can be usable with 100% efficiency is the gross theoretical hydroelectric potential of that country [20]. However, this is a theoretical potential that cannot be fully feasible [20].

The working principle of a traditional dam can be seen in Figure 6. The water is held in an artificial lake or reservoir behind a traditional dam [36]. When the doors of the reservoir that hold the water are opened, the turbine starts to spin and the generator which is connected to the turbine produces electricity [36]. Finally, the water returns to the river from below part of the dam [36]. The efficiency of hydroelectric power plants is high enough to reach 90 percent and above easily [11]. Since the actual efficiency of hydroelectric power plants is hard to estimate during power plant operation, some approaches define output as primary electricity and reach 100 percent efficiency [11].

There are several different advantages of hydropower as shown below:

- With hydropower, electricity can be generated without carbon emissions and at low costs [11].

- In addition to being renewable and reliable energy, hydropower offers many advantages like irrigation, flood control, and water supply [37].

- Created reservoirs may provide many recreational opportunities like swimming, boating, and fishing [37].

- Hydroelectric power plants can easily reach maximum power from zero and these features make them an efficiently working backup system [37].

On the other hand, there are also negative impacts of hydropower as shown below:

- Usually, People's habitats are located near water resources. Therefore, if a hydroelectric power plant is to be built, the people who are living in that area, have to relocate [11].

- Constructing a dam or reservoir can cause water to be cut off from some rivers and this leads to the termination of natural irrigation activities for agricultural purposes [11].

- Artificial irrigation activities due to the termination of natural irrigation activities for agricultural purposes, together with the salinity of the soil, leads to a decrease in yield [11].

The advantages and disadvantages should be well evaluated before building a large hydropower plant and obviously, large hydroelectric power plants will have more negative impacts [11]. It may be an option to build small hydroelectric power plants in this regard, but they also have much higher relative costs [11].

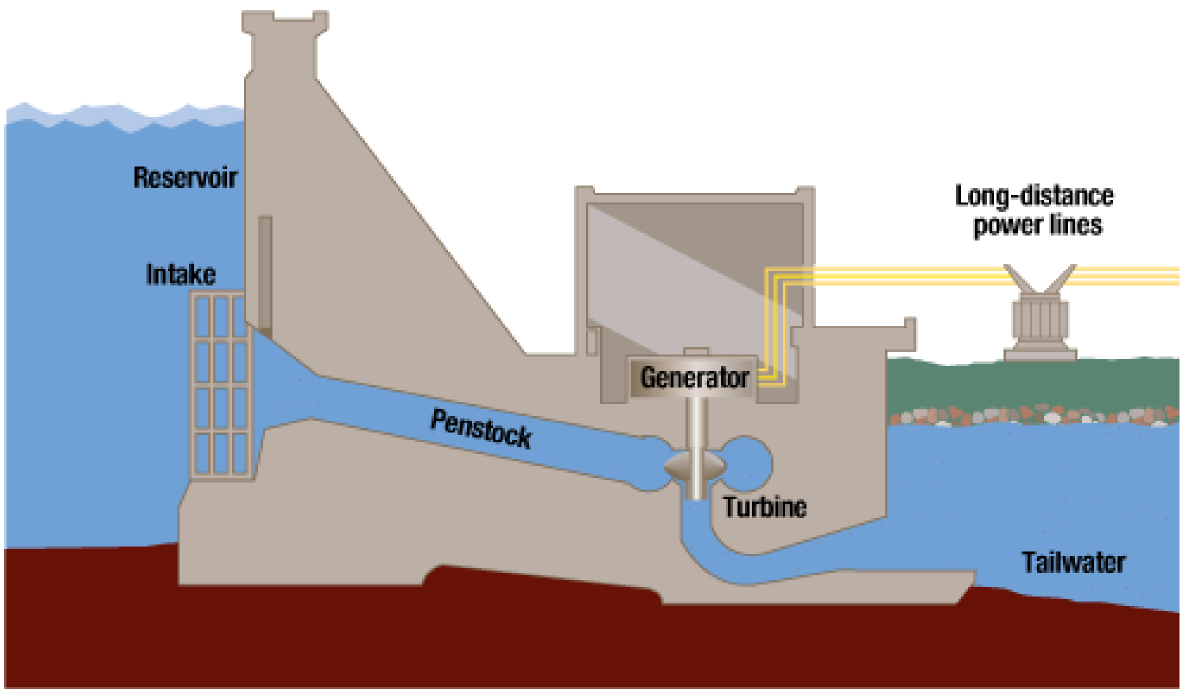


Figure 6 – Generating electricity by using hydropower plant [36]

1.7. Biomass

Agricultural and forestry products and many different crops specially produced for energy production are used as biomass resources for the generation of electricity [10]. Biomass emits carbon dioxide when it is burned to produce energy, but it absorbs carbon dioxide in the air as it grows [10]. Therefore, the process of growing and burning the biomass to generate energy, causes very low or zero carbon emissions, and therefore, it’s considered renewable energy [10].

Like most renewable energy, biomass energy is dependent on various types of biomass as feedstock [10]. Therefore, accessibility and price are key elements for the economically sustainable biomass technologies [10]. Agricultural, industrial and municipal wastes are very important sources of biomass because of their low or zero cost [10]. However, it will not take much time to develop new technologies to reduce these economically attractive waste products [10]. The long-term sustainable solution is to grow energy crops such as trees and grasses that grow efficiently and quickly for use in energy production [10].

Biomass contains the energy which is obtained through the photosynthesis process from the sun [38]. Biomass is can be used in two ways: it can be burned directly or can be converted biofuels such as ethanol and biodiesel or biogas that can be used as fuels [38]. Fuels such as bioethanol, biodiesel, and biogas are obtained by using biomass energy sources [20]. Bioethanol and biodiesel are a type of fuel produced using various plants or animal fats [20]. Biogas is a gas containing mainly methane and carbon dioxide as a result of the fermentation of organic substances (vegetable and animal wastes, urban and industrial wastes) in an oxygen-free environment [20].

Biomass resource types and usage areas can be seen below:

- Wood or wastes of wood products: By burning, it can be used to heat buildings, to produce heat for industry and to generate electricity [38].
- Agricultural crops and waste materials: It can be used as fuel by burning or can be converted to biofuels [38].
- Food, yard, and wood waste in the garbage: It can be used to generate electricity by burning in power plants or can be converted to biogas [38].
- Animal droppings and human sewage: It can be used by converting biogas [38].

The advantages of biomass can be listed below:

- Biomass is almost carbon neutral due to the photosynthesis process [10].

- It decreases the amount of garbage in landfills and helps us to have a cleaner environment [39, 40].

- Biomass is a common energy source and it can be obtained from forestry, agriculture, fishery, aquaculture, and waste [40].

On the other hand, there are also disadvantages of biomass as shown below:

- If it's not controlled properly, biomass may cause deforestation [39].

- There is a seasonal and regional variation of biomass resources and storage problems [40].

- Wood smoke contains environmentally polluting substances such as carbon dioxide and some physical particles [39].

- Biomass plantation deletes useful nutrients from the soil, increases degradation, and damages biodiversity [40].

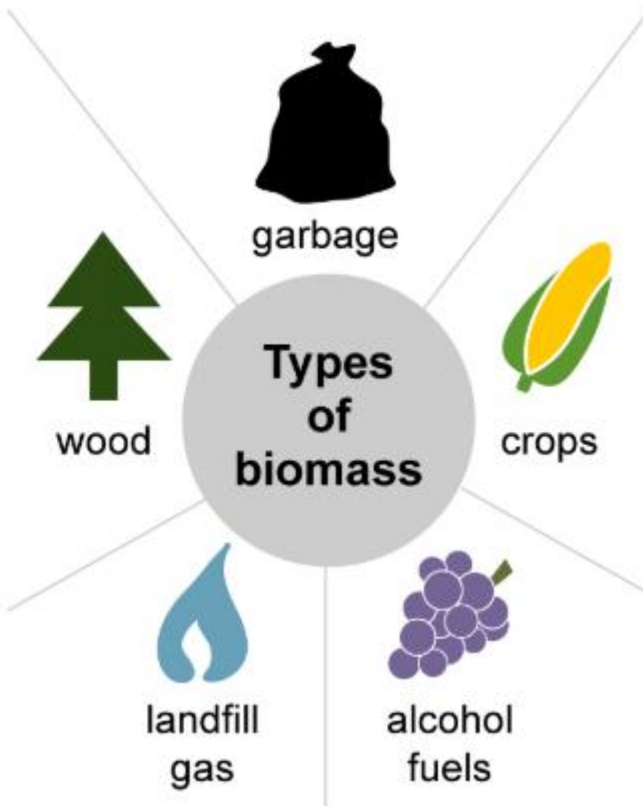


Figure 7 – Sources of Biomass [38]

1.8. Landfill Gas, Sewage Treatment Gas and Biogas

Biogas production can be held during anaerobic digestion of organic substrates like sewage, manure, and the organic fractions of domestic and industrial wastes [41]. Biogas produced during anaerobic degradation in landfills also named landfill gas [41]. Therefore, I will use the term biogas in general, including landfill gas and sewage treatment gas.

Biogas is mainly composed of methane and carbon dioxide and as a renewable energy source, the main usage areas of it are combined heat and power plants, substitution for vehicle fuel, and natural gas. [41]. In addition, methane gas in biogas is used as raw material in industrial processes [41].

Table 2 – Composition of Biogas, Landfill Gas and Natural Gas [Data retrieved from [41]]

Compounds	Biogas	Landfill Gas	Natural Gas Standard (Danish)	Natural Gas Standard (Dutch)
Methane (vol-%)	60–70	35–65	89	81
Other hydro carbons (vol-%)	0	0	9.4	3.5
Hydrogen (vol-%)	0	0-3	0	–
Carbon dioxide (vol-%)	30– 40	15– 50	0.67	1
Nitrogen (vol-%)	~0.2	5– 40	0.28	14
Oxygen (vol-%)	0	0-5	0	0
Hydrogen sulphide (ppm)	0–4000	0 –100	2.9	–
Ammonia (ppm)	~100	~5	0	–
Lower heating value (kWh/Nm^3)	6.5	4.4	11	8.8

There are various and different biogas processing techniques according to the intended use [41]. In cases where high energy is required in the content of the gas, such as gas supply to the grid or using gas as a vehicle fuel, biogas upgrading is needed [41]. The energy content of the biogas is directly related to the amount of methane gas in it and with the biogas upgrading process, the energy content of the gas is increased by removing the carbon dioxide from the biogas [41].

It can be seen in Table 2, the composition of biogas, landfill gas, and the standards of Danish and Dutch natural gas [41]. As can be seen, one of the biggest differences between biogas and natural gas is the amount of carbon dioxide in its content [41]. While carbon dioxide is found very little in natural gas, it is one of the most abundant gases in biogas and there are also other hydrocarbon gases other than methane in natural gas [41]. All these differences cause the energy content of the biogas to be less than natural gas [41].

There are different technologies for biogas upgrading. But the main logic is the same in all methods. The aim is to clean unwanted particles such as nitrogen, hydrogen sulfide, oxygen, and water [41]. These different methods can be listed as follows:

- **Pressure Swing Adsorption (PSA):** With this method, carbon dioxide is separated from the biogas by adsorption on a surface under high pressure [41].

- **Water Scrubbing:** The solubility of carbon dioxide in water is more than methane and this feature is used in the water scrubbing method [41].

- **Organic Physical Scrubbing:** This method is very similar to the water scrubbing method and the only difference is that an organic solvent such as polyethylene glycol is used instead of water [41].

- **Chemical Scrubbing:** In addition to the absorption of carbon dioxide in the liquid, it also reacts with the amine in the liquid, and in this method, chemical scrubbers use solutions of amine [41].

- **Membrane Separation:** The membrane separation method is based on the principle of diffusion of gases from membranes at different speeds [42]. Different types of polymers can be used as membranes [42].

The advantages of biogas can be listed below:

- It releases much less methane gas to the air compared to traditional landfill and manure management methods [41].

- Biogas can be used instead of fossil fuels [41].

- During biogas production, a high-quality digestive product is also produced which can also be used as fertilizer [41].

The disadvantages of biogas can be listed below:

- Biogas processing technologies have not been improved enough [43].

- Although biogas goes through many purification processes, there are still impurities in it [43].

- Large capacity biogas production is not economically feasible [43].

2. Renewable Energy in the European Union

Energy and environment-related topics are the subjects of several programs and initiatives by the European Union [44]. Climate change, the future of carbon emissions, and sustainable development have been the most important issues that the European Union [44]. The European Union has therefore set some legislation and objectives to fulfill future goals [44].

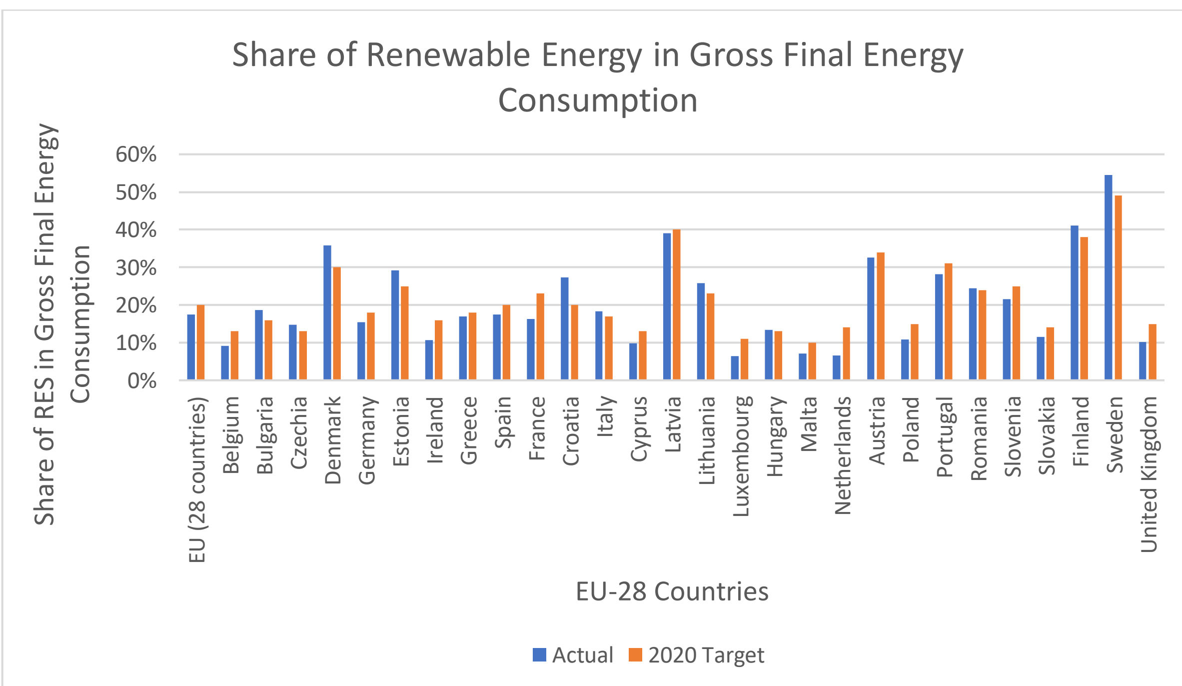
The energy and environmental policy development of the European Union is a set of continuous processes [44]. In 2011, European Commission declared “The Resource Efficiency Roadmap” which is part of the “Resource Efficiency” flagship of the “Europe 2020 Strategy” which contains a set of long-term strategic plans in fields like energy, transport, and climate change [44, 45]. According to the Europe 2020 Strategy, European countries have committed themselves to reduce their greenhouse gas emissions by 20 percent, to increase the share of renewable energy in the European energy mix to 20 percent, and to increase energy efficiency by 20 percent by 2020 [44].

According to the Eurostat 2017 data, European countries have increased the share of renewable energy in the EU energy mix to 17.5 percent [46]. As of 2017, it can be seen in Graph 2, how much the 2020 targets of European Union countries have been met. Bulgaria, Czechia, Denmark, Estonia, Croatia, Italy, Lithuania, Hungary, Romania, Finland, Sweden have achieved their individual 2020 targets, while Belgium, Germany, Ireland, Greece, Spain, France, Cyprus, Latvia, Luxembourg, Malta, Netherlands, Austria, Poland, Portugal, Slovenia, Slovakia, United Kingdom have not [46].

In October 2014, The 2030 Climate and Energy Framework was adopted by the European Council [47]. The framework includes the targets and policies between 2021 and 2020 [47]. The targets for 2030 are:

- 40 percent decrease in greenhouse gas emissions (from 1990 levels) [47]
- 32 percent share of renewable energy in European energy mix [47]
- 32.5 percent increase in energy efficiency [47].

As seen above, the renewable energy target from 20 percent for 2020 has been increased to 32 percent for 2030.



Graph 2 – Share of Renewable Energy in Gross Final Energy Consumption [Data retrieved from [46]]

2.1. Why Renewable Energy?

The need for energy resources in the world continues to increase day by day. Especially in developing countries, demand for energy will be higher in the coming years in parallel with population growth, industrialization, increasing welfare of people and technological developments [48]. Interest in renewable energy sources has increased due to the fact that fossil energy sources cause serious environmental problems in the world, that their reserves will be run short in the near future, the dependence on imported countries causes various political and economic problems and price instability [48]. With renewable energy, not only will the energy dependency disappear, but a sustainable world will be left to future generations. For all these reasons, European countries have also set renewable energy targets as I mentioned previously and started to increase the RES investments to achieve these targets as soon as possible.

As I mentioned in the first part, especially in developed countries, renewable energy sources such as hydropower, wind, geothermal, solar, biomass, wave, biogas, etc. are started to be used in various ways, especially in electricity production [48]. Despite all these developments in Europe, the superiority of fossil energy resources in the world's primary energy consumption continues unarguable [48]. Therefore, not only in Europe but all over the world, steps need to be taken to increase the share of renewables to provide sustainable development.

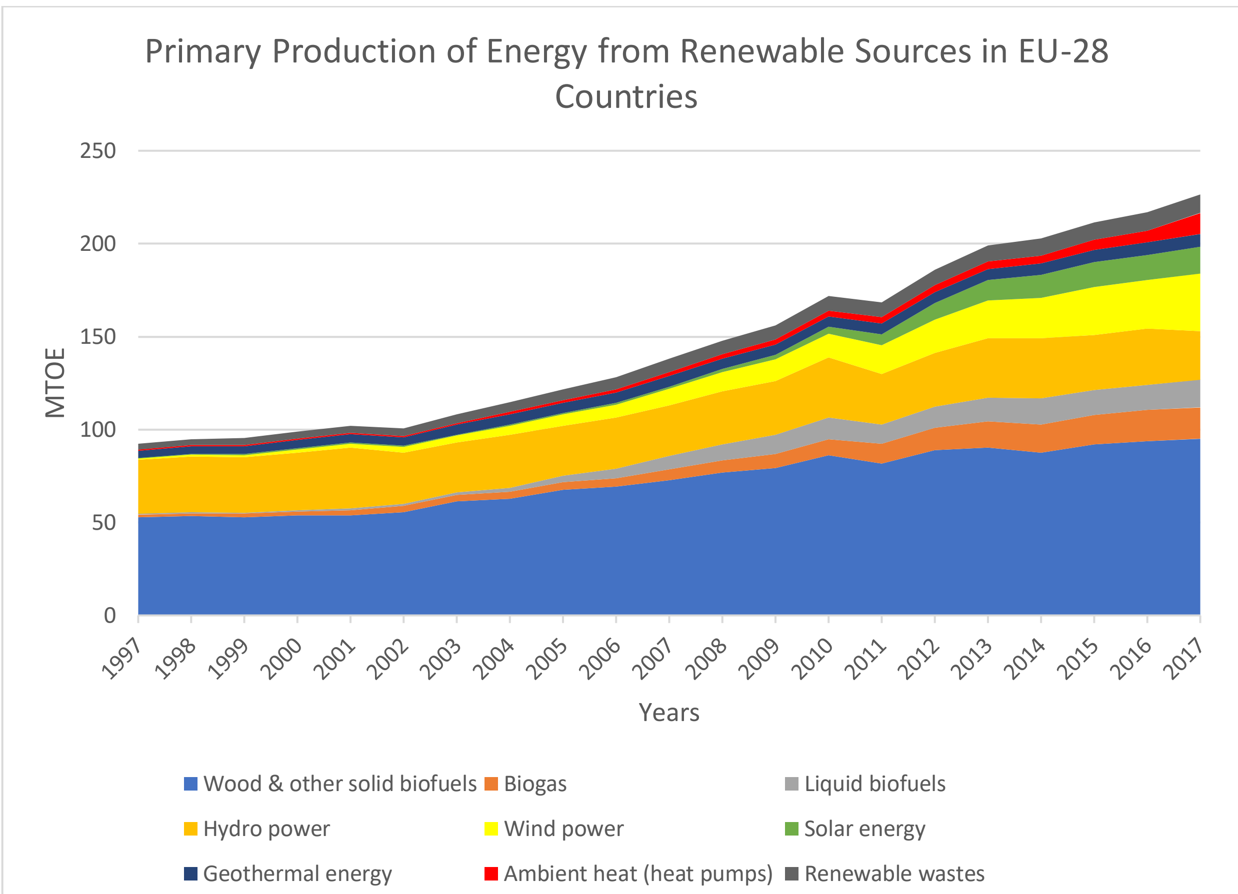
2.2. Main Renewable Energy Sources and Energy Shares of the European Union

As can be seen from Graph 3, all renewable energy sources more or less are used in the European Union. The primary production of renewable energy in EU-28 in 2017 has been increased to 226.5 MTOE [49]. The amount of energy produced in the EU-28 increased overall by 64 percent last 10 years [49].

Table 3 – Primary Production of Energy from RES in the EU-28 in 2017 [Data Retrieved from [49]]

Renewables	Primary Production of Energy from RES in the EU-28 in 2017 (Mtoe)
Wood & other solid biofuels	95.0
Biogas	16.8
Liquid biofuels	15.1
Hydropower	25.9
Wind power	31.2
Solar energy	14.4
Geothermal energy	6.8
Ambient heat (heat pumps)	11.2
Renewable wastes	10.1
Total	226.5

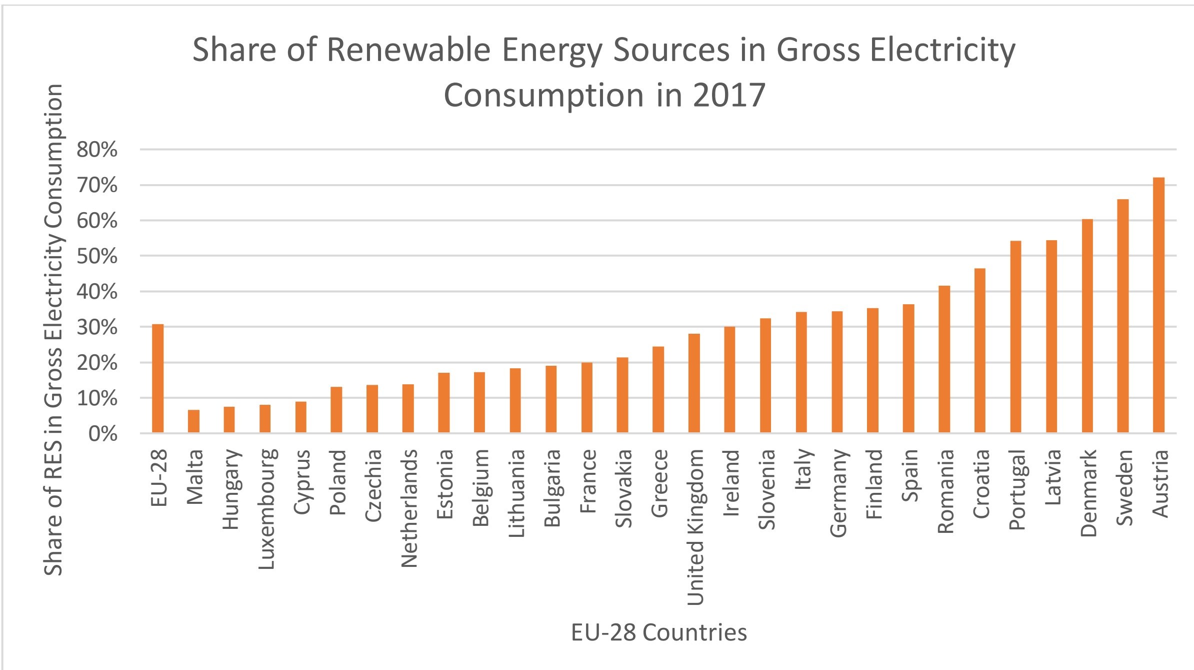
In 2017, the most widely used renewable energy in the EU-28 is wood and other solid biofuels in 2017 which is 42 percent of the primary production of renewable energy in EU-28 [49]. The second and third most widely used ones are respectively wind power and hydropower which are 13.8 and 11.4 percent of the primary production of renewable energy in EU-28. Although their contribution to production is relatively low, there has been a rapid increase in biogas, liquid biofuels, and solar power production. Biogas, liquid biofuels, and solar power account for 7.4, 6.7, and 6.4 percent of the EU-28's primary production of renewable energy. As can be seen from Graph 3, the amount of energy produced with ambient heat has also increased in recent years and the proportion in 2017 for ambient heat is 5 percent. It can be calculated the geothermal energy and renewable wastes' proportions as respectively 3 and 4.4 percent. The amount of energy produced with the tide, wave, and ocean is very low and these systems installed mostly in France and the United Kingdom [49].



Graph 3 – Primary Production of Energy from Renewable Sources in EU-28 Countries [Data retrieved from [46]]

In EU-28 countries, renewable energy is principally used in electricity generation, heating and cooling, and transport. In Graph 4, it can be seen the share of renewable sources in gross electricity consumption in 2017 among the EU-28 countries. According to data, 72.72 percent of Austria's gross electricity consumption, was obtained from renewable energy sources in 2017. Sweden has the second-highest share among the EU-28 countries in 2017 which is 65.9 percent, ahead of Denmark (60.4 percent), Latvia (54.4 percent), Portugal (54.2 percent), and Croatia (46.4 percent).

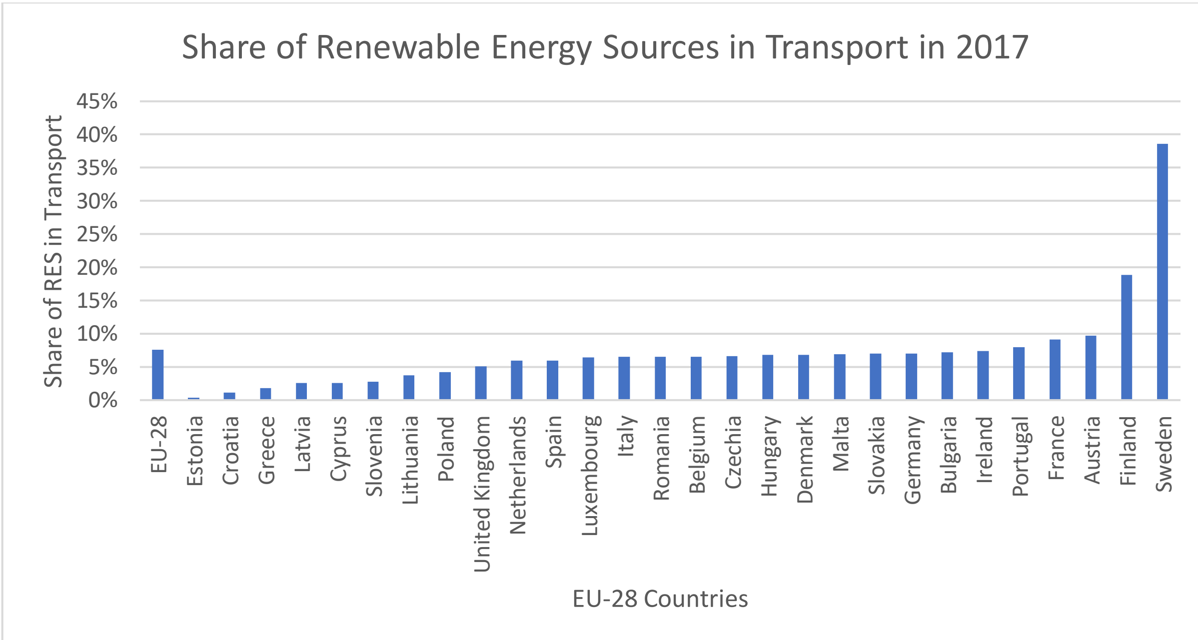
At the opposite end of Graph 4, there is Malta with the lowest share which is 6.6 percent. Hungary has the second-lowest share among the EU-28 countries in 2017 which is 7.5 percent, ahead of Luxembourg (8.1 percent), Cyprus (8.9 percent), Poland (13.1 percent) and Czechia (13.7 percent). The EU-28 countries' average share of renewable sources in gross electricity consumption in 2017 is 30.7 percent.



Graph 4 – Share of Renewable Energy Sources in Gross Electricity Consumption in 2017 [Data retrieved from [46]]

In Graph 5, it can be seen the share of renewable sources in transport in 2017 among the EU-28 countries. According to data, 38.6 percent of Sweden's transportation energy, was obtained from renewable energy sources in 2017. Finland has the second-highest share among the EU-28 countries in 2017 which is 18.8 percent and there is a big difference between first (Sweden) and second (Finland) highest shares. The third highest share is in Austria with 9.7 percent and again the difference between the second (Finland) and third (Austria) is significantly high.

At the opposite end of Graph 5, there are Estonia, Croatia, and Greece with respectively 0.4, 1.2, and 1.8 percent. One of the most important points here is that the share of renewable energy in transport in countries other than Finland and Sweden are low and between 5 and 8 percent in 16 countries. The EU-28 countries' average share of renewable sources in transportation in 2017 is 7.6 percent.



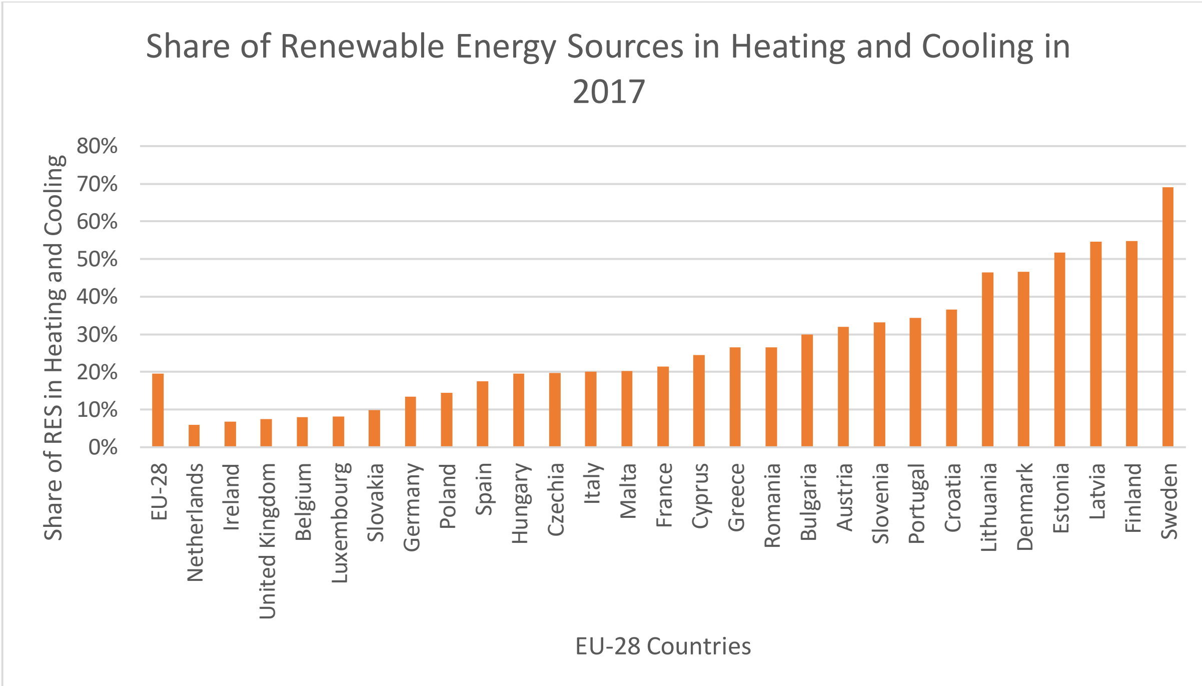
Graph 5 – Share of Renewable Energy Sources in Transport in 2017 [Data retrieved from [46]]

In Graph 6, it can be seen the share of renewable sources in heating and cooling in 2017 among the EU-28 countries. According to data, 69.1 percent of Sweden's heating and cooling energy, was obtained from renewable energy sources in 2017. Finland has the second-highest share among the EU-28 countries in 2017 which is 54.8 percent. Latvia has the third-highest share among the EU-28 countries in 2017 which is 54.6 percent, ahead of Estonia (51.6 percent), Denmark (46.5 percent), Lithuania (46.5 percent) and Croatia (36.5 percent).

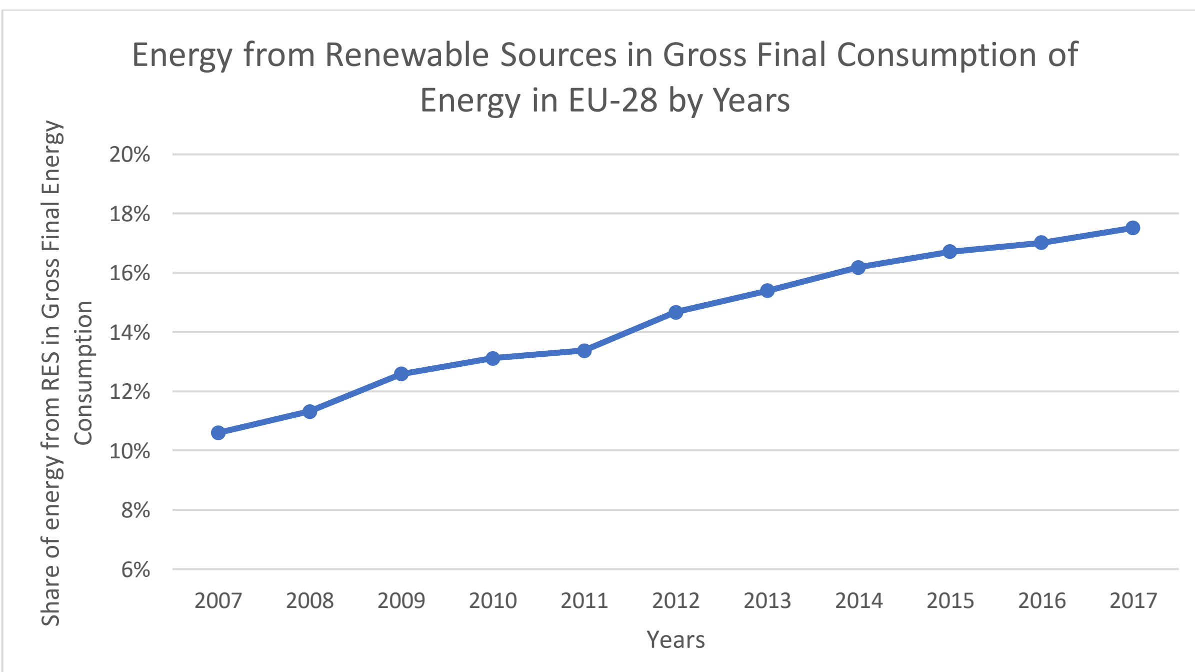
At the opposite end of the Graph 6, there are Netherlands, Ireland, and The United Kingdom with respectively 5.9, 6.9 and 7.5 percent. The EU-28 countries' average share of renewable sources in transportation in 2017 is 19.5 percent.

According to Graph 3, in the last 10 years, the primary production of energy from renewable sources in EU-28 countries increased every year except for the year 2010. The European Debt Crisis in 2010 may be the reason for not increasing. However, this graph only shows the amount of energy produced by renewables every year.

In Graph 7, it can be seen the development of the share of energy from renewable sources in the gross final consumption of energy in the EU-28 between the years 2007 and 2017. Unlike Graph 3, in Graph 7, it can be seen that the share of renewable energy sources in the gross final consumption of energy increased even in 2010. The reason for this is that the primary production of energy from renewable sources in EU-28 between 2010 and 2011 decreased while the energy demand also decreased. While energy consumption was 1098612.491 thousand tonnes of oil equivalent in 2010, it decreased to 1045569.746 thousand tonnes of oil equivalent in 2011 [50].



Graph 6 – Share of Renewable Energy Sources in Heating and Cooling in 2017 [Data retrieved from [46]]



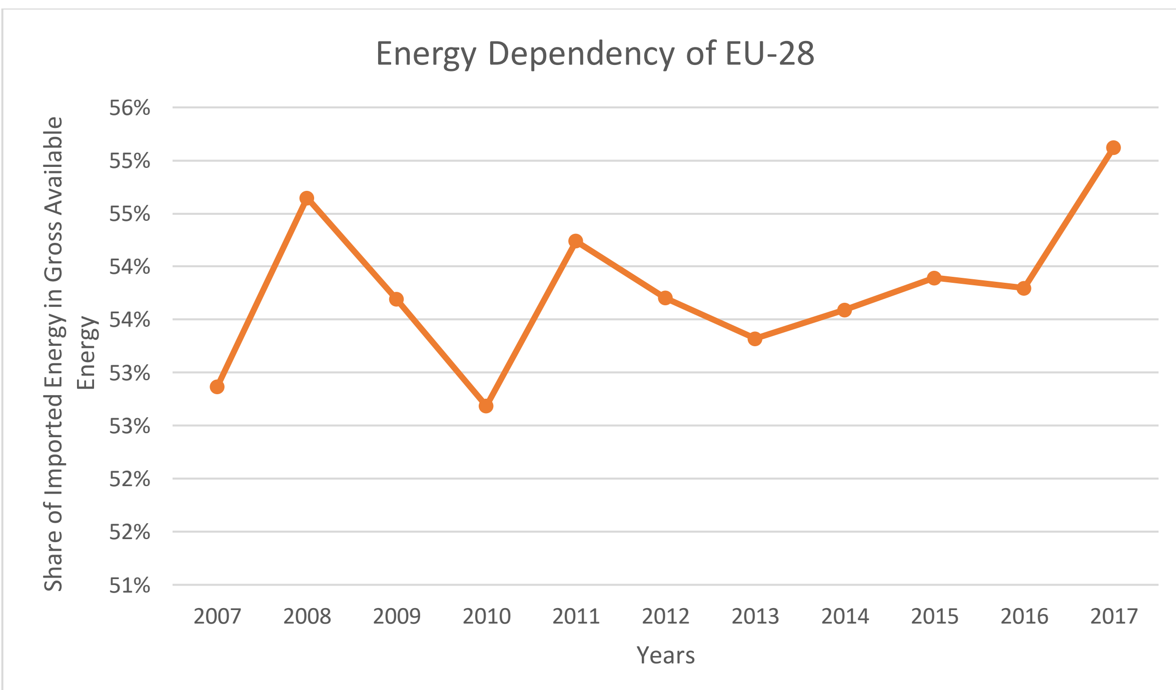
Graph 7 – Share of Renewable Sources in Gross Final Energy Consumption in EU-28 [Data retrieved from [50]]

3. Energy Dependency of the European Union

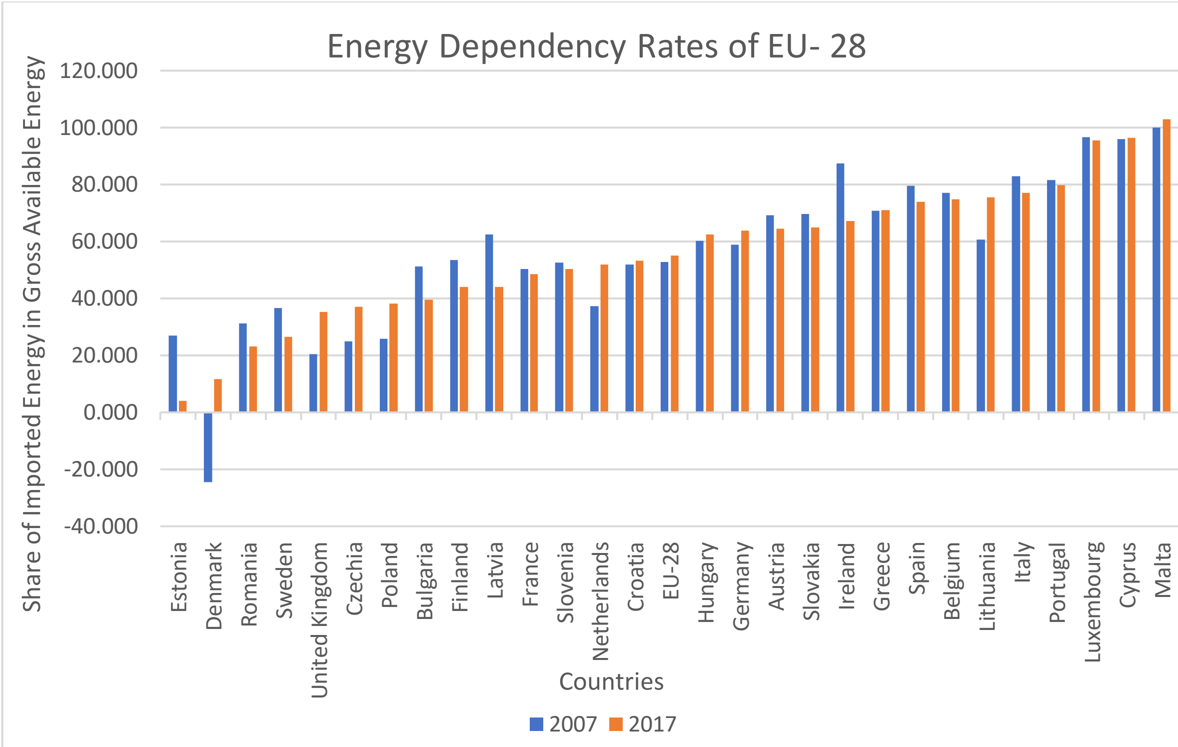
Energy resources are not equally distributed throughout the world. Some countries may be very rich in energy resources, while some other countries may not have enough energy resources. Besides, the population in the world is not evenly distributed. Therefore, the density of the population varies from country to country and therefore, some countries need to import energy. This is called energy dependency. According to the EU, the energy dependency rate shows "the proportion of energy that an economy must import" [4].

According to the Eurostat, as of January 1, 2019, the total population of the EU-28 countries was estimated to be 513.5 million, an increase of 1.1 million people over the previous year [51]. This means that the European Union will need more and more energy, but the European Union's non-renewable energy resources are not enough to cover it. Therefore, EU-28 has to import energy.

Graph 8 shows the European Union's energy dependency rates in the last 10 years. As can be seen, more than 50 percent of the gross available energy of the European Union was supplied from imported energy in the last 10 years and the energy dependency rate rose to 55.1 percent in 2017 which is the highest value [53].



Graph 8 – Energy Dependency of EU-28 [Data retrieved from [52]]



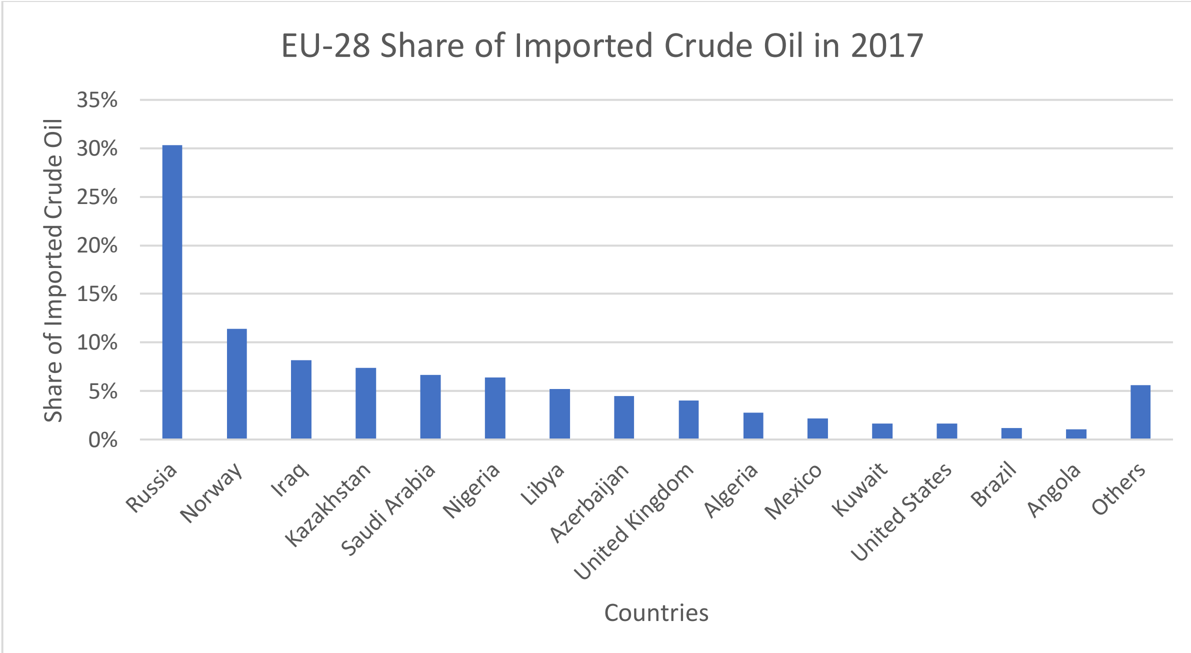
Graph 9 – Energy Dependency of EU-28 Countries [Data retrieved from [52]]

Graph 9 shows the EU-28 countries' energy dependency rates for the years 2007 and 2017. As can be seen from Graph 9, energy dependency of 12 countries including Denmark, United Kingdom, Czechia, Poland, Netherlands, Croatia, Hungary, Germany, Greece, Lithuania, Cyprus, and Malta has increased and energy dependency of 16 countries including Estonia, Romania, Sweden, Bulgaria, Finland, Latvia, France, Slovenia, Austria, Slovakia, Ireland, Spain, Belgium, Italy, Portugal, and Luxembourg has decreased.

3.1. Energy Import of the European Union

In the previous part, we saw that more than 50 percent of the gross available energy of the European Union was supplied from imported energy in the last 10 years [53]. Here I will try to analyze, from which countries the European Union is importing energy and the extent of imports. Because the stability of the European Union's energy supply can be threatened by high levels of energy imported from a few partner countries [54].

The main energy product imported in 2017 was petroleum products (including crude oil as the main component), which is about two-thirds of the energy imported into the EU-28 [54]. Graph 10 shows the EU-28 crude oil import shares by partner countries for the year 2017. As can be seen, In 2017, almost two-thirds of the EU-28's crude oil was imported from Russia (30.4 %), Norway (11.4 %), Iraq (8.2 %), Kazakhstan (7.4 %) and Saudi Arabia (6.6 %).

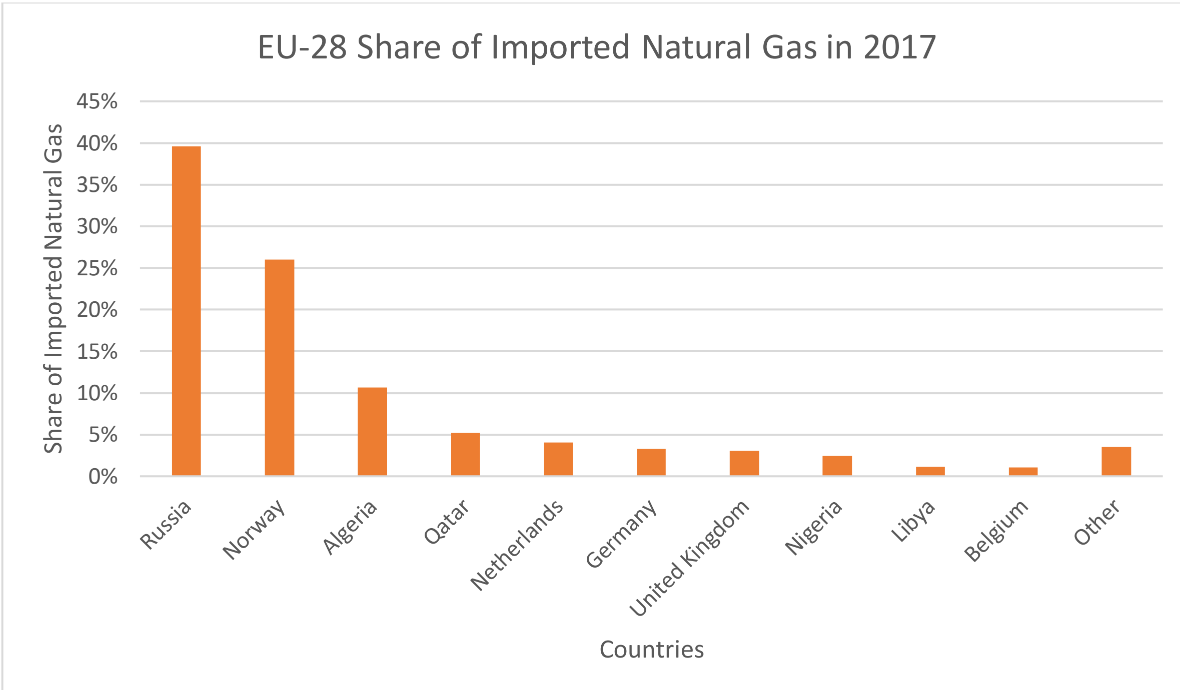


Graph 10 – EU-28 Share of Imported Crude Oil in 2017 [Data retrieved from [55]]

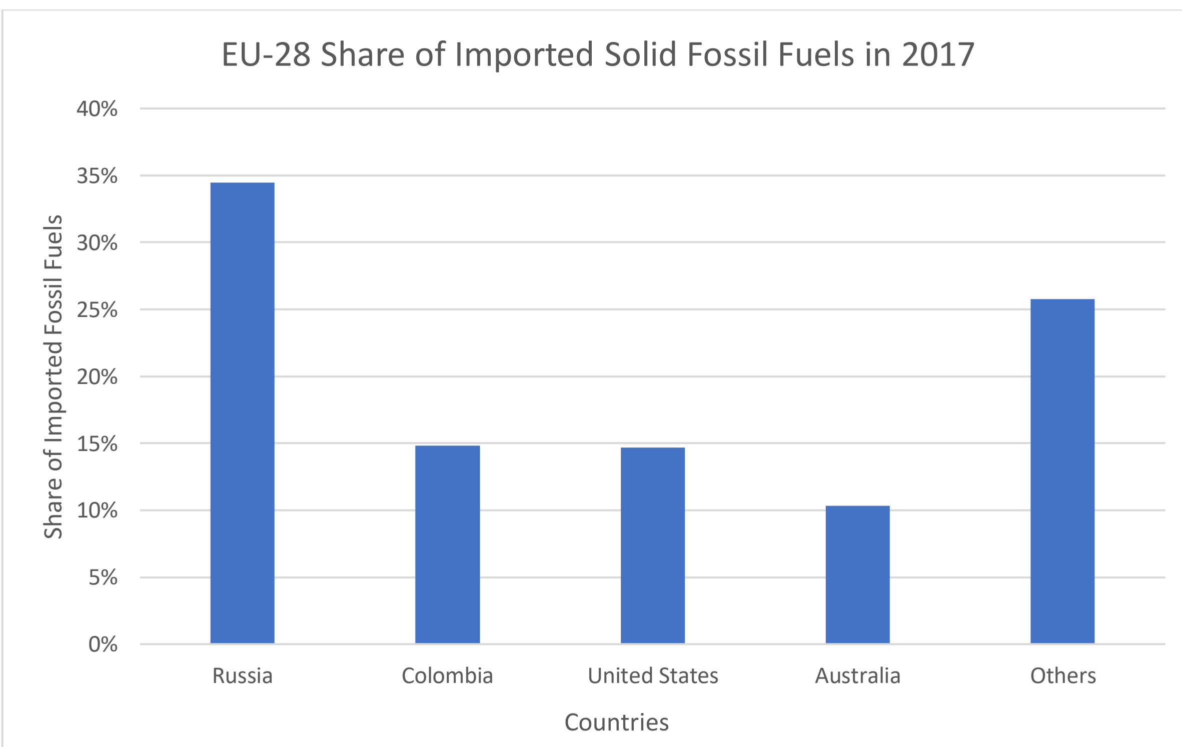
The second most important energy product imported in 2017 was natural gas, which is approximately 26 percent of the energy imported into the EU [54]. Graph 11 shows the EU-28 natural gas import shares by partner countries for the year 2017. As can be seen, In 2017, more than three-quarters of the EU-28's natural gas was imported from Russia (39.6 %), Norway (26 %) and Algeria (10.6 %).

The third most important energy product imported in 2017 was solid fossil fuels, which is approximately 8 percent of the energy imported into the EU [54]. Graph 12 shows the EU-28 solid fossil fuels import shares by partner countries for the year 2017. As can be seen, In 2017, almost three-quarters of the EU-28's solid fossil fuels was imported from Russia (34.5 %), Colombia (14.8 %), United States(14.6 %), and Australia (10.3 %).

If we analyze the overall data for crude oil, natural gas, and solid fossil fuels, we can see that Russia is the most important partner country for EU-28 countries. In each energy type, at least 30 percent of the energy needs of the EU-28, is met by Russia and it leads in each type of energy. Norway is the second most important partner in crude oil and natural gas import. As can be seen from the data, the top 4 countries in which crude oil, natural gas, and solid fossil fuels are imported, respectively meet 57.3 %, 81.5 %, and 74.2 % of the related energy types.



Graph 11 – EU-28 Share of Imported Natural Gas in 2017 [Data retrieved from [56]]



Graph 12 – EU-28 Share of Imported Solid Fossil Fuels in 2017 [Data retrieved from [57]]

3.2. Energy Security of the European Union

Energy security is also one of the most important terms of the energy field. IEA defines energy security as “the uninterrupted availability of energy sources at an affordable price” [6]. Energy security is related to all types of energy products like natural gas, oil, and electricity [58].

One-fourth of the energy used in the European Union is natural gas and the majority of the EU-28 countries imports nearly all needed natural gas [59]. Besides, many EU-28 countries are dependent on a single source of natural gas or a single transport route for gas [59]. Infrastructure failures that may occur along this route or political disagreements with the country of origin may jeopardize the energy supply [59]. For example, the gas dispute between Ukraine and Russia in 2009 had affected the gas supply of some European countries [59].

The European Union has developed some common standards to prevent possible supply interruptions and minimize the losses when they occur [59]. According to the Security of Gas Supply Regulation which has been introduced in 2017;

- European Network for Transmission System Operators for Gas (ENTSOG), is required to perform EU-wide gas supply and simulations for infrastructure outages to decrease the risks of possible supply problems [59].

- EU countries should cooperate in regional groups to jointly assess potential supply risks and to develop and agree on common preventive and emergency measures [59].

- In the case of a gas crisis, EU countries should assist each other in providing gas to customers who are most dependent on gas supply [59].

- Natural gas companies are obliged to inform national authorities about long-term natural gas supply contracts, in case the contracts exceed 28% of the country's annual natural gas consumption [59].

- Operators of the natural gas transmission system should enable permanent two-way capacity (reverse flow, bi-directional) on all cross-border links between EU countries unless an exemption is granted [59].

One of the most important actions that can provide energy security is diversifying the supply routes [60]. By identifying and building new energy routes, European countries are prevented from being dependent on a single supplier of natural gas and other energy resources [60].

Many of the Central and South-Eastern European countries are dependent on a single supplier for the majority of their natural gas [60]. Southern Gas Corridor project which will bring natural gas to the EU from the Caspian Basin, Central Asia, the Middle East, and the Eastern Mediterranean Basin, can eliminate this dependency [60].

Liquefied natural gas (LNG) imported to Europe through LNG terminals is also diversifies the gas supply routes and increases the competition in the gas market and security of supply [60]. Also, the EU plans to establish a Mediterranean gas hub in Southern Europe to get diversified about energy suppliers and routes [60].

Although the transition to alternative energy sources continues, 35 percent of the EU-28's energy need is still met by oil [61]. Therefore, in case of a problem in the supply of oil, emergency stocks are critically important [61]. According to the EU's Oil Stocks Directive (2009/119/EC):

- The countries of the European Union should keep enough oil and/or petroleum products in their emergency stocks to cover at least 90 days of imports or 61 days of consumption (whichever is higher) [61].

- Stocks should be kept ready so that they can be used immediately where needed at the time of crisis [61].

- At the end of each month, the member states must send a stock summary to the European Commission, which contains information about how many days of imports or how many days of consumption are covered by stocks [61].

- During a supply crisis, stocks should not be used except for very emergencies before the European Commission holds a consultation between EU countries [61].

- The Oil Coordination Group is responsible for the coordination between the European countries and the European Commission [61].

Another important point about Europe's energy security is offshore oil and gas safety. A large part of Europe's gas and oil production occurs offshore and the number of installations in European waters is around 550 [62]. To meet the high energy demand of the European Union safely, these operations are extremely important [62]. The Deepwater Horizon oil spill also called the Gulf of Mexico oil spill, which occurred in Mexico in 2010 and is accepted as the largest marine oil spill in history, shows us how important energy security is [62, 63]. Such accidents affect not only the country where the accident occurred but also the neighboring countries economically and environmentally [62]. Therefore, although energy security is the primary responsibility of the individual countries and companies, the laws of the European Union are also important to fulfill the energy security requirements [62].

Under the Directive on Safety of Offshore Oil and Gas Operations (2013/30/EU), the EU has defined safety standards to prevent the occurrence of accidents or to determine how to respond immediately and efficiently when an accident occurs [62]. These standards can be listed below:

- Companies are required to prepare a "Report on Major Hazards" for their offshore installation before production begins and this report should include a risk assessment and an emergency response plan [62].

- Companies should keep the resources ready for use to activate them when necessary [62].

- Before granting licenses, European countries should ensure that a related company provides financial and technical requirements [62].

- Technical subjects that are crucial for the safety of installations must be independently verified before the starting of production [62].

- National authorities are responsible for verifying safety requirements, environmental requirements, and emergency preparedness of the drilling rigs, installations, and platforms [62]. If the minimum requirements are not fulfilled, European countries can impose sanctions or stop production [62].

- Companies are completely responsible for environmental damages that affect protected marine species and natural habitats and in case of any damage to marine habitats, the geographical zone will contain all EU marine waters, exclusive economic zones, and continental shelves [62].

- Under the Offshore Oil and Gas Operations Directive, citizens have the right to express and comment on their ideas about the environmental effects of planned offshore oil and gas installation and the national authorities of the member states are responsible for providing clear information to the citizens [62].

As can be seen in all the above, energy security is one of the major concerns of the European Union, and strict rules and legislations and control mechanisms have been established to ensure energy security.

4. Analysis of Data

In the first part, I gave information about what renewable energy is, the types and usage areas of renewable energy, and their advantages and disadvantages. In the second part, I provided information based on historical statistics about renewable energy sources and use in Europe, and how the European Union countries are concerned about renewable energy. I also tried to explain why renewable energy is so important to Europe. In the third part, I gave information about how the European Union countries are dependent on foreign countries on energy and the regulations prepared against the possible consequences of this dependence. I also mentioned what energy security means for the European Union and what the European Union is doing to ensure energy security.

In the last and fourth part, I will try to analyze whether there is a relationship between the non-renewable energy imports of the European Union and the renewable energy production of the European Union and if there is such a relationship, the level of this relationship.

4.1. Method

I estimate a multiple regression model by using one dependent and three independent variables. I made all calculations with the help of IBM's SPSS Statistics Version 22.0 software. SPSS software platform is IBM's statistical software tool with many advantages such as advanced statistical analysis, a large library of machine learning algorithms, text analysis, and integration with big data [64]. Additionally, I also made the regression analysis by coding in Python 3.7.4 programming language and the Jupyter Notebook Server 6.0.1. Python is an open-source programming language that allows you to work faster and integrate your systems more effectively [65]. Jupyter is a nonprofit, open-source project that emerged from the IPython Project in 2014 and was developed to support interactive data science and scientific computing in all programming languages [66].

I tried the calculate how renewable energy production affects the European Union's non-renewable energy import. To reach that goal, I used the non-renewable energy import of the European Union as a dependent variable and, renewable energy production, non-renewable energy production, the total energy consumption of the European Union as independent variables. My multiple linear regression model and dependent and independent variables are like below:

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

y = Non-Renewable Energy Imports

X_1 = Renewable Energy Production

X_2 = Total Energy Consumption

X_3 = Non-Renewable Energy Production

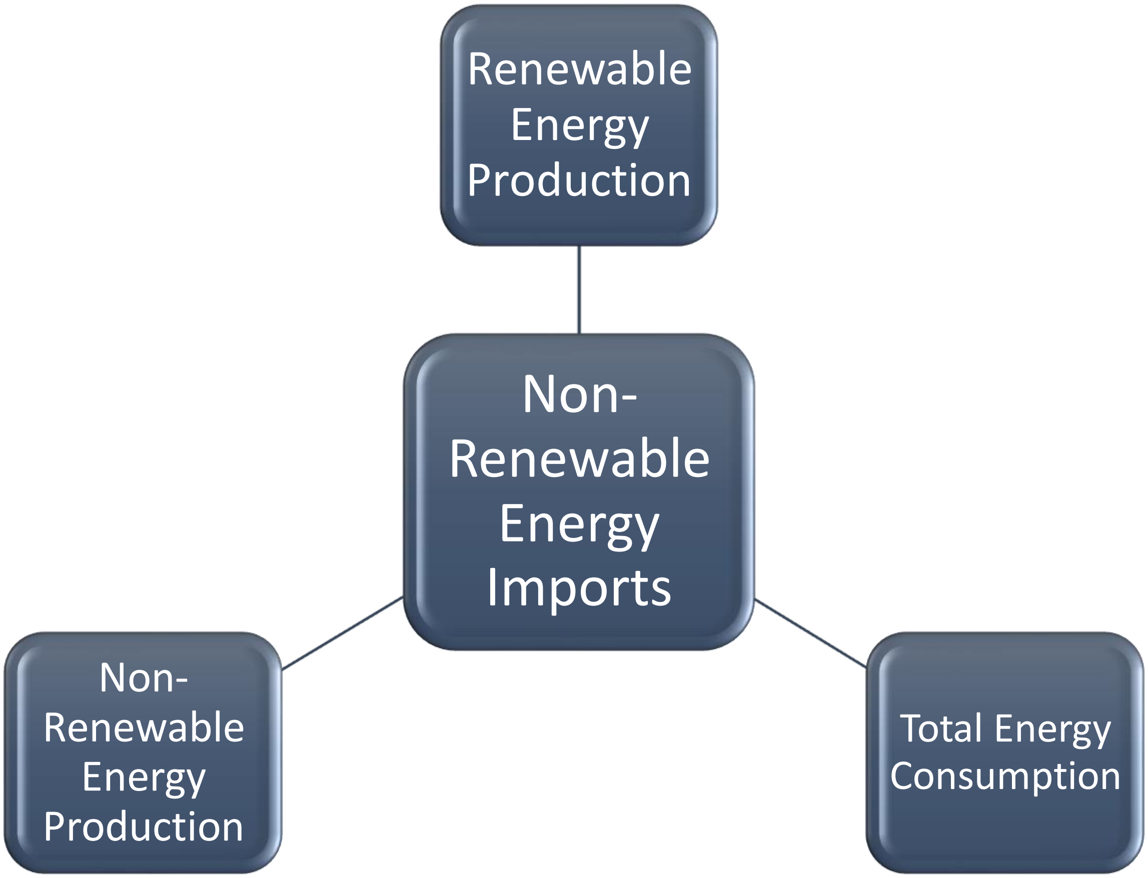


Figure 8 – Factors Affecting Non-Renewable Energy Imports

It's obvious that there can be many different variables that can affect a country's energy imports. However, in my study, I considered the three variables above, which I thought would affect non-renewable energy imports the most. These variables are renewable energy production, non-renewable energy production, and total energy consumption.

Table 4 – Dependent and Independent Variables [Data Retrieved from [67]]

Variable Type	Variable	Description
Dependent Variable	Non-Renewable Energy Imports	A continuous variable measuring imports of all non-renewable fuel types which include oil, natural gas, and solid fossil fuels - (Thousand TOE)
Independent Variables	Renewable Energy Production	A continuous variable measuring primary production of renewables and biofuels - (Thousand TOE)
	Non-Renewable Energy Production	A continuous variable measuring primary production of non-renewable fuel types which includes oil, natural gas, and solid fossil fuels (Thousand TOE)
	Total Energy Consumption	A continuous variable measuring the total final energy consumption of all sectors which includes industrial, transport, and other sector energy consumptions - (Thousand TOE)

4.2. Data

Undoubtedly, when doing an analysis, the most important thing is the data. Therefore, the data must be obtained from reliable sources. In my study, all data is taken from the Eurostat database.

The data of the dependent variable of annual non-renewable energy imports is calculated by the sum of the gas, oil, and solid fossil fuels imports of the related year. Annual renewable energy production data is found in the Eurostat database directly. Annual non-renewable energy production is calculated by the sum of the gas, oil, and solid fossil fuel production of the related year. Total energy consumption is calculated by the sum of the industry, transport, and other energy consumptions of the related year. For all independent and dependent variables, the unit of the data is thousand tonnes of oil equivalent (TOE).

In my analysis, I used the non-renewable energy import, renewable energy production, non-renewable energy production, and total energy consumption panel data for the European Union for the years 1990-2018.

The data which is collected from the Eurostat database is as follows:

Table 5 – Non-Renewable Energy Import, Renewable Energy Production, Non-Renewable Energy Production and Total Energy Consumption in the EU-28 between 1990-2018 (Unit for data: Thousand tonnes of oil equivalent) [Data Retrieved from [67]]

Years	Non-Renewable Energy Import	Renewable Energy Production	Non-Renewable Energy Production	Total Energy Consumption
1990	1,082,800	71,832	657,551	1,033,353
1991	1,074,918	74,722	641,193	1,041,526
1992	1,077,036	76,881	625,427	1,012,972
1993	1,066,784	81,392	617,684	1,016,279
1994	1,073,750	82,246	631,686	1,006,660
1995	1,095,718	84,371	637,020	1,024,098
1996	1,144,897	88,283	650,036	1,071,882
1997	1,160,001	91,730	635,625	1,057,625
1998	1,195,069	94,310	610,218	1,064,983
1999	1,176,437	94,758	606,054	1,063,947
2000	1,238,053	98,306	594,172	1,066,103
2001	1,265,926	101,461	580,023	1,092,197
2002	1,279,668	100,015	579,334	1,081,608
2003	1,323,890	108,667	561,785	1,111,281
2004	1,387,131	114,932	546,676	1,120,848
2005	1,433,960	121,915	513,536	1,124,339
2006	1,472,166	129,299	488,715	1,125,783
2007	1,435,141	139,378	469,763	1,104,889
2008	1,468,630	150,607	457,094	1,113,836
2009	1,374,916	157,497	421,401	1,059,616
2010	1,417,878	174,201	414,971	1,102,768
2011	1,399,405	171,696	387,920	1,050,557
2012	1,401,826	190,381	370,321	1,053,648
2013	1,395,251	202,801	351,199	1,053,336
2014	1,356,823	204,540	330,686	1,005,790
2015	1,415,889	213,508	321,524	1,028,875
2016	1,423,287	217,530	309,029	1,048,596
2017	1,475,699	226,719	301,046	1,061,542
2018	1,436,459	234,092	288,984	1,061,836

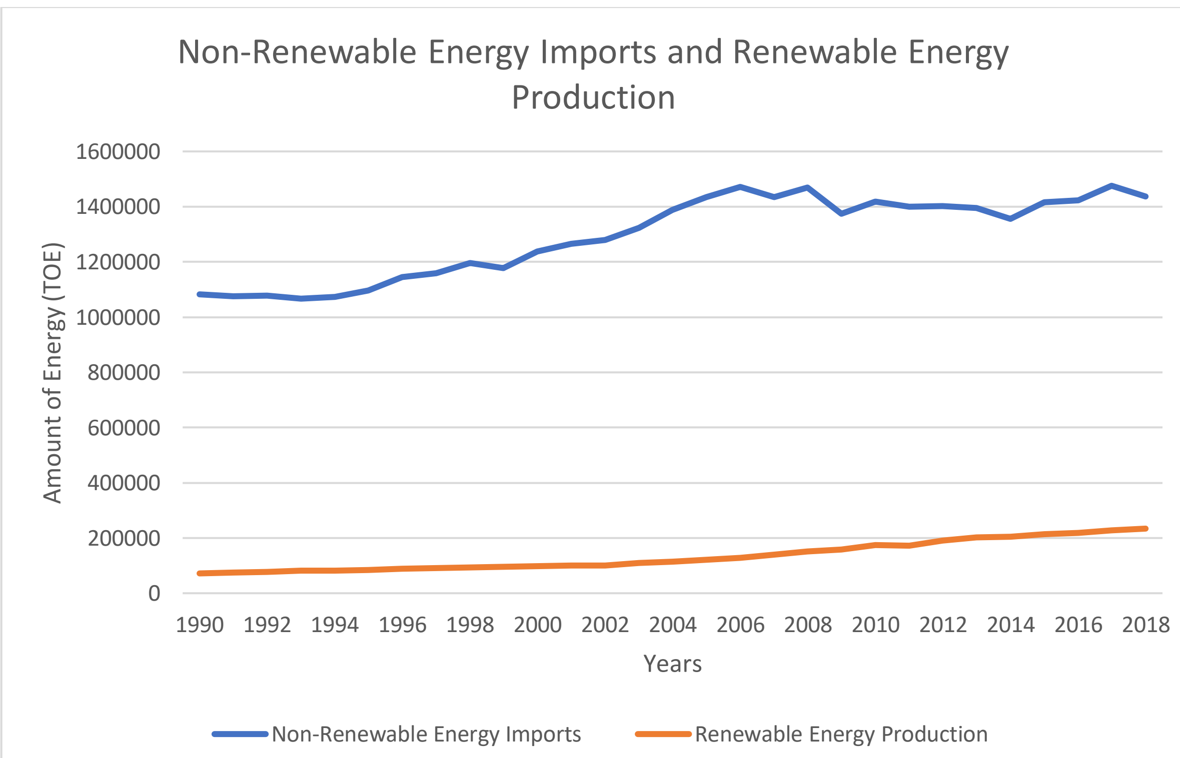
As we can see above data, non-renewable energy import was 1,082,800 thousand TOE in 1990 and has reached 1,436,459 thousand TOE in 2018. That means non-renewable energy imports increased by more than 32 percent in 29 years.

Non-renewable energy production was 657,551 thousand TOE in 1990 and decreased to 288,984 thousand TOE in 2018. This shows us that non-renewable energy production has dropped off 56 percent between the years 1990 and 2018.

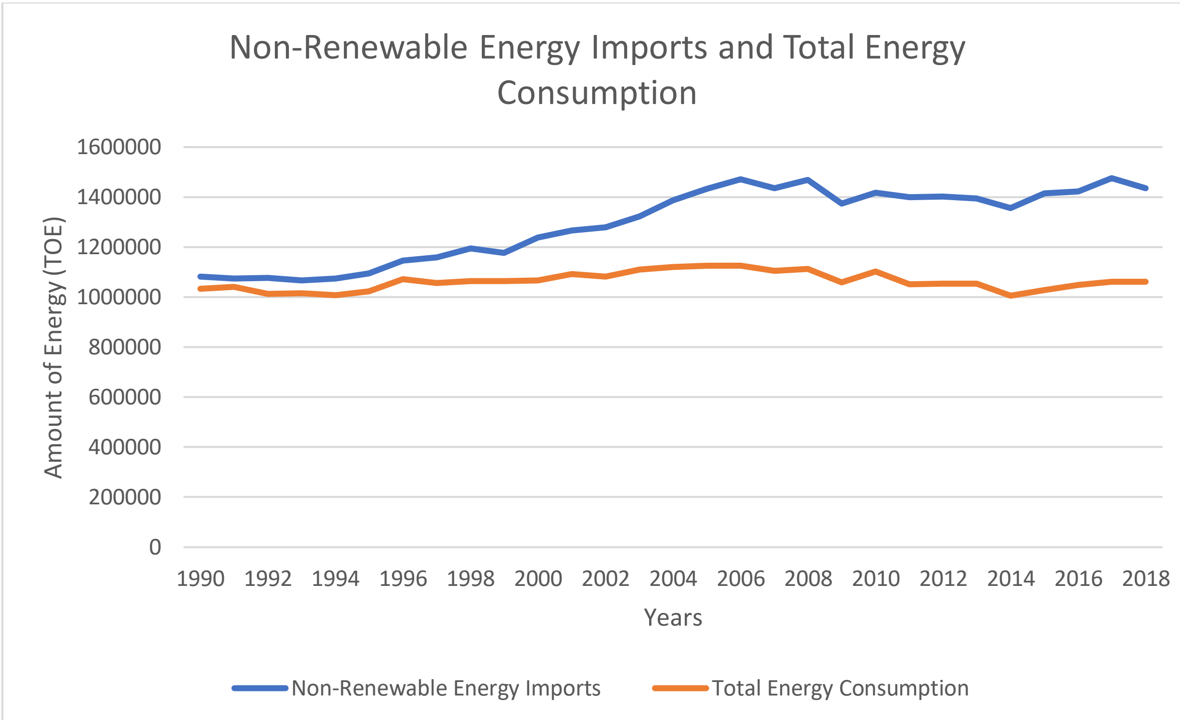
Total energy consumption was 1,033,353 thousand TOE in 1990 and happened 1,061,836 thousand TOE in 2018. There is a very small increase which is 2.8 percent of total energy consumption between the years 1990 and 2018.

Lastly, renewable energy production was 71,832 thousand TOE in 1990 and climbed up 234,092 thousand TOE in 2018. That indicates a huge increase of 226 percent of renewable energy production.

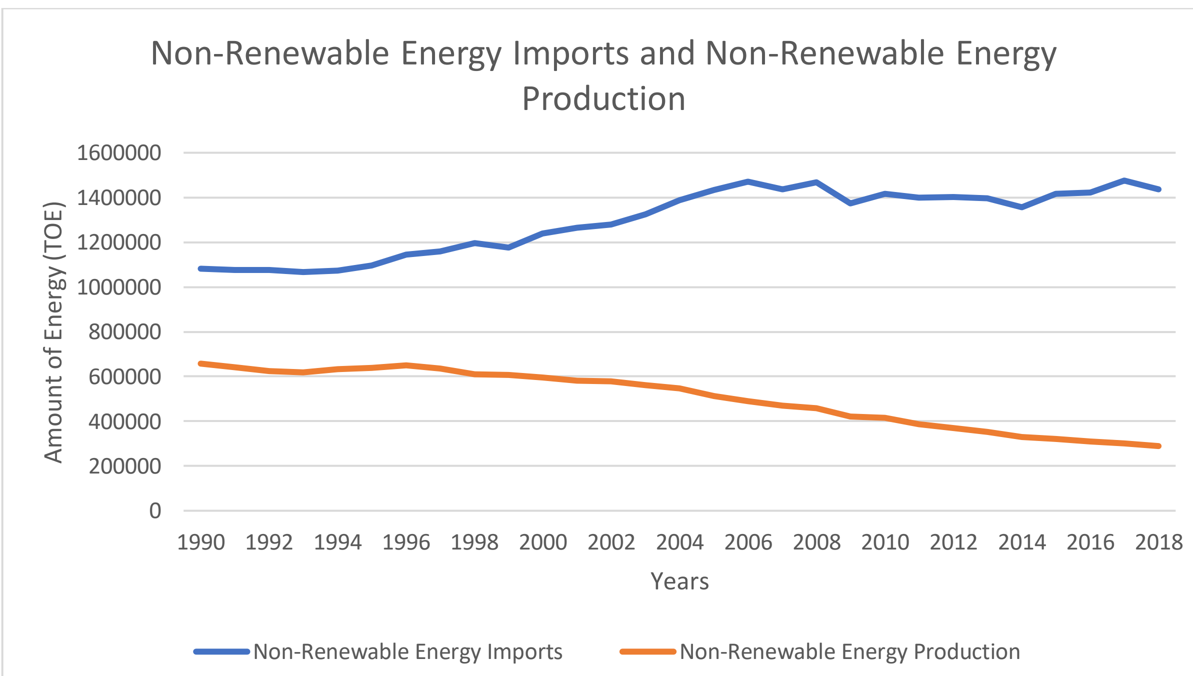
As can be seen from the above data, we cannot clearly explain the effect of the European Union’s renewable energy production on European Unions’s non-renewable energy imports. Because all other independent variables like non-renewable energy production and total energy consumption are also changing between the years 1990 and 2018. Therefore, we need to use more complex calculation methods to explain the effect of the European Union's renewable energy production on the European Union’s non-renewable energy imports.



Graph 13 – EU-28 Non-Renewable Energy Imports and Renewable Energy Production between 1990-2018 [Data retrieved from [67]]



Graph 14 – EU-28 Non-Renewable Energy Imports and Total Energy Consumption between 1990-2018 [Data retrieved from [67]]

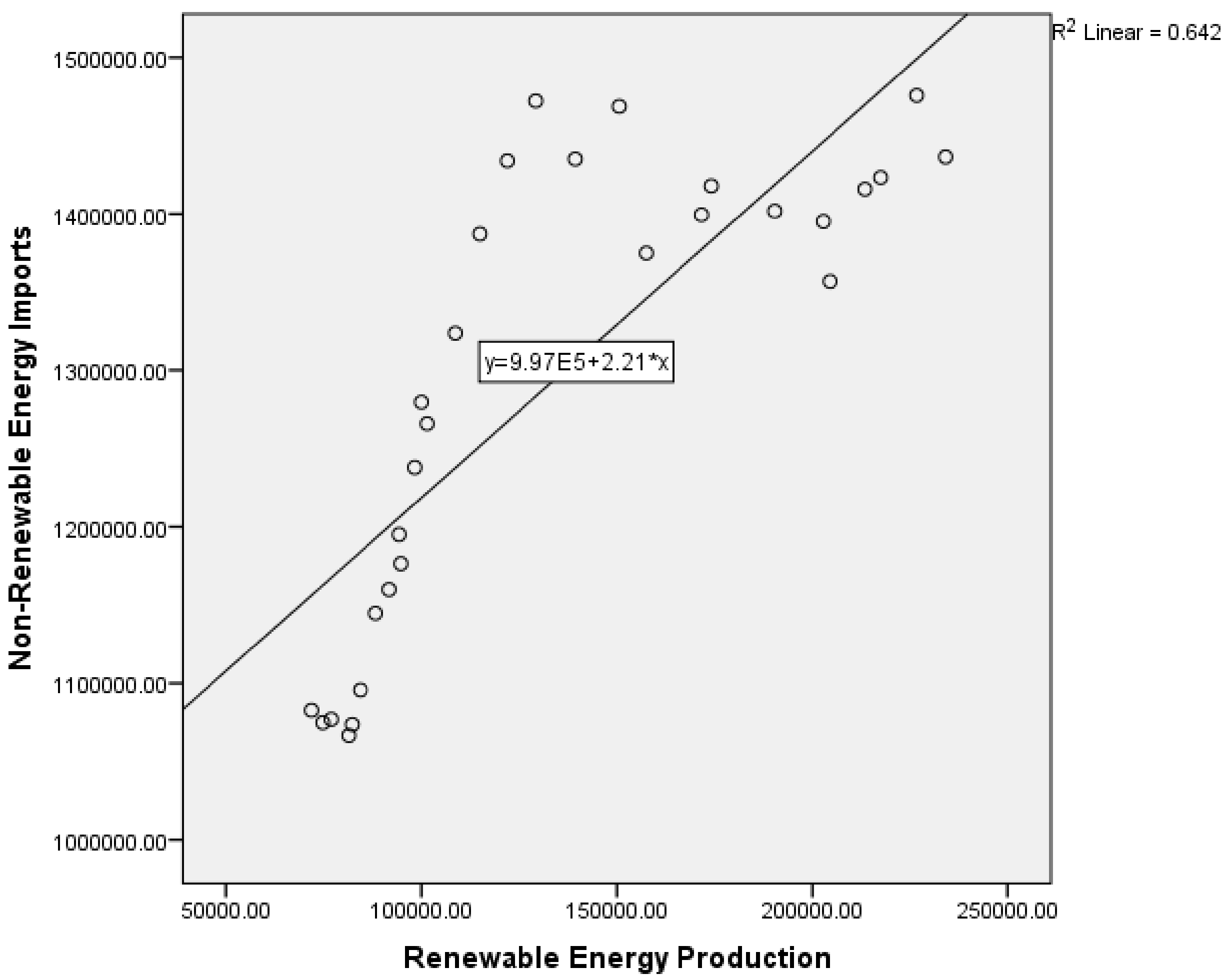


Graph 15 – EU-28 Non-Renewable Energy Imports and Non-Renewable Energy Production between 1990-2018 [Data retrieved from [67]]

4.3. Scatter Plot of Dependent and Independent Variables

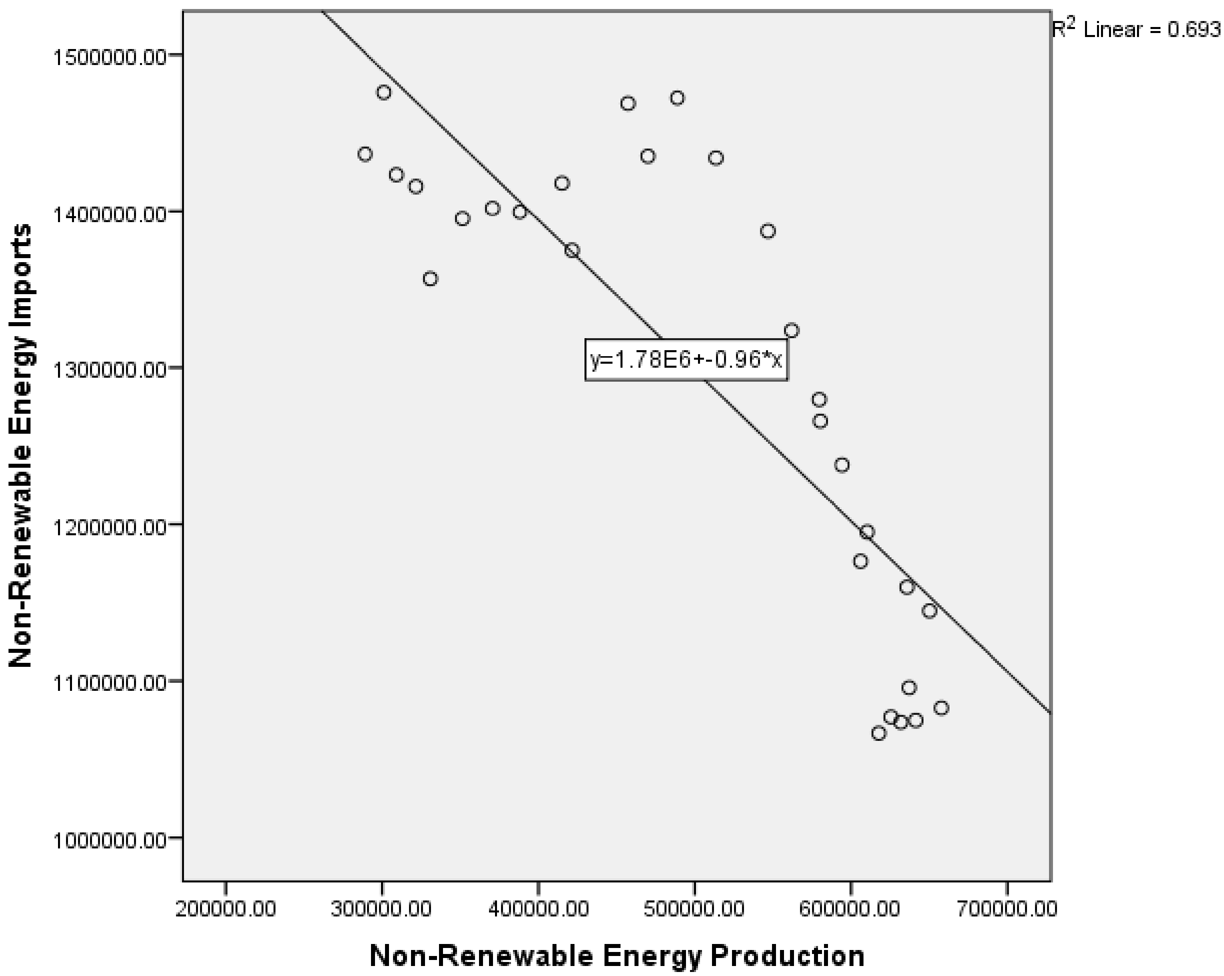
Before starting the regression analysis, I drew the scatter plot diagrams of the dependent and independent variables to see if there is a linear relationship between the variables.

First, I drew the scatter plot diagram of the non-renewable energy imports and renewable energy production. As we can see below, there is linearity between these two variables.



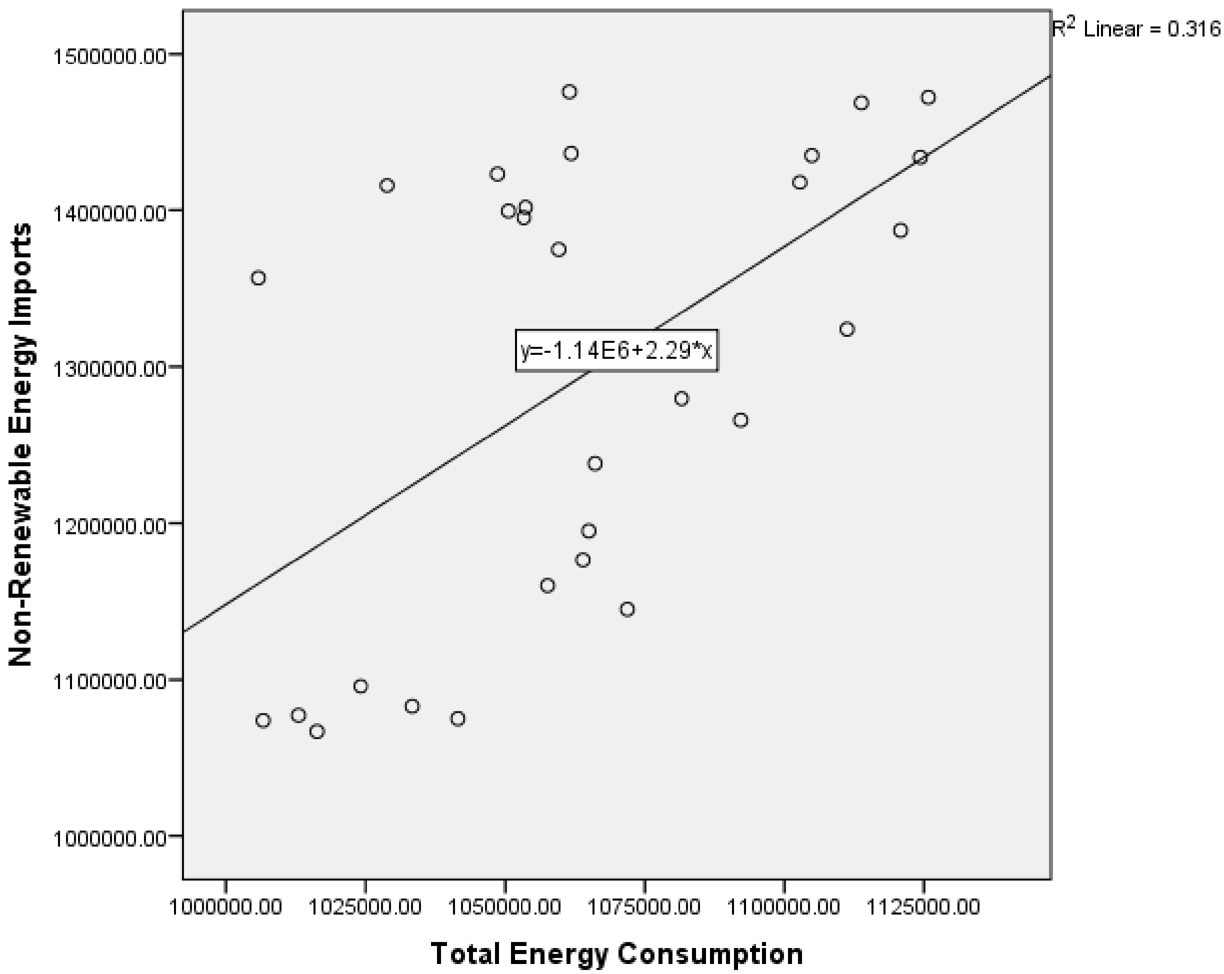
Graph 16 – Scatter Plot Diagram of the Non-Renewable Energy Imports and Renewable Energy Production [Data retrieved from [67]]

Second, I drew the scatter plot diagram of the non-renewable energy imports and non-renewable energy production. As we can see above from Graph- 17, there is linearity between these two variables.



Graph 17 – Scatter Plot Diagram of the Non-Renewable Energy Imports and Non-Renewable Energy Production [Data retrieved from [67]]

And finally, I drew the scatter plot diagram of the non-renewable energy imports and total energy consumption As we can see below from Graph- 18, there is linearity between these two variables too.



Graph 18 – Scatter Plot Diagram of the Non-Renewable Energy Imports and Total Energy Consumption [Data retrieved from [67]]

4.4. Correlation Analysis

Before starting the regression analysis, first I checked the correlations between variables. It can be done by correlation analysis in SPSS. The results can be seen below. Here, the correlation coefficient between non-renewable energy imports and renewable energy production is r = 0.801 and two-tailed P-value is 0.000 (rounded to 3 decimal places by software). The correlation coefficient between non-renewable energy imports and non-renewable energy production is r = 0.832 and two-tailed P-value is 0.000 (rounded to 3 decimal places by software). The correlation coefficient between non-renewable energy imports and the total energy consumption is r = 0.562 and two-tailed P-value is 0.002 (rounded to 3 decimal places by software). Regardless of our significance level, this yields a significant linear correlation.

Also, it's needed to check the correlations between independent variables. The correlation coefficient between total energy consumption and non-renewable energy production is r = -0.039. The correlation coefficient between total energy consumption and renewable energy production is r = 0.012. The correlation coefficient between renewable energy production and non-renewable energy production is r = -0.992. This yields a strong correlation between these two independent variables.

Table 6 – Correlations between Variables

Correlations

		Renewable Energy Production	Non-Renewable Energy Production	Total Energy Consumption	Non-Renewable Energy Imports
Renewable Energy Production	Pearson Correlation	1	-.992**	.012	.801**
	Sig. (2-tailed)		.000	.951	.000
	N	29	29	29	29
Non-Renewable Energy Production	Pearson Correlation	-.992**	1	-.039	-.832**
	Sig. (2-tailed)	.000		.842	.000
	N	29	29	29	29
Total Energy Consumption	Pearson Correlation	.012	-.039	1	.562**
	Sig. (2-tailed)	.951	.842		.002
	N	29	29	29	29
Non-Renewable Energy Imports	Pearson Correlation	.801**	-.832**	.562**	1
	Sig. (2-tailed)	.000	.000	.002	
	N	29	29	29	29

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

Due to a strong correlation between renewable energy production and non-renewable energy production, I excluded the non-renewable energy production and conducted my correlation analysis again. As can be seen below, the correlation coefficient between non-renewable energy imports and renewable energy production is r = 0.801. The correlation coefficient between total energy consumption and renewable energy production is r = 0.012. The correlation coefficient between total energy consumption and non-renewable energy imports is r = 0.562. There is no strong correlation between variables, therefore I can continue with regression analysis.

Table 7 – Correlations between Variables

Correlations

		Renewable Energy Production	Total Energy Consumption	Non-Renewable Energy Imports
Renewable Energy Production	Pearson Correlation	1	.012	.801**
	Sig. (2-tailed)		.951	.000
	N	29	29	29
Total Energy Consumption	Pearson Correlation	.012	1	.562**
	Sig. (2-tailed)	.951		.002
	N	29	29	29
Non-Renewable Energy Imports	Pearson Correlation	.801**	.562**	1
	Sig. (2-tailed)	.000	.002	
	N	29	29	29

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

4.5. Descriptive Statistics

In Table- 8 descriptive statistics for the dependent variable and all independent variables can be seen. According to the table, we observed values from 29 years which is between 1990- 2018 for all variables. As can be seen below, the mean values for non-renewable energy imports, renewable energy production, and total energy consumption are 1294807.13, 134416.26, and 1064164.66 Thousand TOE respectively. Likewise, the minimum values for non-renewable energy imports, renewable energy production, and total energy consumption are 1066784.08, 71831.67, and 1005790.09 Thousand TOE respectively and the maximum values are 1475698.99, 234092.45, 1125783.42 respectively.

The standard deviation values for non-renewable energy imports, renewable energy production, and total energy consumption are 146635.28, 53081.82, and 36002.29 Thousand TOE respectively.

If we examine the skewness and kurtosis values, we can find out whether the data meet the normality assumptions.

In distribution, skewness is a measure of symmetry and if skewness is 0, that means our distribution is symmetric [70]. Kurtosis is a measure of whether data is light-tailed or heavy-tailed compared to the normal distribution [70].

The figure below shows how the distribution looks like when the skewness and kurtosis values are greater or less than zero. If skewness and kurtosis both are equal to 0, it refers to the normal distribution [70].

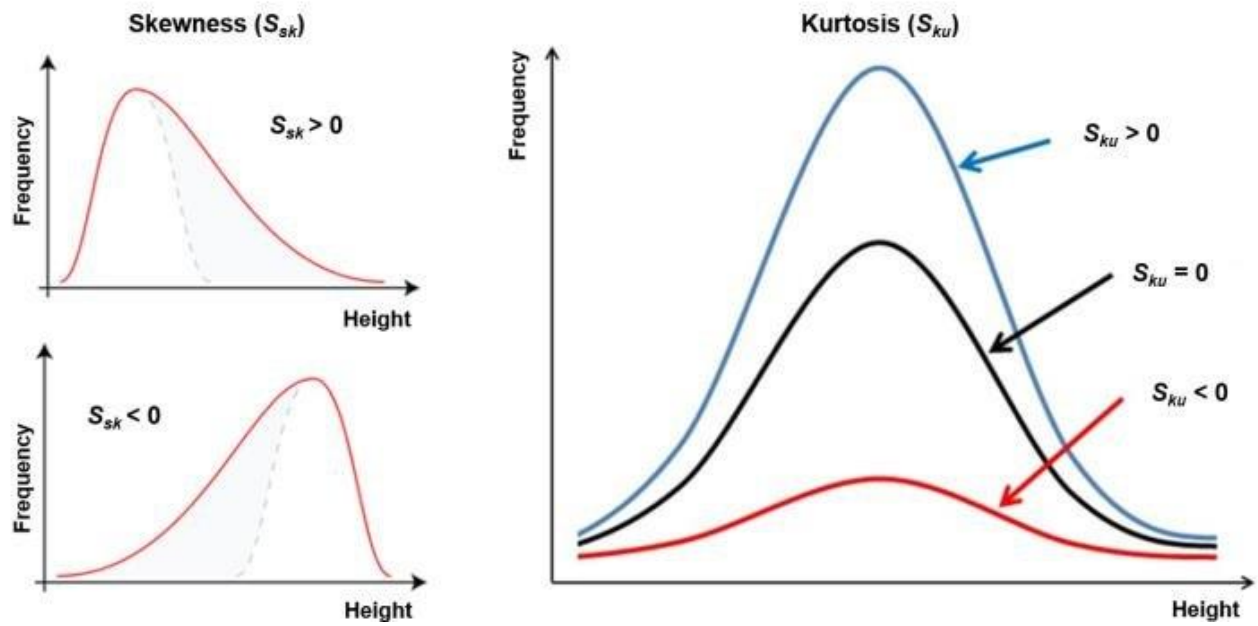


Figure 9 – Skewness and Kurtosis [69]

According to George and Mallery, the values for skewness and kurtosis between -1.96 and +1.96 are considered acceptable in order to meet normality [71].

According to our model, if we check the skewness and kurtosis values, it can be seen; for non-renewable energy imports, it's respectively -0.413 and -1.460; for renewable energy production, it's 0.590 and -1.136; and finally, for total energy consumption, it's 0.183 and -0.857. As can be seen, all values are between -1.96 and +1.96 and therefore it can be said that they meet the normality assumptions.

Table 8 – Descriptive Statistics

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Non-Renewable Energy Imports	29	1066784.08	1475698.99	1294807.13	146635.28	-.413	.434	-1.460	.845
Renewable Energy Production	29	71831.67	234092.45	134416.26	53081.82	.590	.434	-1.136	.845
Total Energy Consumption	29	1005790.09	1125783.42	1064164.66	36002.29	.183	.434	-.857	.845
TIME	29	1990.00	2018.00	2004.0000	8.51469	.000	.434	-1.200	.845
Valid N (listwise)	29								

4.6. Regression Analysis

After completing the correlation analysis and finding out that the correlation is significant at any level, we can proceed to the regression analysis. The predictive power of the relationship between the independent variables; renewable energy production and total energy consumption and the dependent variable; non-renewable energy imports, which have a significant relationship between them, were examined by multiple regression analysis. It can be done by regression analysis in SPSS.

In **Table – 9**, it shows all entered/ removed variables. As can be seen, all variables are entered, because the correlation is significant at any level for all variables.

Table 9 – All entered and removed variables

Variables Entered/ Removed

Variables Entered	Variables Removed
Total Energy Consumption, Renewable Energy Production	.

a. Dependent Variable: Non-Renewable Energy Imports

b. All requested variables entered.

The model summary table can be seen below. Below model summary table shows us the strength of the relationship between our model and the independent variables [68].

The multiple correlation coefficient R shows the linear correlation between the observed and model-predicted values of the dependent variable and the larger this value means a stronger relationship [68]. Here R-value is 0.973 and that means there is a strong relationship.

The coefficient of determination R Square is the squared value of the multiple correlation coefficient [68]. 0.947 means, 94.7 percent of the changes in non-renewable energy imports can be explained by our model.

Adjusted R Square is a corrected R Square value and these values along with standard error of the estimate, are very useful to make comparisons and decide between two or more models [68].

Table 10 – Model Summary

Model Summary

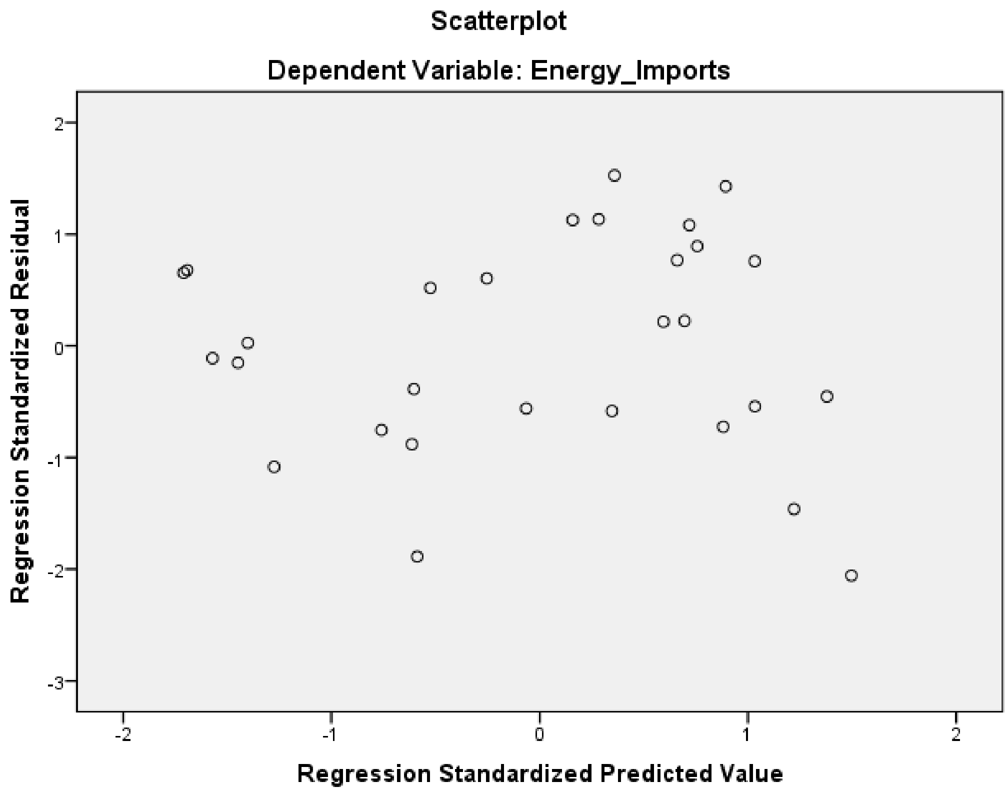
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.973	.947	.943	34963.51159

a. Predictors: (Constant), Total Energy Consumption, Renewable Energy Production

In Table 11, it can be seen the confidence intervals for regression coefficients. As the interpretation of values, it can be said that we are 95% confident that the mean score will fall between 1239030.049 and 1350584.206 for non-renewable energy imports, between 114225.0198 and 154607.5091 for renewable energy production and between 1050470.122 and 1077859.203 for total energy consumption. Similarly, we are 99% confident that the mean score will fall between 1219564.905 and 1370049.350 for non-renewable energy imports, between 107178.6577 and 161653.8712 for renewable energy production and between 1045690.987 and 1082638.338 for total energy consumption.

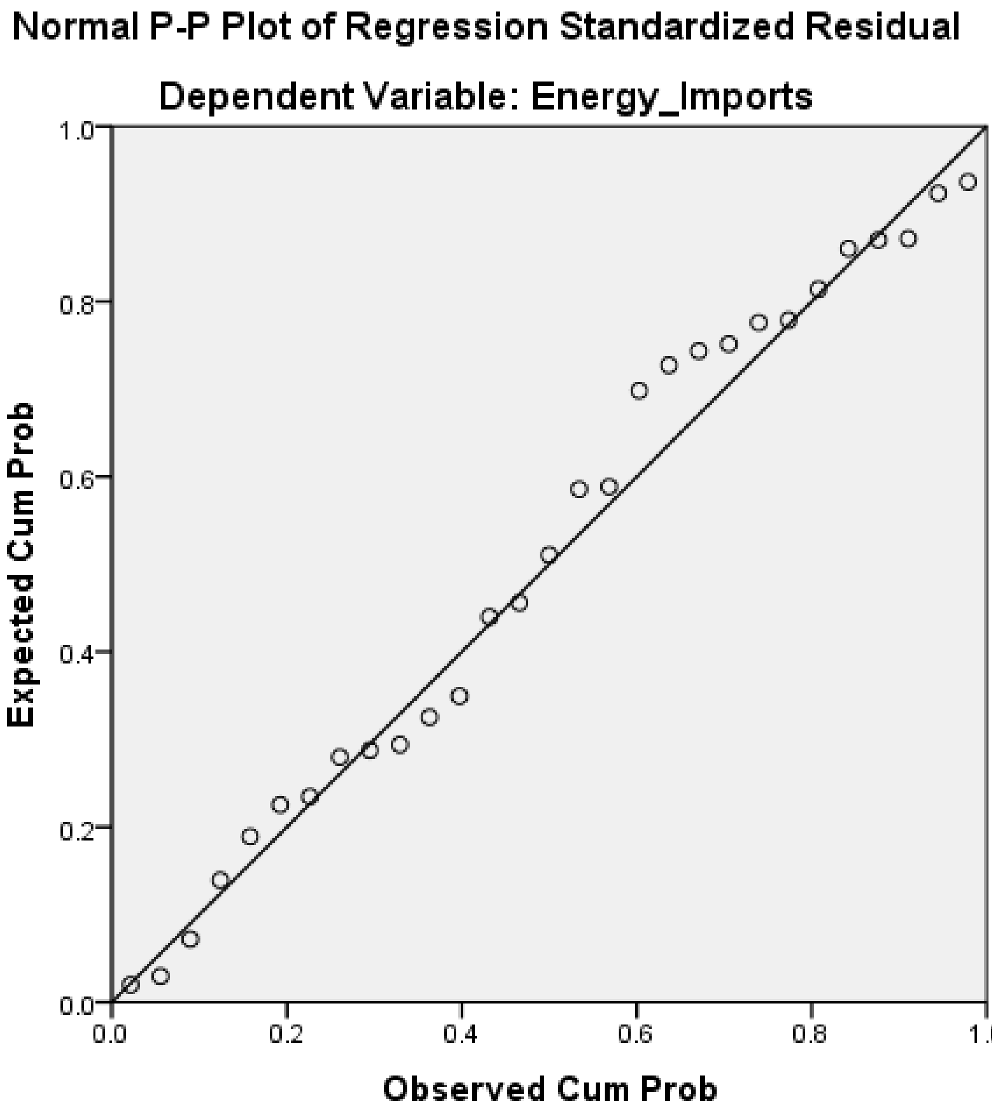
Table 11 - 95 % Confidence Intervals for Regression Coefficients

Regression Coefficients	Mean	Lower Bound 95%	Upper Bound 95%	Lower Bound 99%	Upper Bound 99%
Non-Renewable Energy Imports	1294807.128	1239030.049	1350584.206	1219564.905	1370049.350
Renewable Energy Production	134416.2644	114225.0198	154607.5091	107178.6577	161653.8712
Total Energy Consumption	1064164.663	1050470.122	1077859.203	1045690.987	1082638.338



Graph 19 – Scatter Plot of the Standardized Residuals

In Graph 19, it can be seen the scatter plot of the standardized residuals. In order to do the regression analysis, both the sum and the mean of the residuals should be equal to zero. According to the graph, we can say that it does not have an obvious pattern which means the points are equally distributed above and below zero both on the X and Y-axis. Therefore we can say that the means of regression residuals are as expected.



Graph 20 – Normal P-P Plot of Regression Standardized Residuals

In Graph 20, it can be seen the normal P-P plot of regression standardized residuals. Here we can say that our data is approximately normally distributed because the points are on or close to the line. Therefore we can say that the distribution of regression residuals is as expected.

ANOVA Table tests whether the model is acceptable from a statistical point of view [69]. While the regression line provides information about the changes that can be explained by our model, the residual line provides information about the changes that can not be explained by our model [69].

In our model, the regression sum of squares is approximately 18 times larger than the residual sum of squares, which shows us that most of the variation in the non-renewable energy imports is explained by our model. Also, the significance value is 0.000b which is less than 0.05 shows that the variation explained by our model is not due to chance.

Table 12 – ANOVA Table

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.703E+11	2	2.851E+11	233.249	.000b
	Residual	3.178E+10	26	1222447142		
	Total	6.021E+11	28			

a. Dependent Variable: Non-Renewable Energy Imports

b. Predictors: (Constant), Total Energy Consumption, Renewable Energy Production

According to the results of multiple linear regression analysis conducted to find out how renewable energy production and total energy consumption which are thought to have an impact on energy imports, affect energy imports; renewable energy production, and total energy consumption all together showed a significant relationship with non-renewable energy imports. It can be seen R is equal to 0.97 and R Square is equal to 0.95 ($F(3,25)= 233.249$; $p <0.001$). According to the results, these two independent variables; renewable energy production and total energy consumption, explains 95 percent of the changes in non-renewable energy imports. According to Cohen, the effect size results for R square as follows: $R^2 = 0.0196$ is stated as small effect size, $R^2 = 0.1300$ as medium effect size, and $R^2 = 0.2600$ as large effect size [72]. Therefore, it can be said that the R^2 value ($R^2 =.95$) obtained in this analysis has a large effect size.

Table 13 – Multiple Regression Results

Results of Regression Analysis									
Model	B	Std. Error	β	t	p	R	R^2	F	p
Constant	-1394683.699	195943.842	-	-7.118	.571				
Renewable Energy Production	2.195	.124	.795	17.635	.008	.97	.95	233.249	.000
Total Energy Consumption	2.250	.184	.552	12.259	.000				

According to the standardized regression coefficients (β), the relative importance of independent variables on non-renewable energy imports in respectively descending order is renewable energy production (0.795) and total energy consumption (0.552).

According to the significance test of the regression coefficients, it can be seen all independent variables; renewable energy production ($p < 0.001$) and total energy consumption ($p < 0.001$) are significant on non-renewable energy imports.

According to the regression results, regression equation of my model is below:

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

$$y = -1394683.699 + 2.195 X_1 + 2.25 X_2$$

y = Non-Renewable Energy Imports

X_1 = Renewable Energy Production

X_2 = Total Energy Consumption

If we interpret our regression equation, we can simply say that:

- If renewable energy production of the European Union increases by one unit, non-renewable energy imports of the EU will increase by 2.195 units

- If the total energy consumption of the European Union increases by one unit, non-renewable energy imports of the EU will increase by 2.25 units.

4.7. Regression Analysis with Python and AMOS

I also did the same multiple regression analysis with Python programming language. I put the coding and the results below. As can be seen from below, multiple regression analysis results are the same. I only used Python programming language instead of SPSS to make the calculations.

- First, I imported the required libraries for my regression analysis.

```
import numpy as np

import pandas as pd

import matplotlib.pyplot as plt

import statsmodels.api as sm

import seaborn as sns

sns.set()
```

- Here, I uploaded my data file to the Python environment.

```
data_raw = pd.read_csv('Overall-Python.csv')

data_raw
```

- Here, I made some modifications on my data.

```
data_clean = data_raw.drop(['Industry Energy Consumption', 'Transport Energy Consumption', 'Other Energy Consumption', 'Non-Renewable Energy Production'], axis=1)

data_clean
```

- Here, I created the descriptive statistics table for my data.

```
data_clean.describe()
```

Table 14 – Descriptive Statistics (Python)

	Non-Renewable Energy Imports	Renewable Energy Production	Total Energy Consumption
count	29	29	29
mean	1.29E+06	134416.2655	1.06E+06
std	1.47E+05	53081.82044	3.60E+04
min	1.07E+06	71831.67	1.01E+06
25%	1.16E+06	91730.2	1.04E+06
50%	1.36E+06	114931.6	1.06E+06
75%	1.42E+06	174200.76	1.09E+06
max	1.48E+06	234092.45	1.13E+06

- Here, I made some variable assignments for multiple regression analysis.

```
y = data_clean['Energy Imports']

x1 = data_clean[['RE Production', 'Total Energy Consumption']]
```

- Finally, I made my regression analysis.

```
x = sm.add_constant(x1)

results = sm.OLS(y,x).fit()

results.summary()
```

Table 15 – Results of Multiple Regression Analysis (Python)

OLS Regression Results			
Dep. Variable:	Energy Imports	**R-squared:**	0.947
Model:	OLS	**Adj. R-squared:**	0.943
Method:	Least Squares	**F-statistic:**	233.2
Date:	Sat, 09 May 2020	**Prob (F-statistic):**	2.47E-17
Time:	13:28:53	**Log-Likelihood:**	-342.97
No. Observations:	29	**AIC:**	691.9
Df Residuals:	26	**BIC:**	696.0
Df Model:	2		
Covariance Type:	nonrobust		

Table 16 – Results of Multiple Regression Analysis 2 (Python)

	coef	std err	t	P>|t|	[0.025	0.975]
const	-1.395E+06	1.96E+05	-7.118	0.000	-1.8E+06	-9.92E+05
Renewable Energy Production	2.1953	0.124	17.635	0.000	1.939	2.451
Total Energy Consumption	2.2500	0.184	12.259	0.000	1.873	2.627

Table 17 – Results of Multiple Regression Analysis 3 (Python)

Omnibus:	1.242	**Durbin-Watson:**	1.719
Prob(Omnibus):	0.537	**Jarque-Bera (JB):**	1.164
Skew:	-0.358	**Prob(JB):**	0.559
Kurtosis:	2.329	**Cond. No.**	3.24E+07

- I also did a path analysis using the software AMOS V.20. The values shown below represent the standardized regression weights and e1 represents the error term.

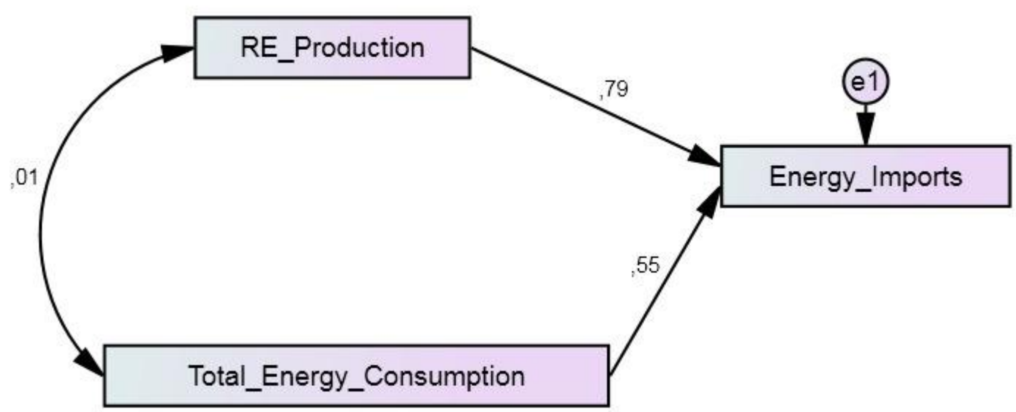


Figure 10 – AMOS Path Analysis

Conclusion

It is known by everyone that energy has a huge importance in our lives and this importance is increasing day by day. It is also a well-known fact that energy resources are not equally distributed to all countries in the world. While some countries are very rich in energy resources, some countries have very limited energy resources. That makes the countries that are poor in energy resources dependent on the countries that are rich in energy resources.

The European Union is also dependent on imports in terms of energy. In addition to the energy dependency, the energy security that I explained in detail in the second part of my study is a very important concept. Therefore, the European Union is trying to decrease the energy dependency on imports and to provide energy security by increasing the energy which is produced from renewable energy resources.

In my study, I tried to predict if there is a relationship between renewable energy production of the European Union and the energy import of the European Union and if so, I tried to calculate the degree of this relationship.

Firstly, I gathered the data from the Eurostat database for the EU for the years between 1990-2018. I used non-renewable energy imports as the dependent variable and, renewable energy production and total energy consumption as independent variables.

Before starting the regression analysis, first I checked the correlations between variables. I found that the correlation coefficient between non-renewable energy imports and renewable energy production is $r = 0.801$ and two-tailed P-value is 0.000, the correlation coefficient between non-renewable energy imports and non-renewable energy production is $r = 0.832$ and two-tailed P-value is 0.000 and the correlation coefficient between non-renewable energy imports and the total energy consumption is $r = 0.562$ and two-tailed P-value is 0.002. Regardless of my significance level, this yields a significant linear correlation.

Also, I checked the correlations between the independent variables. The correlation coefficient between total energy consumption and non-renewable energy production is $r = -0.039$. The correlation coefficient between total energy consumption and renewable energy production is $r = 0.012$. The correlation coefficient between renewable energy production and non-renewable energy production is $r = -0.992$. The correlation coefficient between renewable energy production and non-renewable energy production yields a strong correlation between these two independent variables. Due to a strong correlation between them, I excluded the non-renewable energy production and after doing my correlation analysis again, I found that there is no strong correlation between variables, therefore I continued with regression analysis.

Then, I did the model summary. According to the model summary, I found that the coefficient of determination R Square is 0.947, and it means 94.7 percent of the changes in non-renewable energy imports can be explained by our model.

After completing the significance test, I found that all independent variables; renewable energy production ($p < 0.001$) and total energy consumption ($p < 0.001$) are significant on non-renewable energy imports.

Finally, I completed my regression analysis and created the regression equation of my model as below.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

$$y = -1394683.699 + 2.195 X_1 + 2.25 X_2$$

y = Non-Renewable Energy Imports

X_1 = Renewable Energy Production

X_2 = Total Energy Consumption

According to my regression analysis results;

- If renewable energy production of the European Union increases by one unit, non-renewable energy imports of the EU will increase by 2.195 units.

- If the total energy consumption of the European Union increases by one unit, non-renewable energy imports of the EU will increase by 2.25 units.

In this study, I assumed that there are three independent variables (renewable energy production, non-renewable energy production, total energy consumption) that I think could affect the energy imports of the European Union. After completing the correlation analysis, I excluded non-renewable energy production due to the strong correlation between variables. But, there can be more independent variables that could affect the energy imports of the European Union like the study of Sarah J. Unbehaun [72]. She included many different independent variables like heating degree days, GDP per capita, and stock changes [72]. She also found in the simple ordinary least squares regression of non-renewable energy imports on renewable energy production with no control variables that, if renewable energy production increases one KTOE, non-renewable energy imports increase 7.6 KTOE [72]. Although there are also some previous studies claiming that increasing renewable energy production will decrease energy imports, according to the results and conclusions of my study, if the renewable energy production of the European Union increases, the energy imports of the European Union will also increase.

About the possible reasons of my results, firstly, In my study, I used the EU's overall data from the Eurostat database, but there are 28 members of the European Union and all these 28 countries have some different characteristics. For example, there are different subsidy mechanisms in different EU countries. Therefore, if the countries are analyzed separately, the results of my study can be changed.

Secondly, for total energy consumption, I did not separate total energy consumption by sectors or by energy source. If this is done, results may differ. Because in some sectors like transportation, it's been used renewable energy more than the other sectors. For example, in most of the European cities, subways, trams and even the buses are using green energy.

One last factor that can change my results can be how the EU countries use renewable energy efficiently. As we know, energy efficiency has effects from energy consumption to energy production. Also due to the different energy policies of individual EU countries, maybe in some countries, renewable energy production is reducing energy imports, but these countries have no major impact due to low energy production and consumption. Therefore, the countries having high levels of energy production and consumption are leading the EU's energy trend in my analysis.

In summary, In my study, I could not find any evidence that renewable energy production reduces non-renewable energy imports. But the European Union is still encouraging renewable energy investments by providing subsidies, green bonuses, or tax allowances. Because there are also some other benefits of increasing renewable energy like reducing greenhouse gas emissions and pollution. Therefore, the European Union should continue to invest in renewable energy and also think about how to reduce energy imports and energy dependence and how to ensure energy security.

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Appendices

Appendix 1. The 28 member countries of the EU [2]

EU-28	
Austria	Italy
Belgium	Latvia
Bulgaria	Lithuania
Croatia	Luxembourg
Cyprus	Malta
Czechia	Netherlands
Denmark	Poland
Estonia	Portugal
Finland	Romania
France	Slovakia
Germany	Slovenia
Greece	Spain
Hungary	Sweden
Ireland	United Kingdom