İleri Mühendislik Çalışmaları ve Teknolojileri Dergisi, 1(2), 130-141

İLERİ MÜHENDİSLİK ÇALIŞMALARI VE TEKNOLOJİLERİ DERGİSİ

A 100% Renewable Energy System: The Case of Turkey In The Year 2050

Hasan Hüseyin ÇOBAN*[1]

Ardahan University, Engineering Faculty, Department of Electrical Electronics Engineering, Ardahan, 75002, Turkey

Research Article, Received Date: 29.10.2020, Accepted Date: 23.11.2020

Abstract

Energy demand is increasing rapidly in developing countries (Turkey is one of them) and fossil fuels play an important role in meeting this demand. In terms of pricing, it seems unlikely that energy produced by fossil fuels can compete with renewable energy sources. This paper investigates whether the possibility of converting to a 100% renewable energy system for the current energy system. A simulation tool, EnergyPLAN, was used to investigate the implementation of 100% renewable energy system. EnergyPLAN is a computer-based tool that models a country's energy system and predicts system behavior and explores future energy systems to identify trends for energy use and emissions. The study has been performed for renewable scenarios designed for 2050. Turkey is used as a case study; however, it reflects various energy systems today which use power plants for the heating, cooling, industry, electricity, and transport sectors. There are five analysis steps which are: 1) a reference model of the current Turkish energy system was constructed, 2) increase and install new renewable energy generation to replace the remaining fossil fuels, 3) introduction of district heating, 4) removal of nuclear power plants, and finally, 5) the implementation of electric vehicles (EVs). These energy-systems were compared according to carbon emission and produced energy; so that the benefits from each could be used to create an ‘optimum’ scenario. The results are very promising since they indicate that the transition to a 100% renewable energy system can begin today, without increasing the fossil fuel power plants in the short- or long-term, if the generated power based on the volatile energy sources photovoltaics (PV), wind energy (onshore) and hydropower forecasted for 2050 become a reality.

Keywords: 100% renewable energy, Energy savings, Power system flexibility, Solar energy, Transport, Wind energy.

%100 Yenilenebilir Enerji Sistemi: 2050 Türkiye Örneği

Özet

Gelişmekte olan ülkelerde (Türkiye de bunlardan biri) enerji talebi hızla artmakta ve fosil yakıtlar bu talebin karşılanmasında önemli rol oynamaktadır. Enerji fiyatları açısından, fosil yakıtlar tarafından üretilen enerjinin yenilenebilir enerji kaynakları ile rekabet etmesi pek olası görünmemektedir. Bu makalede, mevcut enerji sistemi için %100 yenilenebilir bir enerji sistemine dönüştürme olasılığının olup olmadığını araştırılmaktadır. % 100 yenilenebilir enerji sisteminin uygulanmasını araştırmak için EnergyPLAN adlı bir yazılım simülasyon aracı kullanılmıştır. EnergyPLAN, bir ülkenin enerji sistemini modelleyen ve sistem davranışını tahmin eden, enerji kullanımı ve emisyon eğilimlerini belirlemek için gelecekteki enerji sistemlerini araştıran bilgisayar tabanlı bir yazılımdır. Çalışma, 2050 için tasarlanan yenilenebilir senaryolar için gerçekleştirilmiştir. Vaka çalışmasında Türkiye örneğinde; günümüzdeki ısıtma, soğutma, sanayi, elektrik ve ulaştırma sektörleri için enerji santrallerini kullanan çeşitli enerji sistemlerini yansıtılmıştır. Beş analiz adımı uygulanmıştır: 1) mevcut Türk enerji sistemi referans modeli olarak alınmış, 2) fosil yakıtların yerine yenilenebilir enerji üretiminin artırılması ve yeni santrallerin kurulması hedeflenmiş, 3) bölgesel ısıtmanın sistemlerinin hayata geçirilmesi amaçlanmış, 4) nükleer enerji santralleri kaldırılmış ve son olarak, 5) elektrikli araçlar uygulanmıştır. Her bir enerji sistemi için karbon salınımına ve üretilen enerjiye göre karşılaştırılmıştır; böylece her birinden elde edilen

[1]Corresponding author huseyincoban@ardahan.edu.tr

sonuçlar "optimum" bir senaryo oluşturmak için kullanılmıştır. Sonuçlar, fosil yakıt santrallerini kısa veya uzun vadede arttırmadan; 2050 için öngörülen yenilenebilir enerji kaynakları fotovoltaik, rüzgar ve hidroelektrik enerjisine dayalı olarak üretilen güç gerçeğe dönüştürüldüğünde % 100 yenilenebilir enerji sistemine geçişin bugün umut verici olarak başlayabileceğini göstermektedir.

Anahtar Kelimeler: % 100 yenilenebilir enerji, Enerji tasarrufu, Güneş enerjisi, Elektrikli araçlar, Rüzgar enerjisi.

1. INTRODUCTION

As of 2018, global daily oil production has reached for the first time the amount of 100 million barrels (Hacquard, Simoën, Hache, 2019). The unsustainable massive scale of fossil fuel production and its dependence pollutes the Earth. According to the estimates of the American Energy Information Agency (EIA), as of the end of 2019; in the light of new technologies such as developing technologies, marine drilling and rock oil, global crude oil, biofuel, and liquid hydrocarbons have a life of up to 30 years (“International Energy Outlook”, 2019). According to current estimates, at this rate, we'll run out of gas and oil in 50 years or so, and in about a century for coal (Agbulut, Bakir, 2019; Stolic, Pesic, Milosevic, Spasic, Lazic, 2018). Conversely, we have abundant sun, rain, and wind which are all renewable energy (Foley, 1992). What if we could replace fossil fuel dependence with an existence based completely on renewables?

The ecological debt began to form in the early 1970s in separate countries and large industrial cities. Now, almost all countries are debtors, and unfortunately, every year the day of exceeding the opportunities of the Earth comes ever earlier. Can we stop this huge conveyor? It may be possible but it's too difficult. The keyword in this mission is renewable resources!

Everyone likes electricity, technology, and being able to visit interesting parts of the world through the miracles of travel, television, the internet, all things that have now become commonplace, thanks to energy from fossil fuels. If fossil fuels have given us all these benefits, does that mean we should continue to use them forever? It's appropriate to acknowledge and be grateful for the benefits that coal, and gas, and oil have brought us, but what we know today that we didn't know all that much about 300 years ago, is that they also have significant drawbacks.

First, there's the simple issue of pollution due to usage of fossil fuels. Extracting and burning fossil fuels creates an enormous amount of pollution, choking our lungs, dirtying our air, and contaminating our water and our soil. Coal is the worst. Considering only the health costs from air pollution, coal has not been economically viable for a long time. So why are we still using it? Because those who bear the costs are not those who reap the profits. Around the world it's estimated that almost four million people die prematurely every year from outdoor air pollution, 200,000 of those in the U.S. alone. In 2018, the State of Global Air report estimated that 95% of the world's population lives in areas that don't have healthy air according to World Health Organization standards. Imagine people who can afford to buy houses in nicer neighborhoods with better air quality. It's usually those who can't afford a better place to live who bear the brunt of the impacts. From mountaintop coal removal, to oil spills, and the tar sands, fossil fuels exert a massive cost that is subsidized by all of us who share the land, the water, and the air that they pollute, but things are changing. Everyone needs electricity, most of us would agree, and there are still nearly a billion people who don't have it, but did you know that most of the new energy growth is in renewables? Bloomberg's New Energy Outlook estimates that we'll be up to 50% by 2050, only counting wind and solar. Today, continuing to promote fossil fuels is like investing in horse farms and buggy businesses when Henry Ford is already turning out the Model-T Ford, or snapping up Blockbuster stocks and stockpiling DVDs, when Netflix is already taking over the market. The world is changing and even though it might seem scary sometimes, clinging to the past is not going to stop it.

One of the significant drawbacks of using fossil fuels is climate change. Extracting and burning coal, and gas, and oil releases carbon dioxide and other heat-trapping gases directly into the atmosphere that would otherwise take millions of years to reach it. These gases have built up to the point where they're increasing the temperature of the entire planet, and this is already affecting our lives and our economy in very serious ways. The world knows this and that's why, 195 countries met in Paris and agreed to keep warming below at least two degrees Celsius in 2015. This agreement has enormous implications for our energy sources, because, for countries that take this seriously, it means they have to do more to cut fossil fuel use faster and bump up clean energy. China, Britain, France, India plans to ban all gas and diesel vehicles by

2040 (Burch, Gilchrist, 2018). Wind turbines generate 47 % of Danish electricity (Reuters, 2020 January, 02), and the Netherlands plans to cut its emissions by 95% till 2050. Iceland ("The Energy Sector", 2011 November 11) and Norway (Hagos, Gebremedhin, Zethraeus, 2014) are already producing, its electricity from renewables. Many organizations are also divesting from fossil fuels for both practical and ethical reasons.

By 2018, a total of more than $6 trillion had been diverted from fossil fuels, and that number continues to grow. The bottom line is that: fossil fuels got us to where we are today, but they take us further at our peril. Thankfully, now we have better, cleaner, and cheaper ways to get the energy we need, ways that don't pollute our air and our water, and don't change our climate. Imagine fuel without fear. No climate change. No oil spills, dead coal miners, dirty air, devastated lands, lost wildlife. No energy poverty.

At this point, we can increase our negative effects on our health and our planet by choosing to extend our dependence on fossil fuels. On the other hand, we can decide to adopt and invest in cleaner and sustainable opportunities, thereby ending some of our current habits and choices. This may mean: all land vehicles will become electrified in the years ahead, all roofs will be covered with solar panels, all buildings will be insulated to prevent heat loss, all products will be designed to last longer, and their reuse and recycling will be easily provided. This may also mean the discontinuation of fossil fuel use. This represents a major challenge, even if we ignore the relevant politics and focus on science and engineering. By understanding how we use energy, we can better understand the problem. We have thought about this question for decades, while renewable energy sources (RES) are considered an important resource in many countries around the world but currently still only provide about 14% of our needs (Pimentel, Herz, Glickstein, Zimmerman, Allen, Becker, Seidel, 2002). The biggest challenge is to increase the use of renewable resources to generate electrical energy in the supply system and to promote renewable energy production in a safe, economical (Akella, Saini, Sharma, 2009) and cost effective (Frondel, Ritter, Schmidt, Vance, 2010) manner.

The major challenge of sustainable development of RES is identified. Many RES (especially solar and wind and hydro) generate intermittent power. Wherever intermittent power sources reach high grid penetration levels, energy storage becomes a critical factor that can solve these issues to provide reliable energy services (El Bassam, Maegaard, Schlichting, 2013). These intermittent resources have to integrate into the energy system, especially the electricity supply. Some sectors such as transportation may have more difficulty in transitioning to cleaner energy alternatives compared to other sectors (Kemfert, Breyer, Oei, 2020). Many liquid fuels play a primary role in the predominant type of transportation. The attitude we have is to say that this will be a game changer. Based on the example of Turkey, this article identifies and discusses possible solutions for energy problems and to transform it.

Foreign dependence in energy is an important problem not only economically but also politically. As a matter of fact, providing energy to a large extent from foreign sources may also lead to a national security weakness. In terms of Turkey, energy is a major risk threatening the high rate of dependence on foreign energy security. The subject of foreign dependence on energy (Uslu, 2008); in the past, it had become a serious impediment for Turkey's economy. Today, this dependence will continue to reduce at a certain rate primarily ensure achievement of higher growth rates then use that the economic potential of Turkey (Yıldız, 2010).

Despite some difficulties, the transition to clean energy is currently taking place across Europe. Companies, landlords, municipalities, local authorities, and the European Union (EU) are already taking action by building smart grids (Leal-Arcas, Lasniewska, Proedrou, 2017), installing solar (Šúri, Huld, Dunlop, Ossenbrink, 2007) and wind energy systems (González, Lacal-Arántegui, 2016), implementing corporate innovation programs to invest, setting standards and labels (Blok, 2006). Therefore, for sustainable development strategies in Turkey, there are still significant obstacles to overcome in order to increase renewable energy production, savings, efficiency improvements and abandon dependence on fossil fuels (Balat, 2010; Topallı, Alagöz, 2014). As a result, Turkey is now facing these problems from RES to increase the share of intermittent electricity, to improve the efficiency of existing power plants, and to include the transport sector for future strategies (Kaygusuz, 2002).

For sustainable development considering not only environmental but also social and economic aspects must be taken into account together by using RES, because there is no requirement of fuel (Vera, Langlois, 2007). Figure 1 is a diagram that shows the three portions that work together to make up sustainability (Chilán, Torres, Machuca, Cordova, Pérez, Gamez, 2018).

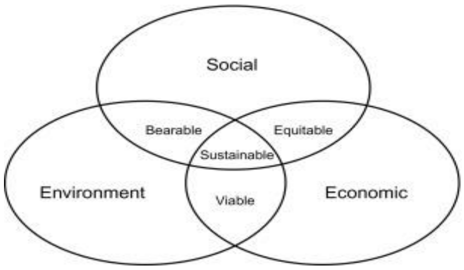

Figure 1. The three pillars of sustainability (Gyamfi, Derkyi, Asuamah, Aduako, 2018)

People could think to start figuring out how can we introduce the same flexibility in other parts of the energy system that we previously had the luxury of in the form of fossil fuels in the past. It is supposed that firstly it is not just a great change because we're replacing fossil fuels but the tones are set that this is also a really good change because it's a very cost-effective thing to do, as illustrated in Figure 2 ("Lazard Levelized Cost of Energy Analysis", 2019, November) It is a pictorial overview in a very simple way about the Turkish energy system looks like today. They're all very dependent on fossil fuels. It is an obvious thing that's happening when it is done this type of change is that it is replacing some fossil fuels in the electricity sector with this new form of energy in the form of renewable energy. The two key things have to be added in Figure 2 which are to use RES and the transport on the demand side. The heat and transport are very separated from one another. There is a kind of have three layers in the energy demand system which are electricity, heating/cooling, and transport.

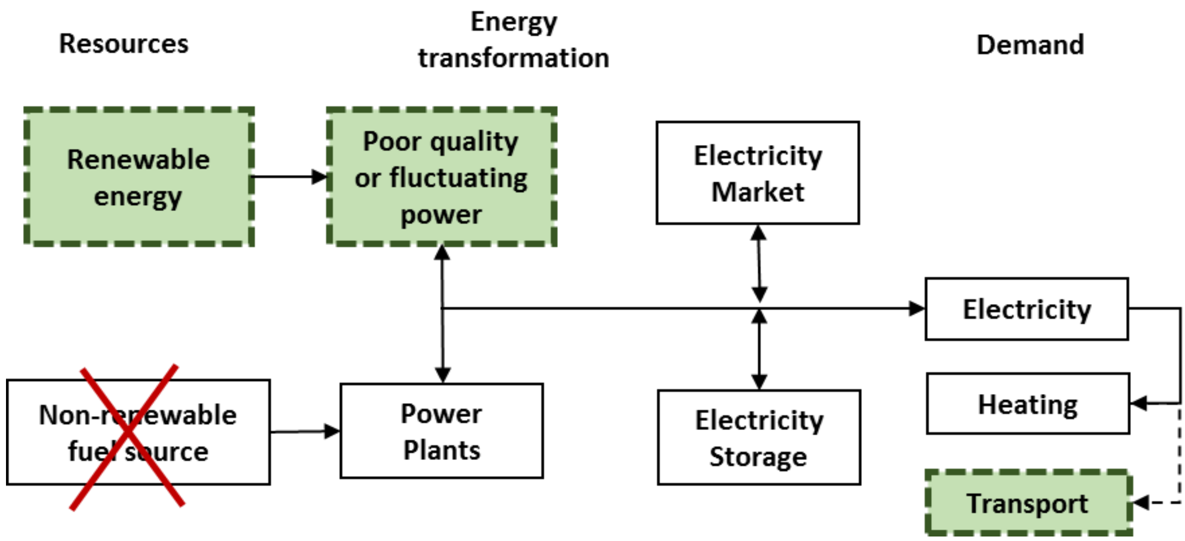

Figure 2. Interactions between technological innovation energy systems today and the future.

The cost of electricity production (Ragheb, 2017; Branker, Pathak, Pearce, 2011; Bemis, Doangelis, Michael, 1990) is based on existing technologies for producing electricity from three types of plants a wind farm, a baseload coal-fired power station, and a base loss combined cycle gas turbine power plant. If we do the calculations based on current technologies and current costs of construction and development wind turbines are now producing electricity at a similar price to baseload coal-fired power stations. That's power stations that have the luxury of operating almost all of the year-round which we know our power stations won't get to do as we bring in more and more wind power. Changing this energy system and the interaction from fossil fuels over to renewable energy can still be done at a cost-effective level. As seen in Figure 3; if we even have to introduce new storage technologies because the price of wind power is relatively cheap compared to what our alternatives are. It's not a burden for countries; it's an opportunity to take a new form of energy production that we can produce ourselves at a very cheap price.

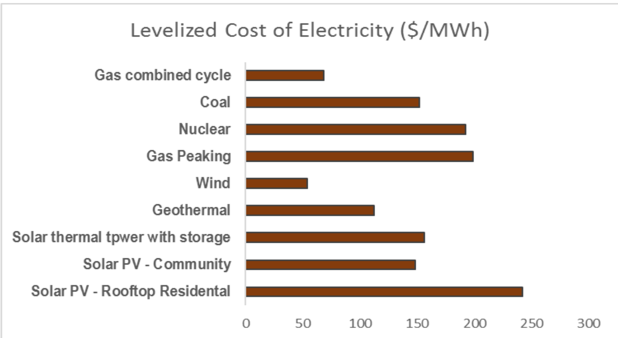

Figure 3. Benchmark Levelized Cost of Electricity

In Turkey, the theoretical hydroelectric potential is 433 billion kWh, while the technically usable potential is 216 billion kWh and the economic hydroelectric energy potential is 140 billion kWh/year (Atalay, Ulu, 2018). Meanwhile, Turkey has considerable potential for other types of renewable energy, especially solar, geothermal, and wind power. Thus, Turkey is a great example of the situation in many ways: the transport sector uses completely liquid fuels, the hydro potential is not big enough to take the place of fossil fuels, but has great potential for intermittent renewable sources. The wind and photovoltaic energy potential of Turkey presented in Figure 4 and 5 respectively. As seen from the figures, there are many areas all over the country, especially in west parts for wind power, where the average wind speed is over 7 m/s at 50 m height and south parts for solar power where the photovoltaic power is over 5 kwh/kwp.

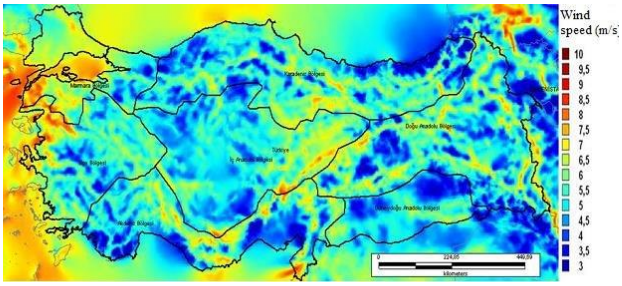

Figure 4. Wind energy potential atlas of Turkey (Kaya, Celik)

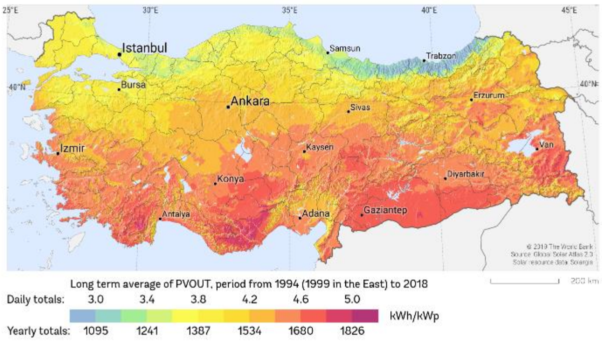

Figure 5. Photovoltaic electricity potential of Turkey ("The World Bank", 2019)

In this study, examine problems and perspectives of energy conversion based on 100 % renewable energy for Turkey. Using 100% renewable energy was first proposed in the Science paper more than 45 years ago (Sørensen, 1975). Figure 6 shows the primary energy consumption in 2018 compared to the potential of RES in Turkey (Tmmob makina mühendisleri odası peport, MMO/691).

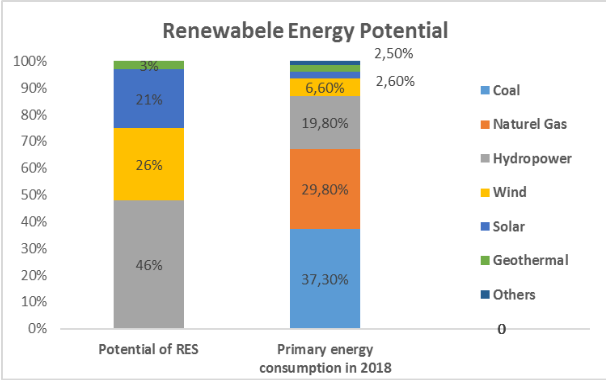

Figure 6. The primary energy consumption in 2018 compared to potential of RES in Turkey.

2. REFERENCE SCENARIO

Domestic resources mainly hydropower, geothermal, and coal reserves of Turkey are approximately 1% of the world's total. The coal-based power plants that use extremely poor-quality lignite supply more than 40% of the total electric energy demand of Turkey (Kilic, 2006). Figure 7 and 8 show the development from 2010 to present and shows the future view up to 2050 according to the reference scenario.

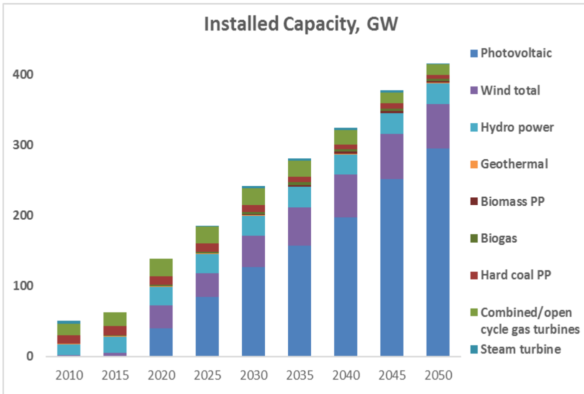

Figure 7. Forecast of installed power generation capacity

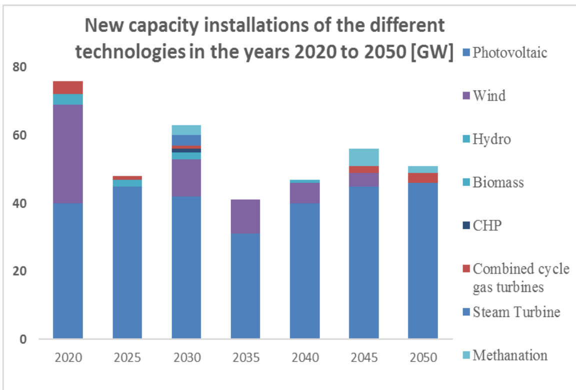

Figure 8. New capacity installations of the different technologies

Two problems arise when analyzing the possibilities of continuing development and replacing more fossil fuels with renewable energy.

First problem is today the transportation sector remains almost totally dependent on petroleum. The total number of vehicles in traffic by the year 2019 reached 2,339,551 in Turkey and 37.7% of these vehicles use Liquified Petroleum Gas (LPG), while 37.3% use diesel, 24.6% use gasoline and only 0.1% use hybrid, and electric (Özer, Vural, 2021).

The other problem which consists of includes power grid operation, system flexibility requirements is the integration of electricity generation from a gas-fired power plant and wind and solar power. The gas-fired power plants have not been operated to balance fluctuations in renewables mostly small hydropower plants. Consequently, the most economical way to prevent the problems caused by fluctuations in electricity consumption during the day and year is to activate more renewable power plants (Akpinar, 2005).

In the workshop titled "Energy Security" which is organized by Presidential Security and Foreign Policy Committee, attended by members of the board of directors, representatives of relevant state institutions, academics, think tank representatives and experts the main elements of Turkey's energy strategy are summarized as follows:

1) Diversification of resources and routes in the supply of oil and natural gas, which are imported energy sources,

2) Increasing the share of domestic and renewable energy,

3) Increasing energy efficiency,

4) The nuclear is intended to be included in the energy basket.

When the situation in 2015 and the reference expected in 2050 are compared, it assumes the following development:

In 2015, the amount of electricity generation increased by 3.07% compared to 2014, reaching 259.69 TWh. Consumption amount increased by 2,69% compared to 2014 and reached 264,14 TWh. Turkey's demand for electricity at the rate of 126% between the years 2017-2050 due to increasing population and rising economic growth in 2050 will reach an annual level of 653 terawatts-hour.

Replacing all existing coal and oil-fired generation across the country by new natural gas-fired and hydropower plant units when the lifetime of the old plants exceeds.

The installed capacity of power in the year 2015 is expected to rise from 73147MW to 415GW in the year 2050. The increase will mainly constitute more than half of the installed power by solar and wind power plants.

2.1. Methodology

The main objective of the study is to evaluate whether it is probable to obtain all of the energy supply from RES until 2050 in Turkey through global transformations to be realized in technical, legal terms. The EnergyPLAN model which is a deterministic input/output tool that uses an hourly simulation over a period of one year is used for calculations. In the calculations, the features of the intermittent nature of RES have been taken into consideration. In recent years, a number of EnergyPLAN models (Lund, 1999; Koo, Park, Shin, Yoon, 2011; Østergaard, Mathiesen, Möller, Lund, 2010) have been proposed in order to analyze the energy, environmental, and economic impact of various energy strategies for large-scale integration of renewable energy.

Using EnergyPLAN results and monitoring data allows to produce realistic results of national energy systems and outline detailed scenarios. The following steps outline the basic steps required to create a reference with EnergyPLAN:

1) The total annual production/demand of electricity, district heating, electricity production from renewable energy and nuclear sources, Electrolysis and electricity storage systems in TWh/year;
2) Demand for heating and cooling systems in TWh/year;
3) Heat supply and distributed generation from individual buildings;
4) Fuel consumption and heat and power production for industry;
5) Annual fuel consumption (jet fuel, diesel, gasoline, natural gas) data in TWh/year. This may require local data collection.
6) Annual energy production conversion of waste in TWh/year;
7) Annual production from biomass conversion plants in TWh/year;
8) Installation costs (these costs include overall investments, fixed operations and maintenance, variable operation and maintenance, fuel, and transportation).

Outputs are total Carbon dioxide (CO_2) emission, costs, including energy balances and resulting annual productions, fuel consumption, electricity import / export, and income from electricity exchange. it is possible to see a block diagram in Figure 9 that describes the model used for the analysis and the construction of the scenarios.

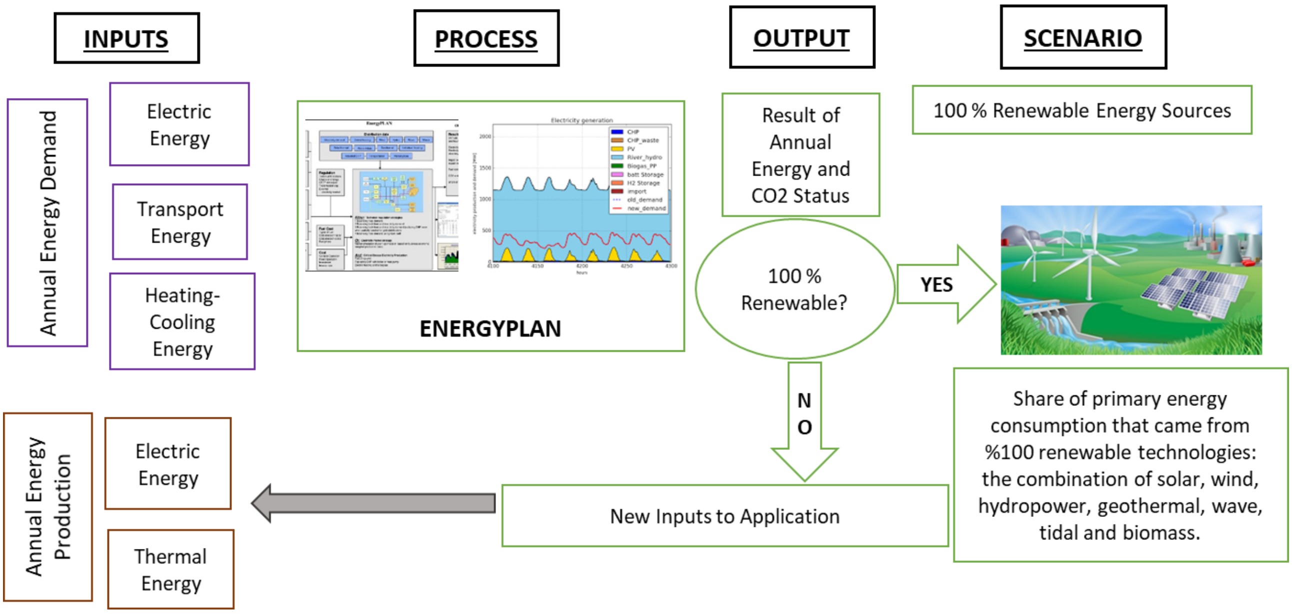

Figure 9. Input, processing and output diagram of EnergyPLAN software

The level of electricity demand from RES is varied for each cycle from 0 % to 100 % to identify the best alternative. As the wind, rain, and solar level increase, electricity generated in a power plant is more than the consumption and the batteries are unable to absorb it. It is defined as Excess Electricity Production and when it occurs it cannot be exported outside the country; as a consequence, players cannot get additional income from EEP. As an example; so much power was produced by German (“Independent”, Berke, 2018, January 04) and Danish (“Theguardian”, Neslen, 2015, July 10) renewable power sources that the country was able to meet its domestic electricity demand and export power to neighbor countries or people essentially got paid to use electricity.

The initial point for the study is the key assumption that development with sustainable generation and use of electricity involves four main technological changes, namely energy savings on the demand side, improve energy efficiency on the production side, replacing conventional vehicles with electric vehicles and replacing of fossil fuels by various types of completely renewable energy. As a result, the following four technological innovations have been implemented for the study.

Savings: 82% of the energy consumption in the buildings is used for heating and it constitutes 26% of the total energy spent in the country. Turkey meets 70% of its energy needs from imported sources. The most effective way to achieve energy efficiency in heating as well as cooling is through thermal insulation. Insulating homes is like covering the house with a blanket. In this way, cold cannot enter inside and heat cannot escape from inside. Materials with high insulation value should be preferred in buildings and installations. In windows with double or triple glass, heat loss might be reduced by half. Roof, wall, floor insulation should be made without interruption. As we know, the heated air rises and tries to escape from the roof. Therefore, the roof must first be insulated. More than 20% savings can be achieved in energy bills just by doing roof insulation. When the buildings are insulated with the right products and the right applications, heating and cooling can be achieved by consuming an average of 50% less energy. Thus, fuel and electricity bills can be halved. This savings in homes also contributes to the country's economy.

Efficiency: A combination of more thermal power stations with better efficiencies. The better operational ratio of system throughput over total power is defined as 40% electric output and 35% heat output of thermal power station plants. For this purpose, energy output and energy economic efficiency can be achieved by the improvement of existing steam-turbine/engine technologies or the decision to utilize waste heat rather than produce another power energy to satisfy the new cooling energy demand.

Renewable energy sources (RES): It is planned to produce 34000 MW hydroelectric, 20000MW wind energy, 5000 MW solar energy, 1000 MW geothermal energy, and 1000 MW biomass energy within the 2023 targets. This is the direction with the objectives of RES by the year 2023, the provision of at least 30% of Turkey's demand for electricity is planned. By 2050, the country aims to switch to 100% renewable energy use.

Transport: Today, the most important fuel for transport is fossil fuels. Today, 20% of CO_2 emissions in EU countries are due to road transport (Westbrook, Westbrook, 2001). The EU aims to reduce the "Greenhouse Gas Density" originating from vehicles to 10 % by 2020. Fossil fuels will run out in the near future and irreversible damages to the environment have the biggest ignition share in the development of electric vehicle technology.

Alternative energy supply options were evaluated and electricity and biodiesel could be used for light vehicles. Biodiesel fuel, which is produced by converting organic oils such as sunflower, soybean, safflower and canola into fuel by mixing them with alcohol and base, is a renewable and reliable bioenergy source (Eryilmaz, Yesilyurt, Cesur, Gokdogan, 2016). It is formed by mixing these oils with the required alcohol (methanol or ethanol) in the presence of a catalyst and the necessary chemical reactions to produce the final product. In this way, a fuel with less exhaust emission and more environmentally friendly can be produced (Hosseini, Wahid, 2012). As an agricultural country; it is also possible to supply enough biomass for the biofuels in this scenario in Turkey (Oguz, Ogut, Eryilmaz, 2007). This means that this scenario could be implemented quicker since less biomass is required to grow over the coming years.

According to the Turkish Statistical Institute data, 54.1% of the 23,132,670 registered motor vehicles constitutes cars (12509319 units). 4711205 of the cars are diesel, 4710863 are LPG and 3038788 are gasoline. Converting less than 2 tons of petrol or diesel vehicles into an electric one and fuel cell electric vehicles that are powered by hydrogen. Aircraft fuel was not taken into account in this transformation. Here, the same ratio was used in the reference scenario to convert 201 TWh total oil consumption to 70.5 TWh electricity consumption. Turkey's first domestically produced all-electric car was introduced December 2019 and it's expected to be out on the roads by 2022. According to estimates 3 out of 10 people in Turkey will use electric vehicles by 2030.

3. RESULTS

The transition is divided into 5 steps to help explain the changes that are taking place. For each step, findings are presented separately; the Reference 2050 scenario as the initial point, and moving towards the Electric vehicles for Turkey. For these 5 steps, the aim is to assess the observable effect on the environment and primary energy. The Primary Energy Supply indicator is measured by major fuel type to properly assess the impact on energy. On the other hand, evaluating typically measurements of total yearly carbon dioxide emissions is to analyze the impact on the environment. These data have been chosen since the 'optimum' case can often vary depending on the basic aim, such as maximum green energy or minimum CO_2 emissions.

In the second step, it is planned to obtain the highest level of efficiency from RES and to maximize installed power which is planned to reach 294.8GW for solar power, 63.3GW for wind power, 28.9 for hydropower in 2050.

In the third step, in order to have green buildings that often include measures to reduce energy consumption the heat and cooling demand in buildings is reduced by means of improvements in insulation, windows, and doors. In this study, it is assumed that there will be a 11% reduction in electricity demand compared to the Reference scenario in households and industry by using savings methods as it is mentioned. As expected, this additional heat-saving reduces energy demand, CO_2 emissions, and costs of the energy system.

In the fourth step, nuclear power is removed which reduces the Primary Energy Supply, but it increases the CO_2 emissions. Primary Energy Supply is comparatively less because the assumed efficiency of nuclear power is 35%, which is lower than the efficiency of power plants that replace nuclear power. Consequently, the total energy demand is lower when power plants replace nuclear power. Nuclear power plants generally operate at full capacity hence it cannot offer flexible working arrangements as well. When nuclear power plants are removed from the system, it is possible for intermittent renewables to supply a large share of grid electricity and to decrease foreign dependency in energy demand.

The last step is the implementation of electric vehicles (EVs) in the transport system. In this scenario, 80 % of the fuel used in cars whether petrol, diesel, or even LPG with a weight of less than 2 tons is replaced with electricity. To achieve this transformation, it is presumed that EVs have an efficiency of 200Wh/km, while petrol and diesel vehicles have an average efficiency of 780Wh/km and 600Wh/km respectively. Figure 10 displays the Primary Energy Supply and CO2 emissions for each technological change steps.

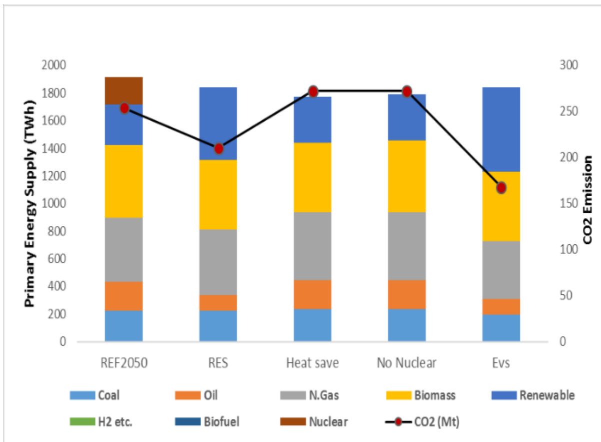

Figure 10. Comparison of the five steps in the transition to sustainable development by primary energy supply and carbon dioxide emissions.

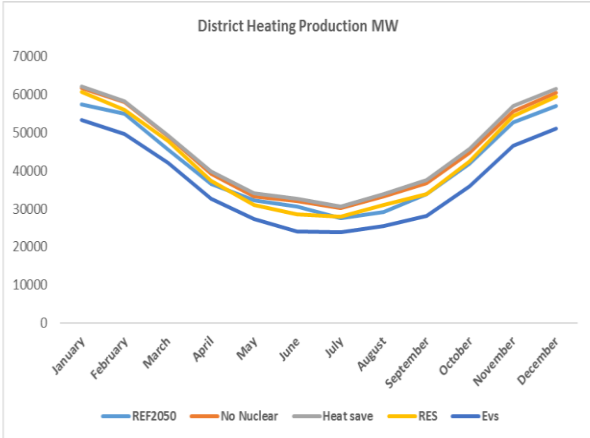

Figure 11. The modelled district heat production distribution in 2050 in MW.

It can be difficult to quantify the demand for electric heating, as it is documented with hot water, rather than as a separate entity. It was estimated that 6% of all domestic electricity is used for space heating and 6% for hot water. Figure 11 shows overall heat production for the residential and tertiary sectors. As seen in the figure, the heat demand half was reduced in the summer months; for hot water use only.

These 5 steps outline a basic pathway to convert the Turkish energy system from traditional fuels to 100% renewable energy. The energy system including the transport sector can also be supplied with renewable potential. The sustainable energy system has been designed which potentially can be maintained by domestic renewable resources mostly wind and solar. The full block model diagram is presented with a Sankey diagram in Figure 12.

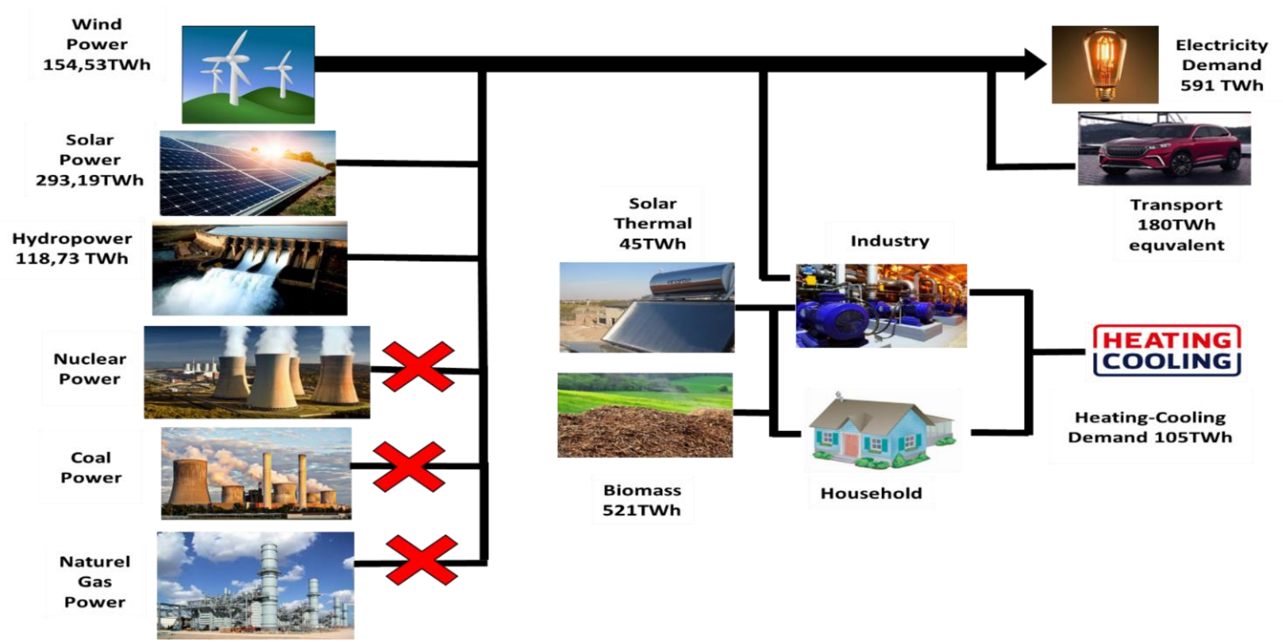

Figure 12. Sankey diagram of the 100% renewable energy system.

4. CONCLUSIONS

This study has presented the possibility of a potential pathway to 100% renewable energy for the Turkish energy system toward 2050. The design methodology is a very complex process. The combination of a creative phase, which includes experienced experts and detailed system analysis, seems effective and can be recommended.

The main technological changes at all stages of required to implement the carbon-free and green energy system scenario are wind energy, hydroelectricity, solar energy, electric vehicles, heat saving, individual heat pumps, district heating. The virtues of that it will be delivered a green power and district heating a cost-effective and last extend our country will be independent. Many of the technologies are already mature enough that everyone can use them easily and it can be applied today, particularly in the electricity and heat industries.

Transitioning is presented in a series of 5 steps, which the Turkish energy system is converted from primarily fossil fuels resources to 100% renewables means the end of power production from fossil fuel-based power plants. These steps are rigorous processes based on hourly analyses of the complete green energy system, including electricity, heating, cooling, as well as industry, and transport. The corresponding effect is quantified in energy (PES), environment (carbon emissions) for each step. This ambitious undertaking will help the country to reach its final goal of a decarbonized energy system and generating 100 % of its electricity from renewable sources by 2050.

Future aspects

In the future, it is recommended to investigate:

- What is the key to using alternative sources such as solar and wind energy? It is storage - so we can have ready energy when the sun is not rising or when the wind is not blowing.
- Other sectors must also change; the 100% clean renewable energy solution also requires; transport is lacking behind other sectors, needs to step up through comprehensive action and support of other sectors. Transport (electric cars, trucks and trains, air and sea transport) needs clean energy, less energy consumption, and should be more energy-efficient. Experts think that Turkey can replace 40% of road transportation by trains.
- The heating, cooling, and hot water demand conversion into renewables.
- It is necessary to have a smart grid to manage intermittent renewable energy generation and energy storage.
- Whether more energy savings can be made within the industry sector.
- Whether waste incineration can be more efficient and sustainable.

REFERENCES

Agbulut, Ü., Bakir, H. (2019). The investigation on economic and ecological impacts of tendency to electric vehicles instead of internal combustion engines. Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 7(1), 25-36.

Akella, A. K., Saini, R. P., Sharma, M. P. (2009). Social, economical and environmental impacts of renewable energy systems. Renewable Energy, 34(2), 390-396.

Akpinar, E. (2005). The Place of River Type Power Plants in Turkey Hydroelectric Production. Erzincan Üniversitesi Eğitim Fakültesi Dergisi, 7(2), 1-25.

Atalay, O., Ulu, E. Y. (2018). Hydropower Capacity of Turkey and Actual Investments. The Eurasia Proceedings of Science Technology Engineering and Mathematics, (4), 162-166.

Balat, M. (2010). Security of energy supply in Turkey: Challenges and solutions. Energy Conversion and Management, 51(10), 1998-2011.

Bemis, G. R., DoAngelis, Michael (1990). Levelized cost of electricity generation technologies. Contemporary Economic Policy, 8(3), 200-214.

Blok, K. (2006). Renewable energy policies in the European Union. Energy policy, 34(3), 251-255.

Branker, K., Pathak, M. J. M., Pearce, J. M. (2011). A review of solar photovoltaic levelized cost of electricity. Renewable and sustainable energy reviews, 15(9), 4470-4482.

Burch, I., Gilchrist, J. (2018). Survey of global activity to phase out internal combustion engine vehicles. Center of Climate Protection: Santa Rosa, CA, USA.

Chilán, J. C. H., Torres, S. G. P., Machuca, B. I. F., Cordova, A. J. T., Pérez, C. A. M., Gamez, M. R. (2018). Social impact of renewable energy sources in the province of Loja. International journal of physical sciences and engineering, 2(1), 13-25.

Denmark sources record 47% of power from wind in 2019. Reuters. 2020-01-02. Retrieved 2020-04-30

El Bassam, N., Maegaard, P., Schlichting, M. (2013). Distributed renewable energies for off-grid communities: strategies and technologies toward achieving sustainability in energy generation and supply. Newnes.

Eryilmaz, T., Yesilyurt, M. K., Cesur, C., Gokdogan, O. (2016). Biodiesel production potential from oil seeds in Turkey. Renewable and Sustainable Energy Reviews, 58, 842-851.

Foley, G. (1992). Renewable energy in third world development assistance Learning from experience. Energy Policy, 20(4), 355-364.

Frondel, M. Ritter, N. Schmidt, C. M. Vance, C. (2010). Economic impacts from the promotion of renewable energy technologies: The German experience. Energy Policy, 38(8), 4048-4056.

González, J. S., Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602.

Gyamfi, S., Derkyi, N. S., Asuamah, E. Y., Aduako, I. J. (2018). Renewable Energy and Sustainable Development. In Sustainable Hydropower in West Africa (pp. 75-94). Academic Press.

Hacquard, P. Simoën, M. Hache, E. (2019). Is the oil industry able to support a world that consumes 105 million barrels of oil per day in 2025? Oil Gas Science and Technology–Revue d'IFP Energies nouvelles, 74, 88.

Hagos, D. A., Gebremedhin, A., Zethraeus, B. (2014). Towards a flexible energy system–A case study for Inland Norway. Applied energy, 130, 41-50.

Hosseini, S. E., Wahid, M. A. (2012). Necessity of biodiesel utilization as a source of renewable energy in Malaysia. Renewable and sustainable energy reviews, 16(8), 5732-5740.

https://www.independent.co.uk/environment/germany-power-grid-pays-customers-christmas-sustainability-renewable-energy-a8141431.html

International Energy Outlook 2019 with projections to 2050, September 2019.

Jeremy B, Independent, Business Insider 04 January 2018

Kaya, M. N., Celik, Y. Vertical Axis Wind Turbines for Turkey: Overview to Application Opportunities.

Kaygusuz, K., Kaygusuz, A. (2002). Renewable energy and sustainable development in Turkey. Renewable Energy, 25(3), 431-453.

Kemfert, C. Breyer, C. Oei, P. Y. (Eds.). (2020). 100% Renewable Energy Transition: Pathways and Implementation. MDPI.

Kilic, A. M. (2006). Turkey's main energy sources and importance of usage in energy sector. Energy exploration exploitation, 24(1-2), 1-17.

Koo, J., Park, K., Shin, D., Yoon, E. S. (2011). Economic evaluation of renewable energy systems under varying scenarios and its implications to Korea's renewable energy plan. Applied Energy, 88(6), 2254-2260.

Lazard Levelized Cost of Energy Analysis, Nov. 2019 (source: screenshot/ Lazard)

Leal-Arcas, R., Lasniewska, F., Proedrou, F. (2017). Smart grids in the European Union: Assessing energy security, regulation social and ethical considerations. Colum. J. Eur. L., 24, 291.

Lund, H. (1999). A green energy plan for Denmark. Environmental and Resource Economics, 14(3), 431-440.

Oguz, H., Ogut, H., Eryilmaz, T. (2007). Investigation of biodiesel production, quality and performance in Turkey. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 29(16), 1529-1535.

Østergaard, P. A., Mathiesen, B. V., Möller, B., Lund, H. (2010). A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. Energy, 35(12), 4892-4901.

Özer, S , Vural, E . (2021). Turboşarjlı Enjeksiyonlu Benzinli Bir Motorda LPG Kullanımının Emisyonlar ve Motor Performansı Açısından İncelenmesi. Politeknik Dergisi.

Pimentel, D., Herz, M., Glickstein, M., Zimmerman, M., Allen, R., Becker, K., Seidel, T. (2002). Renewable Energy: Current and Potential IssuesRenewable energy technologies could, if developed and implemented, provide nearly 50% of US energy needs; this would require about 17% of US land resources. Bioscience, 52(12), 1111-1120.

Ragheb, M. (2017). Economics of wind power generation. In Wind Energy Engineering (pp. 537-555). Academic Press.

Sørensen, B. (1975). Energy and Resources: A plan is outlined according to which solar and wind energy would supply Denmark's needs by the year 2050. Science, 189(4199), 255-260.

Stolic, N., Pesic, B., Milosevic, B., Spasic, Z., Lazic, M. (2018). Possibilities of applying biomass for the purposes of energy production and environmental protection. Journal of Agricultural, Food and Environmental Sciences, JAFES, 72(1), 152-156.

Šúri, M., Huld, T. A., Dunlop, E. D., Ossenbrink, H. A. (2007). Potential of solar electricity generation in the European Union member states and candidate countries. Solar energy, 81(10), 1295-1305.

The Energy Sector. November 11, 2011.

"Theguardian", Arthur Neslen 10 July 2015, https://www.theguardian.com/environment/2015/jul/10/denmark-wind-windfarm-power-exceed-electricity-demand

Tmmob makina mühendisleri odası peport, MMO/691 ISBN: 978-605-01-1198-9

Topallı, N., Alagöz, M. (2014). Energy consumption and economic growth in Turkey: An empirical analysis. Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, (32), 151-159.

Uslu, T. (2008). Turkey's foreign dependence on energy. Energy Sources, Part B, 3(2), 113-120.

Vera, I., Langlois, L. (2007). Energy indicators for sustainable development. Energy, 32(6), 875-882.

Westbrook, M. H., Westbrook, M. (2001). The Electric Car: Development and future of battery, hybrid and fuel-cell cars (No. 38). Iet.

Yıldız, T. (2010). Turkey's energy economy and future energy vision. Turkish Policy Quarterly, 9 (2), 16.

2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis.